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ECONOMY-WIDE MODELLING OF SEASONAL LABOUR AND NATURAL RESOURCE POLICIES

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who taught me to never give up;
and to Brie Husted, Chantal Davids
and Ryan Wentzel, who have left
this earth too early.

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Abstract

In many developing economies, the largest part of the population still resides in rural areas and the agricultural sector absorbs the highest share of the labour force. In this context, rural livelihoods are dependent on the utilization of natural resources and with agriculture being a biological process, employment opportunities are largely determined by climatic seasonality. Against this background, policies related to the use of agricultural and other natural resources have a high relevance for efforts of rural development and poverty eradication. Natural resource policies often have implications for the whole economy, due to the agricultural sector's high absorption of employment and strongly established backward and forward linkages with the remaining sectors of the economy. For these cases, economy-wide models have generally proven to be effective tools for the ex-ante analysis of policies and exogenous shocks. Yet, in the context of developing agrarian countries and sustainable natural resource policies, these models have so far neglected the role of seasonality of labour markets.

Using an economy-wide modelling approach, this thesis investigates methodological and empirical research questions related to seasonal labour markets and natural resource policies in the broader context of rural development. The Kingdom of Bhutan, located in the south-eastern Himalayas, serves as a case study. The South Asian and landlocked country is a natural resource dependent economy and a detailed description of the country is provided in Chapter 2. More than 50% of Bhutan's population is employed within the agricultural sector, in which the patterns of seasonal labour demand are determined by Monsoon rains. The country is not only known for its unique development philosophy of Gross National Happiness, but also for its ambitious environmental conservation agenda, which entails many governance challenges balancing political priorities of sustainable resource management with objectives of rural development and food self-sufficiency.

The methodological research objective of this thesis is to gain an understanding of the relevance of seasonal labour markets in the context of economy-wide modelling. This objective is addressed in Chapter 3. The literature on economy-wide modelling has so far neglected the seasonal dimension of labour demand and supply. A social accounting matrix (SAM) for Bhutan is developed in Chapter 3, depicting seasonal labour market accounts and including satellite accounts with seasonal leisure and labour quantities. The SAM serves as the underlying database of a computable general equilibrium (CGE) model. Pursuing the methodological research objective, the model is extended in various ways. The multi-level production structure is extended in order to depict the activity specific characteristics of season labour demand. Moreover, a labour-leisure trade-off is integrated into the model's household demand system to model seasonal labour supply.

The depiction of seasonal labour markets at national scale using a seasonal SAM and CGE-model presents a novel development within the literature. It is demonstrated, that the absence of seasonal labour markets leads to systematic bias of model results. The bias originates from the common assumption in models with annualized labour markets that units of labour supplied in different seasons are perfect intertemporal substitutes. This assumption of homogeneity of labour units sidesteps the reality of farming, for which seasonal fluctuations of labour demand are considered inherent features. The consequences are distorted supply responses and biased welfare effects, underlining the pivotal implications of seasonality for economy-wide analysis in the context of agrarian economies, particularly for scenario analysis involving structural changes and agricultural policy interventions.

The empirical research objective addresses the interdependence of natural resource policies with the objectives of environmental conservation and rural development. Employing modelling techniques, three studies included in the Chapter 4 to 6 focus on specific questions of sustainable natural resource management related to agriculture and forest policies in Bhutan.

Chapter 4 analyses Bhutan's ambitious and unprecedented objective to convert to 100% organic agriculture. This study follows a two-step approach. Firstly, on-farm data are analysed revealing that organic crop yields are on average 24% lower than conventional yields. Secondly, a CGE model for Bhutan incorporating agroecological zones, crop nutrients, and field operations is employed to assess the economy-wide implications of a large-scale conversion policy. Methodologically, the study represents a novel approach by modelling field operations such as weeding and manuring explicitly in a CGE model. According to the model results, Bhutan's 100% organic policy is likely to result in substantial welfare losses and adverse impacts on food security, causing trade-offs with the objectives of rural development and food self-sufficiency. The analysis further finds that current organic-by-default farming practices in Bhutan are still underdeveloped, and that adopting the systems approach of organic farming as defined in the IFOAM organic farming standards could reduce the yield gap. Due to data limitations, the study could not account for the potential synergies stemming from increased eco-system services or potential price-premiums in export markets, which is an avenue for future research.

Chapter 5 and 6 focus on Bhutan's policies for forest conservation and utilization. Unlike many other countries, Bhutan has achieved an exceptional track record in forest conservation, with forests still covering more than 70% of the land area. However, because only about 5% of forest area is under commercial management, the country is highly dependent on wood-based imports from India, mainly in the form of charcoal, which faces high demand by metallurgical industries.

Chapter 5 examines how increasing the forest area under commercial management might allow for sustainable charcoal production in Bhutan, thereby reducing the country's dependence on charcoal imports. Using a transportation and investment model, cost efficient locations of charcoal production sites are identified at the subnational level. Simulation results show that charcoal production is profitable in 11 of the 19 districts with an aggregate potential to offset up to 61% of charcoal imports. The requirement in additional fuelwood supply would increase the commercially managed forest area from 5% to 15% of total forest area. Unlike earlier claims, the study finds that transportation cost and availability of labour do not present barriers for the economic viability of charcoal production. Monte Carlo simulations and sensitivity analyses confirm that using a decentralized approach, Bhutan could increase commercial forest management without jeopardizing its highly acclaimed forest conservation agenda. However, further research is needed to address the limitations of the analysis, particularly with regards to estimating timber extraction cost from additionally managed commercial forest areas and potential cost of externalities stemming from increased forest utilization.

Lastly, the methodological contributions and empirical research objective are combined in the fourth and final study presented in Chapter 6. This study contributes to the literature on sustainable forest management in the rather rare context of forest underutilization. In addition, it analyses the economy-wide potential of forestry to provide seasonal employment during the lean season. Bhutan's current forest conservation framework has so far largely constrained households to utilize fuelwood for subsistence use only. Employing a CGE model that incorporates seasonal underemployment, three forest policies are simulated that link households to the commercial fuelwood value chain. Building on the findings of the study in Chapter 5, the model includes a domestic charcoal sector, which can absorb additional supply in fuelwood. The unutilized potential of forest resources is estimated using satellite data and spatial criteria for sustainable forest management.

All three forest policy scenarios increase rural households' welfare, mainly due to additional employment opportunities in the winter months and increases in forest utilization. The efficiency of fuelwood use is improved when its opportunity cost increases due to the opportunity of selling it, which is reflected by the increase in shadow prices. The estimated benefits for rural households are likely to be at the lower bound, since the study does not quantify the health co-benefits due to reduced indoor air pollution. However, the forest policy scenarios' success also hinges on the effectiveness of monitoring and governance systems that ensure compliance with sustainable forest management criteria. Furthermore, the study's scope is restricted as any potential adverse effects on ecosystem services are not included due to data limitations.

Livelihoods dependent on natural resources are inevitably linked to climatic seasonality and challenges of sustainable resource use. All four studies are related to these themes, although from different angles. Literature on modelling rural labour markets in economy-wide models is relatively scarce and the dissertation contributes to this literature by capturing the seasonal dimension of labour markets. This research area provides a large potential for further development. Methodologically, CGE models can, for instance, be extended to incorporate seasonal labour markets with technological trade-offs in agriculture, by integrating the field-operations approach as used in Chapter 4. Accounting for gender or age dimensions within the division of labour and time-use is of high relevance for future model extensions, which requires additional data. More data are also necessary for the incorporation of ecosystem services into economy-wide models, which this thesis likewise identifies as a key limitation and area of future research.

Keywords:

Economy-wide modeling: CGE model. Rural livelihoods; Seasonal labour; Natural resource policies; Agricultural policy; Forest policy; Bhutan

Zusammenfassung

In vielen Entwicklungsländern lebt nach wie vor ein Großteil der Bevölkerung in ländlichen Gebieten und arbeitet mehrheitlich in der Landwirtschaft. Die Nutzung natürlicher Ressourcen ist daher eine wichtige Lebensgrundlage für die ländliche Bevölkerung. Zudem stehen Arbeitszeiten und Beschäftigungsmöglichkeiten unter der Beeinflussung klimatischer Saisonalität. Ländliche Entwicklung und Armutsbekämpfung ist somit stark abhängig von der nachhaltigen Nutzung natürlicher Ressourcen und der Verfügbarkeit ganzjähriger Einkommensmöglichkeiten. In diesem Zusammenhang haben politische Maßnahmen oft erhebliche gesamtwirtschaftliche Auswirkungen. Die Ursache hierfür liegt einerseits im hohen Anteil der Landwirtschaft an der Gesamtbeschäftigung und andererseits in der starken Integration des Agrarsektors innerhalb der übrigen Sektoren der Volkswirtschaft durch Vorwärts- und Rückwärtsverflechtungen. Für solche Fälle haben sich gesamtwirtschaftliche Modelle grundsätzlich als nützliche Methode für die ex-ante Analyse von Politiken und exogenen Schocks erwiesen, sie haben jedoch bisher die Bedeutung von saisonal schwankender Arbeitsnachfrage vernachlässigt.

Die vorliegende Dissertation widmet sich empirischen und methodischen Forschungsfragen mit Bezug auf saisonale Arbeitsmärkte und die Einflussnahme der Politik auf die nachhaltige Nutzung natürlicher Ressourcen im Kontext der ländlichen Entwicklung. Hierfür wird ein gesamtwirtschaftlicher Modellierungsansatz angewendet, für den das im südöstlichen Himalaya gelegene Königreich Bhutan als empirische Fallstudie dient. Die Volkswirtschaft dieses südasiatischen Binnenlands ist stark von der Nutzung natürlicher Ressourcen abhängig. Über die Hälfte der Bevölkerung Bhutans arbeitet in der Landwirtschaft, in welcher die saisonale Arbeitsnachfrage hauptsächlich durch den Beginn des Monsunregens beeinflusst wird. Bhutan ist nicht nur für seine Philosophie des Bruttonationalglücks bekannt, sondern auch für seine ehrgeizige Umweltschutzagenda. Diese ist mit der Herausforderung verbunden, politische Prioritäten der nachhaltigen Nutzung von natürlichen Ressourcen mit Zielen der ländlichen Entwicklung und Selbstversorgung mit Nahrungsmitteln abzuwägen.

Das methodische Forschungsziel der Arbeit ist, die Relevanz der Darstellung von saisonalen Arbeitsmärkten innerhalb von gesamtwirtschaftlichen Modellen zu ergründen. Dazu wird in Kapitel 3 zuerst eine Sozialrechnungsmatrix (sog. *Social Accounting Matrix* (SAM)) für Bhutan entwickelt, welche die Saisonalität des Arbeitsmarktes darstellt und in einem Nebenkonto die Anzahl von saisonalen Arbeitstagen und arbeitsfreien Tagen erfasst. Diese SAM dient als

Datengrundlage für ein allgemeines Gleichgewichtsmodell (sog. *Computable General Equilibrium* (CGE) Modell). Um das Forschungsziel zu erreichen wird dieses Modell vielfältig erweitert: Die Produktionsstruktur wird zur Abbildung der ausgeprägten saisonalen Nachfragemuster angepasst. Des Weiteren wird eine Arbeit-Freizeit-Austauschbeziehung in das Nachfragesystem der Haushalte integriert, um das saisonale Arbeitsangebot modellieren zu können.

Die Darstellung von saisonalen Arbeitsmärkten auf nationaler Ebene, unter Verwendung einer SAM und eines CGE Modells, stellt eine Neuheit in der Literatur dar, die zeigt, dass Modelle ohne saisonale Arbeitsmärkte systematisch Ergebnisse verzerren. Die Ursache hierfür ist durch die implizite Annahme der Modelle mit jährlichen Arbeitsmärkten zu erklären, welche die in unterschiedlichen Perioden angebotenen Arbeitseinheiten als perfekte intertemporale Substitute behandelt. Diese Annahme der Homogenität von Arbeitseinheiten ist nicht gültig für die reale Landwirtschaft, in der die saisonal schwankende Arbeitsnachfrage ein inhärentes Wesensmerkmal ist. Dieser systematische Fehler führt zu verzerrten Angebotsreaktionen und fehlerhaften Wohlstandseffekten. Daher hat die Saisonalität von Arbeit überaus wichtige Folgen für gesamtwirtschaftliche Analysen im Kontext von landwirtschaftlich geprägten Volkswirtschaften, insbesondere für Untersuchungen zu Fragen des Strukturwandels und agrarpolitischer Interventionen.

Empirisch untersucht die vorliegende Arbeit die wechselseitige Abhängigkeit von politischen Maßnahmen zur Nutzung natürlicher Ressourcen mit Zielen des Umweltschutzes und der ländlichen Entwicklung. Basierend auf unterschiedlichen Modellierungsansätzen, konzentrieren sich drei Studien in den Kapiteln 4 bis 6 auf spezifische Fragestellungen zum nachhaltigen Management von natürlichen Ressourcen mit Bezug auf Agrar- und Forstpolitiken in Bhutan.

Das ambitionierte und beispiellose Ziel Bhutans, seinen landwirtschaftlichen Sektor auf 100% ökologische Landwirtschaft umzustellen, stellt den Forschungsschwerpunkt in Kapitel 4 dar. Zuerst werden Betriebsdaten analysiert, welche aufzeigen, dass ökologische Erträge im Vergleich zu konventionellen Erträgen im Durchschnitt 24% niedriger ausfallen. Als zweiter Schritt wird ein CGE Modell für Bhutan angewandt, welches agrarökologische Zonen, Pflanzennährstoffe und Feldarbeitsgänge erfasst, um die gesamtwirtschaftlichen Auswirkungen dieser weitreichenden politischen Intervention zu ermitteln. Methodisch neu, ist die explizite Modellierung von Feldarbeitsgängen wie Unkrautjäten und Anwendung von

Wirtschaftsdünger. In der Analyse der Ergebnisse stellt sich heraus, dass Bhutans Ziel auf 100% Ökolandbau umzustellen zu substantiellen Wohlfahrtsverlusten und negativen Folgen für die Ernährungssicherung führen würde. Außerdem stellt die Studie fest, dass die bisherigen nicht zertifizierten Ökolandbaupraktiken (auch bekannt unter „organic-by-default") in Bhutan noch großes Entwicklungspotential aufzeigen und die Einführung von systemischen Ansätzen des Ökolandbaus, wie sie in den IFOAM Standards definiert sind, die Ertragslücke verringern könnten. Aufgrund von beschränkter Datenverfügbarkeit konnte die Studie keine potentiellen Synergien durch erhöhte Ökosystemleistungen oder Preisaufschläge in Exportmärkten berücksichtigen, was ein Feld für zukünftige Forschungsaktivitäten darstellt.

Kapitel 5 und 6 konzentrieren sich auf Bhutans politische Rahmenbedingungen für die Erhaltung und Nutzung des Waldes. Mit einer Waldbedeckung von mehr als 70% der Landesfläche hat Bhutan im Gegensatz zu vielen anderen Ländern eine außergewöhnliche Erfolgsbilanz vorzuweisen, was die Erhaltung der Forstressourcen betrifft. Da aber nur ca. 5% der Waldfläche für kommerzielle Bewirtschaftung genutzt werden, ist das Land sehr abhängig von holzbasierten Importen aus Indien, hauptsächlich in der Form von Holzkohle, für die seitens der bhutanesischen Hüttenindustrie eine hohe Nachfrage besteht.

In Kapitel 5 wird untersucht, ob eine gesteigerte Forstnutzung durch kommerzielle Bewirtschaftung eine nachhaltige Holzkohleproduktion in Bhutan ermöglichen würde, um dadurch die Abhängigkeit von Holzkohleimporten zu verringern. Es wird sowohl ein Transport- und Investitionsmodell angewandt, um kosteneffiziente Standorte für Holzkohleproduktion auf subnationaler Ebene zu identifizieren. Simulationsergebnisse zeigen, dass die Holzkohleproduktion in 11 der 19 untersuchten Distrikte profitabel wäre und das Potential hätte, insgesamt bis zu 61% der Holzkohleimporte zu ersetzen. Der erforderliche Anstieg an Brennholzproduktion würde die Forstnutzung unter kommerzieller Bewirtschaftung von 5% auf 15% der gesamten Waldfläche erhöhen. Entgegen früherer Behauptungen, stellt die Studie fest, dass Transportkosten und Arbeitsverfügbarkeit keine Hürden für die Wirtschaftlichkeit der Holzkohleproduktion darstellen. Monte Carlo Simulationen und Sensitivitätsanalysen bestätigen, dass Bhutan, unter Verwendung eines dezentralen Ansatzes, die kommerzielle Forstbewirtschaftung erhöhen könnte, ohne dabei seine viel gepriesene Agenda der Walderhaltung gefährden zu müssen. Jedoch wäre weitere Forschung notwendig, um den Einschränkungen der Studie nachzugehen. Dies betrifft vor allem die Abschätzung der Kosten der Waldarbeiten von zusätzlich genutzten Forstflächen und potentiellen Kosten negativer Externalitäten, die durch die erhöhte Forstnutzung entstehen könnten.

Kapitel 6 führt die methodischen Erkenntnisse und das empirische Forschungsziel zusammen. Diese Studie leistet einerseits einen Beitrag zur Literatur der nachhaltigen Forstbewirtschaftung im eher seltenen Kontext der Unternutzug von Wäldern. Andererseits wird das gesamtwirtschaftliche Potential der Forstwirtschaft, Einkommensmöglichkeiten für ländliche Haushalte in der Nebensaison zu schaffen, analysiert. Die gegenwärtige Forstpolitik Bhutans beschränkt die ländlichen Haushalte nahezu ausschließlich auf den Eigenverbrauch von Brennholz. In drei Szenarien werden unterschiedliche Politikreformen simuliert, welche den ländlichen Haushalten einen mengenbeschränkten Zugang zur kommerziellen Brennholzwertschöpfungskette ermöglichen würde. Um die nachhaltige Nutzung der Wälder zu gewährleisten werden Satellitendaten und räumliche Kriterien herangezogen. Die gesamtwirtschaftlichen Auswirkungen werden mit einem CGE Modell simuliert, welches als methodische Neuheit saisonale Unterbeschäftigung abbildet. Außerdem werden die Ergebnisse aus Kapitel 5 genutzt, um einen inländischen Holzkohlesektor zu modellieren, welcher das zusätzliche Angebot an Brennholz absorbiert.

In allen drei Forstpolitikszenarien erhöht sich die Wohlfahrt der ländlichen Haushalte, hauptsächlich aufgrund der zusätzlichen Beschäftigungsmöglichkeiten in den Wintermonaten und der erhöhten Waldnutzung. Die Effizienz der Brennholznutzung wird dadurch verbessert, dass deren Opportunitätskosten für die ländlichen Haushalte durch die Verkaufsmöglichkeit erhöht werden, was auch durch gestiegene Schattenpreise ersichtlich wird. Dies verstärkt den Anreiz, auf sauberere Energieträger wie Strom und Flüssiggas umzusteigen und verringert die Innenraumluftverschmutzung. Der dadurch entstehende gesundheitliche Nutzen wurde in der Studie jedoch nicht quantifiziert. Der Erfolg der Forstpolitikszenarien hängt auch von effektiven Überwachungs- und Regulierungssystemen ab, welche die Einhaltung von nachhaltiger Forstwirtschaft gewährleisten müssen. Des Weiteren ist der Umfang der Studie insofern begrenzt, dass mögliche negative Auswirkungen auf Ökosystemleistungen aufgrund von Dateneinschränkungen nicht berücksichtigt worden sind.

Lebensgrundlagen, die auf der Nutzung von natürlichen Ressourcen basieren, sind unweigerlich mit klimatischer Saisonalität und der Herausforderung der nachhaltigen Nutzung von natürlichen Ressourcen verbunden. Alle vier Studien befassen sich aus unterschiedlichen Perspektiven mit diesen Thematiken. Die Literatur zur Modellierung von ländlichen Arbeitsmärkten in gesamtwirtschaftlichen Modellen ist relativ spärlich und diese Dissertation leistet hierzu einen Beitrag, indem sie die saisonale Dimension von Arbeitsmärkten erfasst. Dieses Forschungsfeld bietet ein großes Potential für weitere Entwicklungen. Methodisch könnten CGE Modelle beispielsweise so erweitert werden, dass saisonale Arbeit in Kombination mit verschiedenen landwirtschaftlichen Technologien modelliert wird, was durch die Integration des Ansatzes der Feldarbeitsgänge aus Kapitel 4 möglich wäre. Die Berücksichtigung unterschiedlicher Formen von Arbeitsteilung und Arbeitseinsatz zum Beispiel im Hinblick auf das Geschlecht oder Alter hat eine hohe Relevanz für die Modellweiterentwicklung, wofür jedoch eine verbesserte Datengrundlage notwendig wäre. Mehr Daten würden auch für die Integration von Ökosystemdienstleistungen innerhalb von gesamtwirtschaftlichen Modellen benötigt, was in dieser Arbeit ebenfalls als eine wesentliche Einschränkung und zukünftiges Forschungsfeld identifiziert wird.

Schlagwörter:

Modellierung der Gesamtwirtschaft; Allgemeines Gleichgewichtsmodell; Ländliche Lebensgrundlagen; Saisonale Arbeit, Politik zur Nutzung natürlicher Ressourcen; Agrarpolitik: Forstpolitik: Bhutan

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List of Abbreviations

AAC	Annual Allowable Cut
ADB	Asian Development Bank
AEZ	Agroecological zone
AIDS	Almost Ideal Demand System
AMC	Agricultural Machinery Centre
BEA	Bhutan Electricity Authority
BLSS	Bhutan Living Standard Survey
BoP	Balance of Payments
CA	Conventional Agriculture
CES	Constant Elasticity of Substitution
CET	Constant Elasticity of Transformation
CFG	Community Forestry Group
CGE	Computable General Equilibrium
CoP	Cost of Production
CPI	Consumer Price Index
DoFPS	Department of Forest and Park Services
EC	European Council
EU	European Union
EV	Equivalent Variation
FAO	Food and Agriculture Organization
FMU	Forest Management Units
FOB	Free on Board
FRMD	Forest Resources Management Devision
FRPA	Forest Resources Potential Assessment
GAMS	General Algebraic Modeling System
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GNH	Gross National Happiness
GNHC	Gross National Happiness Commission
GTAP	Global Trade Analysis Project
HDI	Human Development Index
HH	Household
IES	Intertemporal elasticity of substitution
IFOAM	International Federation of Organic Agriculture Movements
IFPRI	International Food Policy Research Institute
ILO	International Labour Organization
IRR	Internal Rate of Return

IUCN	International Union for Conservation of Nature
K	Potassium
LES	Linear Expenditure System
LU	Livestock Unit
MCS	Monte Carlo simulations
MoAF	Ministry of Agriculture and Forests
MoEA	Ministry of Economic Affairs
MoF	Ministry of Finance
MoLHR	Ministry of Labour and Human Resources
MWh	Megawatthours
N	Nitrogen
NA	National Accounts
NAB	National Assembly of Bhutan
NEC	National Environment Commission
NLC	National Land Commission
NOP	National Organic Programme
NPK	Nitrogen-Phosphorus-Potassium
NPV	Net Present Value
NRDCL	Natural Resource Development Corporation Limited
NSB	National Statistics Bureau (of Bhutan)
Nu.	Ngultrum (1 US-$ = 53.40 Nu.)
NWFP	Non-Wood Forest Products
OA	Organic Agriculture
P	Phosphorus
PPI	Producer Price Index
PPP	Purchasing Power Parity
RGoB	Royal Government of Bhutan
RH	Rural Households
RHG	Representative Household Groups
RMA	Royal Monetary Authority
RNR	Renewable Natural Resources
RSTA	Road Safety and Transport Authority
SAM	Social Accounting Matrix
SNA	System of National Accounts
SUT	Supply Use Table
UN	United Nations
UNCTAD	United Nations Conference Trade and Development
UNDP	United Nations Development Programme
WWF	World Wide Fund for Nature

Chapter 1 Introduction

Human societies are facing enormous challenges in reconciling their own existence and the maintenance of the Earth System within acceptable planetary boundaries (Rockström et al., 2009; Steffen et al., 2015). The Sustainable Development Goals have superseded the Millennium Development Goals and now explicitly recognize the importance of environmental sustainability (UN, 2016). Development and environmental sustainability thus cannot be considered separately. However, the challenges of trade-offs and synergies remain, especially regarding the conservation of the global commons that are threatened by climate change. Under the facilitation of the United Nations, different instruments and frameworks have been put into place to provide incentives to developing countries, for instance, to reduce greenhouse gas (GHG) emissions or to achieve land degradation neutrality.[1] While these instruments may increase the cost-efficiency of mitigation measures, a controversial debate remains on how to balance the sustainable use of natural resources and conservation of the environment with objectives of economic development and poverty eradication (Combes Motel, Choumert, Minea, & Sterner, 2014; Lélé, 1991; McShane et al., 2011; Pearce, Barbier, & Markandya, 2013).

1.1 Natural Resources, Seasonality and Rural Development

Dependence on natural resources and climatic seasonality are the main features of rural livelihoods in the developing agrarian economies. Despite a persistent trend of urbanization, the majority of the population in low- and middle income countries (50.6%) is still residing in rural areas, numbering about 3.2 billion people in 2017 (World Bank, 2018). Furthermore, it is estimated that the largest share of the labour force in low- and middle income countries (30%) is employed in agriculture (ILO, 2015). Agriculture is therefore the main employer in rural areas, and agricultural land and other natural resources such as forests are the key resource base for most rural livelihoods (Barbier, 2010; E. Robinson, 2016).

The management of natural resources is often determined by climatic seasonality, e.g., farmers can only start cultivation of their land at the beginning of the rainy season. Unlike employment in the secondary or tertiary sector, farmers pursue a diversity of economic activities in order to secure income throughout the year (Ellis, 1998). Seasonality is a factor that complicates the

[1] Most known are the Clean Development Mechanism and REDD+, which stands for "Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries".

analysis of rural livelihoods. There are seasonal patterns of hunger, diseases, income, migration, births and many other dimensions of development (Chambers, Longhurst, & Pacey, 1981; Devereux, Sabates-Wheeler, & Longhurst, 2012; Schofield, 1974; Vaitla, Devereux, & Swan, 2009). These all have impacts on the living conditions of the rural population and are potential sources of bias when measuring households' welfare or performance of policies and interventions in the field of rural development (Chambers, 2012; Dercon & Krishnan, 2000).

Seasonality plays a distinct role in the rural labour markets of agrarian economies, causing special employment problems such as seasonal labour shortages and underemployment (Rosenzweig, 1988). Empirical studies have recorded evidence of seasonal labour shortages and underemployment in economies as divergent as China (Zhang, Yang, & Wang, 2011), Malawi (Wodon & Beegle, 2012) and the U.S. (Fisher & Knutson, 2013; J. Edward Taylor, Charlton, & Yúnez-Naude, 2012). Open unemployment in the absence of unemployment benefit programs is rather the exception in low-income countries. Instead, high levels of underemployment are prevalent and workers in rural areas mitigate seasonal underemployment by seeking employment in non-farm activities during slack periods (Binswanger & Rosenzweig, 1981; Reardon, Stamoulis, Cruz, Berdegué, & Banks, 1998). Seasonal underemployment was found to disproportionately affect women (Bardhan, 1984; Jarvis & Vera-Toscano, 2004) and to trigger seasonal migration (Ahamad, Khondker, Ahmed, & Tanin, 2011; Kleinwechter & Grethe, 2015).

Natural resources policies and the understanding of seasonal rural livelihoods are central for rural development. The poverty-reducing potential of investments in agriculture has increasingly come to the centre of development interventions and policies after decades of urban-biased development planning that is characterized by industrialization strategies (Christiaensen, Demery, & Kuhl, 2011; Datt & Ravallion, 1998; Irz, Lin, Thirtle, & Wiggins, 2001; Alain de Janvry & Sadoulet, 2010). However, the prevalence of poverty in rural areas is still extremely high. More than 80% of the extreme poor (i.e., living below 1.90 US-$ per person per day in 2011 purchasing power parity (PPP) terms) live in rural areas, and more than two-thirds of the extremely poor workers are employed in the agricultural sector (Castañeda et al., 2018). Eradicating poverty thus has to improve productivity within the agricultural sector, predominantly the productivity of labour, which is the most important and often only available resource of the poor.

Throughout this thesis, the stand-alone term development relates to the improvement of people's standard of living using measures of national income and welfare as indicators. Hence, the socio-economic dimension of development is emphasized, despite the many further aspects of development, that are for instance captured by the Human Development Index (HDI) (Anand & Amartya Sen, 1994) and the research on multidimensional poverty (Alkire & Foster, 2011). There also seems to be no commonly agreed definition of development, specifically in the context of economic development, as many definitions and concepts have emerged from various schools of thinking (H. Arndt, 1981; Amartya Sen, 1988). Nevertheless, the relevance of balancing development with environmental conservation has been recognized, and arguably it has become a consensus that policies with the objective of poverty alleviation should prevent any undermining of the resource base of rural livelihoods (UN, 2016).

Yet, policy interventions geared towards improving rural development are often accompanied by unintended consequences. The green revolution for example has led to increases in crop productivity (Pingali, 2012) and resulted in poverty alleviation, however with very different effects across regions and household categories (Evenson & Gollin, 2003; Alain de Janvry & Sadoulet, 2010). While increases in crop yields reduced the land expansion of agriculture (Stevenson, Villoria, Byerlee, Kelley, & Maredia, 2013), there were still negative environmental impacts associated with the degradation of the agricultural resource base such as soil degradation (Aeschbach-Hertig & Gleeson, 2012; Matson, 1997; Pingali, 2012). Another example highlighting the trade-offs of rural development policies is the adoption of oil palm cultivation by smallholders. In the humid tropics, oil palm development is among the most profitable options for land use with the potential to have substantial benefits for rural livelihoods (Rist et al., 2010; Sayer et al., 2012). Yet, at the same time, oil palm expansion has led to losses in tropical rainforest with drastic negative impacts on biodiversity (Fitzherbert et al., 2008). Other interventions, such as the conversion of farming systems from conventional to organic agriculture may yield environmental benefits such as improved biodiversity (Bengtsson, Ahnström, & Weibull, 2005), but is associated with lower yields (Ponisio et al., 2015) and when compared on a per product unit, the environmental benefits are reduced or even reversed (Tuomisto, Hodge, Riordan, & Macdonald, 2012).

Although the above examples show that rural development can lead to trade-offs with environmental conservation, there is also evidence of the potential of achieving synergies between economic development and environmental conservation. Following the Limits to Growth report of the Club of Rome (Meadows, Meadows, Randers, & Behrens III, 1977), the

Brundtland Report *Our Common Future* (Brundtland, 1987) established and popularized the concept of sustainable development. Around the time of the third Earth Summit in Rio de Janeiro (Rio+20), new terms and refinements were added such as "Green Growth" and the "Green Economy" (Barbier, 2012; Toman, 2012).[2] Conceptually, these terms did not offer substantial new insights, rather they highlighted that policies leading to positive environmental benefits (e.g. policies reversing fuel subsidies) do not necessarily hamper economic growth but can instead boost it (Coady, Parry, Sears, & Shang, 2017).

Furthermore, at the micro-level, i.e., in the case of rural livelihoods, there are potential synergies between poverty alleviation and sustainable resource management. Essentially, the rural poor with high dependency on natural resources are susceptible to being trapped in a vicious cycle of environmental degradation and poverty. This relationship has been described as the downward spiral (Scherr, 2000) or environment-poverty nexus (Duraiappah, 1998). Development interventions and policies that improved household income levels and livelihood options have shown to be successful in breaking this cycle, hence resulting in both sustainable resource management and alleviation of poverty (Dasgupta, Deichmann, Meisner, & Wheeler, 2005).

1.2 Economy-wide Modelling

Economy-wide models are numerical models suitable for the systematic analysis of both ex-ante and ex-post economic problems on the global, regional, national or sub-national levels. An economy-wide model can be developed for analytical (i.e., for methodological or theoretical developments) or empirical purposes. They are often used to simulate the economy-wide implications of counterfactual shocks (i.e. "what if scenarios") from an ex-ante instead of an ex-post perspective. A model is considered economy-wide when it comprehensively incorporates the linkages of an economy's circular flow (Figure 1.1). Some linkages within an economy deserve particular emphasis such as the forward and backward production linkages (Dorosh & Hazell, 2003). Forward production linkages measure how well a production activity is integrated with downstream sectors that use its output as intermediate input (e.g. supplying fruits to agro-processing industries). The backward production linkages comprise the same activities' demand for intermediate inputs supplied by upstream sectors (e.g. demanding seedlings from nurseries). There are further linkages describing interdependencies within an

[2]The third United Nations Conference on Sustainable Development (UNCSD) which took place from 13th to 22nd of June 2012 in Rio de Janeiro, Brazil.

economy. For instance, trade linkages - defined as import or export intensities - measure how much domestic demand or output is comprised of imports or exports, respectively (C. Arndt, Benfica, Maximiano, Nucifora, & Thurlow, 2008). Consumption linkages reflect that with higher income, private households increase consumption of goods. Incorporating all these linkages is relevant in order to assess not only the direct effects, but also the indirect effects of an exogenous shock (Breisinger, Thomas, & Thurlow, 2009).

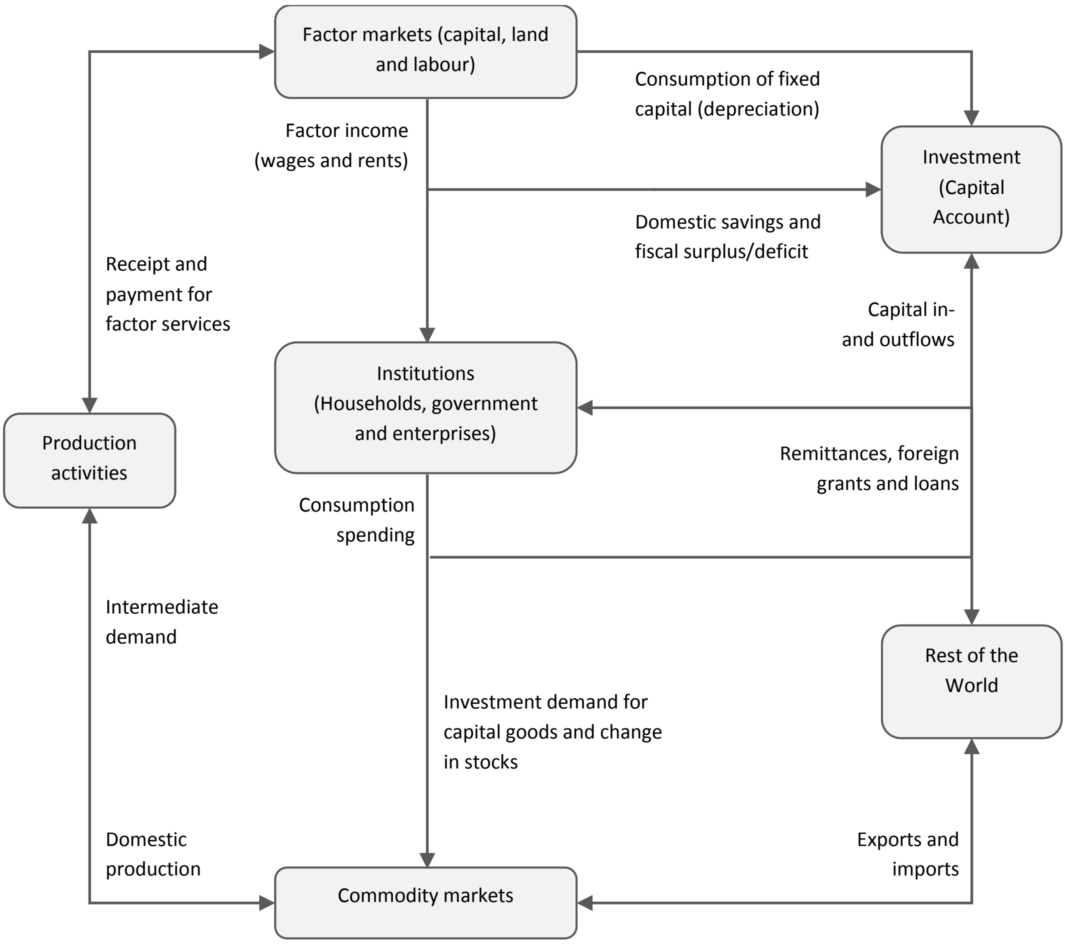

Figure 1.1. Circular flow of an economy

Source: Author's own illustration based on Pyatt, 1988.

1.2.1 Theoretical Foundation of Computable General Equilibrium (CGE) Models

Computable general equilibrium (CGE) models are arguably the most common type of economy-wide models. They are grounded in general equilibrium and Walrasian theory. An equilibrium can be defined as a "constellation of selected interrelated variables so adjusted to one another that no inherent tendency to change prevails in the model which they constitute" (Machlup, 1958, p. 9). This definition is used by Chiang and Wainwright (2005, p. 30), who highlight three important characteristics of the meaning of equilibrium:

(1) An equilibrium is based on a pre-selected choice of variables. Thus, there can be variables which are left out by the analyst, and the equilibrium state of a model is only valid for its underlying constellation of variables.

(2) An equilibrium can only exist if all (selected) variables are in a simultaneous state-of-rest. This requires that each specific variable's state-of-rest has to be compatible with the states of the remaining variables. Otherwise, as the variables are interrelated, we would observe a chain reaction affecting all variables within the model if one variable is changing.

(3) Given the prerequisite of the state-of-rest of all variables, the equilibrium can only change through the adjustment process of the selected variables. All internal forces and external factors that are not represented as variables in the model are assumed to be fixed.

An equilibrium model can represent only a sub-section of an economy, which then involves selected markets (e.g. agricultural markets). These models are referred to as Partial-Equilibrium models and they are simplified in that they only depict the prices of goods reflected within the model, while operating with the assumption that the prices of all other excluded goods are fixed.

General equilibrium theory includes all markets of an economy and dates back to the works of Léon Walras contributed by the end of the 19th century. Walras developed a system of equations in order show that if n-1 of markets are in equilibrium, then the remaining market has to be in equilibrium. This is referred to as the "Walrasian Law" and the Walrasian general equilibrium is defined as the state where the supply and demand of all markets within an economy are equalized, i.e. all markets are cleared (Wing, 2004).

In the 1950s, Walras' general equilibrium theory was advanced by the work of Kenneth Arrow, Gérard Debreu and Lionel W. McKenzie. In their seminal papers, all three economists have proven the existence of a general equilibrium under certain economic conditions such as perfect competition and convex preferences, which today is referred to as the Arrow-Debreu(-McKenzie) model (Arrow & Debreu, 1954; Lionel McKenzie, 1954; Lionel W. McKenzie, 1959). Due to limitation in the computational power and data availability, general equilibrium analysis was largely motivated by theory. This changed in the early 1970s when the first empirical application of the general equilibrium model became computationally possible. According to Dixon and Jorgenson (2013) and others, the first CGE model was developed and applied by Leif Johansen in 1960, whose 22 sectors model was the first of its kind with an explicit identification of agent behaviour (Johansen, 1960).

A few years later, Herbert Scarf was the first to develop an algorithm to solve Arrow-Debreu models (Scarf, 1967b, 1967a), and subsequent work at his institute evolved into the so-called "Applied General Equilibrium" (AGE) models developed by Shoven and Whalley (Shoven & Whalley, 1972, 1973). AGE and CGE models are largely used as synonyms (e.g. Thomas Hertel, 2002). This has also been subject to strong criticism (Mitra-Kahn, 2008), because both models have a different origin. AGEs were directly derived from the Arrow-Debreu model of which the CGEs, in contrast, are rather considered an "empirical special case" (S. Robinson & Lofgren, 2005, p. 272).

Capturing an economy's circular flow and solving all markets simultaneously by determining equilibrium wages and prices, CGE models are "Walrasian in spirit" (S. Robinson, 2006, p. 6). However, CGE models cannot generally be declared Walrasian in the purest sense. Further developments of CGE models have included unemployment and other extensions that go beyond the Walrasian theory. Unemployment is an example of Keynesian theory showing that not all markets have to be in simultaneous equilibrium, which is difficult to be reconciled with the Walrasian general equilibrium theory (S. Robinson & Lofgren, 2005). More recently, Dixon and Rimmer (2011) showed that the 2008-09 recession in the U.S. could only be replicated in a CGE model allowing for excess capacity of capital, which violates the standard CGE assumption of full employment of capital. Dervis et al. (1982) point out that while general equilibrium models may not always be consistent with Walrasian theory, their foundation nevertheless is the neoclassical theory of resource allocation.

CGE models can be understood as "bottom-up" microeconomic models, where the economy is viewed from the perspective of agents and markets. While CGE models report changes of macro-aggregate, they are not macroeconomic models as they usually do not depict asset markets, interest rates and inflation. This is in contrast to Keynesian macro-economic models that take a top-down perspective and capture macro-economic variables and asset markets (S. Robinson & Lofgren, 2005). According to Robinson (1991), despite efforts to move away from the neoclassical setting by developing "macro-micro" CGE models, there is still a considerable theoretical gap to bridge the theories of Walras and Keynes within a CGE framework. These theoretical tensions remain today and most of the CGE literature is focused on applications or methodological development rather than on working towards a reconciliation of both of these economic theories.

1.2.2 The Theory of Social Accounting Matrices (SAMs)

The most common underlying database of CGE models is a social accounting matrix (SAM), which records all transaction within an economy (Scott McDonald, 2013). A SAM is a detailed snapshot of an economy's circular flow (King, 1985). It is referred to as a "social accounting matrix" because, in contrast to other economic statistical frameworks such as national accounts, input-output and supply-and-use tables, it does also capture transactions of households and other institutions within the economy. The development of the modern concept of a SAM is attributed to Richard Stone, who in 1984 was awarded the Nobel Prize for his work on the national account system. Stone published the first ever SAM in 1960, which is based on the economy of Great Britain.

According to Stone (1986), the origin of national economic accounting has to be traced back to William Petty. Petty lived in seventeenth century England and can frankly be considered a genius jack of all trades. In 1664, Petty estimated the value of labour of the population of England and Wales by deducting the income accruing to land and other sources from total expenditure. He thus set total income equal to expenditure, which is the core principle of a SAM. His work inspired Gregory King, a herald by profession, who was interested in estimating how much various societal groups contributed to wealth. King took Petty's approach further to what can be considered the first archetype version of SAMs for England, France and Holland. In 1758, the French economist François Quesnay, however, was the first person to capture the circular flow of an economy by developing his "Tableau Economique" (Pyatt & Round, 1985).

The boundary of transactions recorded within a SAM is determined by the economy for which the SAM is built. A SAM that is built for a country captures all transactions between agents within the production boundary of the National Accounts, including transactions between institutions within the country and between domestic and foreign institutions. Institutions outside the country are usually lumped together in one account and referred to as the "rest of the world" account. Expenditure of institutions is recorded in the column accounts of the matrix, while analogously income is recorded in row accounts as shown in the schematic representation in Table 1.1. An economic agent is represented in the SAM by assigning it with a respective column and row account. The total expenditure of an account needs to equal that account's total income received, which makes a SAM a consistent dataset and compliant with a fundamental law of economics: each recorded expenditure needs to relate to a corresponding income (Pyatt, 1988).

Table 1.1. Schematic representation of a macro-SAM

	Commodities	Margins	Activities	Factors	Households and enterprises	Government	Investments	Rest of the world	Total
Commodities		Margins	Intermediate consumption (Use-Matrix)		HH and ENT consumption	Gov. consumption	Investment demand	Exports	Total demand
Margins	Margins								Margins
Activities	Output (Supply-Matrix)								Domestic output
Factors			Payment for factor services					Factor returns from abroad	Total factor income
Households and enterprises				Factor returns		Gov. transfers to HH		Inward remittances	Total income of HH and ENT
Government and tax accounts	Taxes on products		Taxes less subsidies on production		Income from property; tax income		Government borrowing	Taxes and transfers from RoW	Total government income
Savings				Capital deprec-iation	HH and ENT savings	Government savings		Balance of transactions with RoW	Total savings
Rest of the world (RoW)	Imports			Factor returns to RoW	Transfers to RoW	Gov. transfers to RoW	Balance of transactions with RoW		Total expenditure to RoW
Total	Total supply	Margins	Cost of domestic production	Total factor income	Total HH and ENT expenditure	Total Government expenditure	Total investment	Total income from RoW	

SAMs are used as the basis for multiplier models ("SAM multiplier models"), which can be considered one type of economy-wide model. Unlike the Leontief input-output models, these models capture not only production but also consumption linkages (Breisinger et al., 2009). Multiplier models are based on various simplistic assumptions such as fixed prices and absence of behavioural changes, unlike SAM-based CGE models, which allow for endogenous changes in prices and behavioural changes such as substitution of goods.

1.2.3 Structure and Application of CGE Models

The structure of a CGE model consists of a large set of equations, variables and parameters. Variables can be defined as endogenous (determined within the model) or exogenous (determined outside the model). They represent mostly prices, quantities and the product of both (e.g. household expenditure). Behaviour of producers, households and other institutions is represented in equations. Their functions are specified using different functional forms such as Constant Elasticity of Substitution (CES) or Cobb-Douglas production functions, Constant Elasticity of Transformation (CET) aggregation functions or Linear Expenditure System (LES) demand systems. Each function requires parameters, which are either calibrated using the model database (e.g. in case of coefficients) or determined exogenously by the analyst using point estimates from the literature or based on plausibility considerations.

Equations specify market clearance conditions across all markets (commodity, factors, etc.) in order to ensure that a general equilibrium is achieved (when all markets are cleared). At the same time, the law of one price needs to hold, hence all markets clear at the same prices (but price wedges due to taxes or margins are possible). CGE models are considered bottom-up, because each agent is optimizing its own resource allocation decisions (e.g. households maximize their utility) which are aggregated later at the macro-level. The behaviour of agents is, however, subject to exogenously conditioned macroeconomic closure rules (e.g. savings versus investment driven capital market closure).

CGE models that aim to conduct empirical simulations of scenarios are data intensive, relying either on an input-output table or a SAM. CGE models capture the entire circular flow of an economy including backward and forward linkages. The main application of CGE models is to study empirical research questions by simulating counterfactual scenarios. Unlike econometric methods, the reasoning of CGE models is not inductive, but deductive, given the underlying theoretical foundation. Hence, a thorough understanding of the model mechanisms is necessary in order to scrutinize and interpret model results. Furthermore, sensitivity analysis or depiction of uncertainty via the means of Monte Carlo simulation or Gaussian Quadratures are important tools to check the robustness of model outcomes.

Virtually, all multilateral development agencies (e.g. World Bank, FAO, IFPRI, OECD) have departments that maintain and use CGE models. Over the last decades, CGE models have played a major role in policy analysis (Devarajan & S. Robinson, 2005). Different generic model frameworks were developed that are used for either global economy-wide analysis, e.g. the GTAP model Hertel (Thomas Hertel, 1997b) or LINKAGE (van der Mensbrugghe, 2005), or frameworks specifically designed for single-country CGE analysis, e.g. the IFPRI Standard model (Lofgren, Harris, & Robinson, 2002) and STAGE (Scott McDonald & Thierfelder, 2015). In academia, CGE models were used inter alias to assess the impacts of climate change (e.g. Calzadilla et al., 2013; Nelson et al., 2014), the food price crisis (e.g. C. Arndt et al., 2008; Rutten, Shutes, & Meijerink, 2013) and agriculture and bioenergy policy scenarios (e.g. Banse, van Meijl, Tabeau, & Woltjer, 2008; Lotze-Campen et al., 2010; Stevenson et al., 2013; J. E. Taylor, Yunez-Naude, & Dyer, 1999).

In most developing countries, agriculture has a large share in both employment and gross domestic production (GDP), which makes CGE models particularly suitable for the analysis of research questions related to rural development and natural resource policies. Moreover, with a growing non-farm economy (Haggblade, Hazell, & Reardon, 2010; Reardon, Berdegué, Barrett, & Stamoulis, 2007), forward and backward linkages between agriculture and other sectors are increasing. Therefore, economy-wide impacts originating from the farm or non-farm sector are increasing along with the scope of intersectoral spillovers.

Despite their origin in neoclassical and Walrasian general equilibrium theory, CGE models have been extended for various analytical purposes in order to study market failures and even game-theoretic aspects (Bernard, Haurie, Vielle, & Viguier, 2008; Böhringer, Carbone, & Rutherford, 2016; Alain Janvry & Kanbur, 2006). Extensions do not necessarily concern the underlying general equilibrium theory, but may just focus on particular aspects of CGE models. A large body of literature, for instance, exists on modelling specific aspects of energy markets in CGE models, comprising various model developments such as the depiction of market power or the nesting of production structures. In contrast, there are still components considered to be “rudimentary”, such as the rather simplistic representation of labour markets in CGE models (Dixon & Jorgenson, 2013, p. 20).

A particular simplification of CGE models concerning the labour market derives from the understanding that they are usually solved on an annual basis. This requires the implicit assumption that there is total flexibility in allocating labour among periods within a year, i.e.

labour units are homogenous through the course of a year. However, this presumption is problematic in agrarian developing economies, as labour is not homogenous due to rigid seasonal patterns of labour demand. Consequently, the assumption of homogeneity of labour (or equally the assumption of perfect intertemporal substitutability) is unrealistic and results e.g. in matching demand for labour units in the harvest season (autumn) with the supply of labour units in the summer season.

Micro-level models, such as single-farm or multi-agent models, are characterized as depicting a higher resolution of details of a certain part of an economy. Including the seasonal fluctuation of labour demand is a standard feature in micro-level models (e.g. Acs, Berentsen, & Huirne, 2007; Troost & Berger, 2015) and the exclusion of seasonal labour constraints is known to cause model distortions (Hazell & Norton, 1986). However, unlike CGE models, micro-level models are not able to capture forward and backward linkages since they are limited to a part of the economy, e.g. the agricultural sector.

1.2.4 Empirical Research Gaps

As a case, Bhutan offers some unique characteristics to study the effects of natural resource policies on environmental conservation and rural development. Bhutan is among a small number of countries which, at the early stages of their development, have made sustainability a key theme for consideration within the design of natural resource policies (Brooks, 2013; Flagg, 2015; Lindsey et al., 2017). The small mountainous and landlocked country in the Eastern Himalayas has pledged to stay carbon neutral (RGoB, 2010), to maintain at least 60% of its land area under forest cover at all times (RGoB, 2008) and to convert its agricultural sector to 100% organic agriculture (RGoB, 2012; J. Thinley, 2011). These natural resource policies are all embedded within Bhutan’s unique development philosophy of Gross National Happiness (GNH) which is based on four pillars: (1) Sustainable and equitable socio-economic development; (2) Environmental conservation; (3) Preservation and promotion of culture; and (4) Good governance (GNHC, 2009).

The balancing act of reconciling all four pillars of GNH in the actual operable policies was achieved by adopting the Buddhist concept of pursuing a “middle path” (Brooks, 2013). Policies are revised, for example in the mining sector, if they are found to be in conflict with GNH objectives (Hayden, 2015). Despite Bhutan’s arguably very modern development philosophy, there remain particular challenges to how natural resource policies in Bhutan can serve both the objective of environmental conservation and the provision of sustainable rural livelihoods. More specifically, it is unknown to what extent the policies pursued by Bhutan are resulting in trade-offs or synergies between environmental conservation and rural development.

Empirically, Bhutan presents a rare case, as the history of development in many other countries – particularly the high-income countries of today – rather shows a prioritization of economic-development over sustainable use of resources accompanied by a positive correlation between economic growth and the emission of environmental pollutants. Bhutanese policymakers did not yet accomplish suspending the forces of physics and thus, not surprisingly, problems with the rising level of environmental pollutants, such as air pollution, are already emerging (Narain, Toman, & Jiang, 2014). Moreover, there has hardly been any empirical research studying how formulated natural resource policies affect rural development in Bhutan and how they could be possibly altered in order to avoid trade-offs, and instead realize synergies between both objectives. Given that Bhutan is an agrarian economy with more than 50% of the labour force employed in agriculture, CGE models are particularly suitable to address this research gap.

1.2.5 Methodological Research Gaps

From an income source perspective, seasonality affects the most important resource endowment of the poor: their labour. Seasonality is a key feature of rural labour markets in agrarian economies, which does not require a specific theory but involves special employment problems such as seasonal labour shortages and underemployment (Rosenzweig, 1988)(Rosenzweig, 1988). However, the role of seasonal labour markets at the economy-wide level of analysis, e.g. regarding an economy's adaptive ability to respond towards exogenous shocks and the implications for rural livelihoods, has so far been largely neglected within the economy-wide modelling literature.

It is unknown, whether the prevalent assumption of homogeneity of labour units used by CGE models so far is negligible, i.e. not altering model results in any substantial way, or whether the absence of seasonal labour markets in economy-wide models is responsible for serious bias in model results. Seasonal fluctuations of labour demand are of particular importance for countries in which a large share of the labour force is employed in sectors characterized by seasonality. Only two studies (Filipski, Aboudrare, Lybbert, & Taylor, 2017; Finnoff & Tschirhart, 2008) incorporated seasonal labour. However, these studies did not explicitly focus on the specific features and characteristics of seasonal labour and hence modelled seasonal labour in a rather simplified way without the depiction of national labour markets. Understanding the role of seasonal labour in economy-wide models is a thus a crucial research gap, which could contribute to the wider field of CGE model applications in agrarian economies.

1.3 Research Objectives

The following presents the methodological and empirical research objectives of this dissertation. The main method employed to pursue these objectives consists of the single-country and comparative static CGE model framework STAGE2. The comparative static mode is the preferred mode when the time path over which an adjustment takes place is not critical for the purpose of the analysis (Dervis et al., 1982). In contrast, a dynamic-recursive mode is preferred when the analyst is interested in the adjustment path and the development of factor endowment and investments over time. STAGE2 is a SAM-based CGE model and the core underlying database for all studies is the 2012 SAM for Bhutan, whose development is documented in Appendix A.

1.3.1 Methodological Objectives

The methodological research objective is to investigate how seasonality of labour markets affects economy-wide model outcomes. From this objective, the following methodological research questions are derived:

1. *Does the seasonality of labour matter for economy-wide model outcomes in agrarian economies?*
    a. *Is there a systematic bias if economy-wide models do not capture the seasonality of labour markets?*
    b. *What are the implications of seasonality for households' labour supply decision along the intensive margin (i.e. labour-leisure trade-off)?*

These questions are addressed in Chapter 3 which includes the paper titled *Rural livelihoods and seasonal labour supply.* A theoretical framework is developed that outlines the basic economic theory of labour supply and demand, extending it to reflect the role of seasonality. Furthermore, primary and secondary data sources on seasonal labour have been collected, processed and integrated into a 2012 SAM for Bhutan – the first ever SAM capturing seasonal labour markets. Modifying an existing comparative-static CGE model (STAGE2), seasonal labour was incorporated within the labour demand and supply behavioural specifications. In order to investigate the effect of seasonal labour markets on model outcomes, a variety of shocks of changes in import prices of cereals were simulated using one model setup with annual labour markets and another model setup with seasonal labour markets.

1.3.2 Empirical Research Objectives

The empirical research objective is to assess the impacts of natural resource policies in Bhutan on seasonal rural livelihoods in the context of environmental conservation and rural development. The research scope is limited to the analysis of agricultural and forest policies.[3] Two main research questions are derived from the empirical research objective. The first question relates to Bhutan's 100% organic agriculture policy. The other question focuses on the trade-off between Bhutan's restrictive forest policies, that serve to ensure 60% forest cover at all times, and rural development through more expansive forest policies. The questions are described and contextualized in the following:

2. *What are the implications of Bhutan's 100% organic conversion policy on rural livelihoods and the economy as a whole?*
    a. *Is the agricultural sector in Bhutan in a favourable condition to convert to 100% organic?*
    b. *What trade-offs or synergies does the 100% organic policy cause?*

Question 2a) is addressed in Chapter 4, which contains the paper titled: *Is Bhutan destined for 100% organic? Assessing the economy-wide effects of a large-scale conversion policy*. This study contributes to the scarce literature on large-scale conversion policies, particularly on a country-level taking into account agroecological differences and economy-wide implications. Bhutan's 100% organic policy is mainly motivated by the objectives of environmental conservation, but impacts on rural livelihoods have remained unclear. The question thus addresses the broader issue of how agricultural policies that aim to improve the environmental sustainability impact rural livelihoods in a peasant economy.

A number of subordinate research questions and areas within the field of organic agriculture and food security are linked to the main research question. Question 2a) refers to the general notion that Bhutan has a low dependency on agrochemical use. This question is also related to

[3] This means that policy scenarios on other renewable natural resources and particularly non-renewable resources (e.g. fossil-fuels) are not considered.

the literature on differences in yields between conventional and organic farmers in developing countries since most relevant studies were conducted in developed countries (Ponisio et al., 2015; Ponti et al., 2012; Seufert et al., 2017).

The second related research question 2b) touches upon the trade-off between food security and organic agriculture or more bluntly to the question: "Can organic agriculture feed the world?", which has provoked vigorous and controversial debates within the literature (Badgley et al., 2007; Cassman, 2007; Muller et al., 2017). There are many further subordinate research questions that unfold in this context: the role of agricultural labour in organic agriculture, the availability of crop nutrients, the degree of land expansion, and the potential benefits from reduced environmental externalities and price premiums.

3. *How can forest policies contribute to economic diversification and rural development without jeopardizing Bhutan's forest conservation agenda?*
    a. *Is sustainable charcoal production economically viable in Bhutan?*
    b. *Do rural forest policies that link rural households with the fuelwood value chain increase resource efficiency and rural welfare?*

Even though about 70% of Bhutan's land area is under forest cover, only about 5% of total forest area is under commercial management (MoAF, 2015). The low forest utilization makes Bhutan a net importer of wood products, particularly of charcoal, which comprises about 60% of wood imports. There is a controversy in the literature about whether Bhutan should explore the possibilities of increasing forest utilization, which would, for instance, allow for the establishment of a domestic charcoal industry (Jadin, Meyfroidt, & Lambin, 2015; Narain et al., 2014; Siebert & Belsky, 2015). Conservation of forests is a particularly sensitive issue in Bhutan, as forests provide many ecosystem services for instance by protecting the watersheds in the mountainous country, which is of paramount importance for Bhutan's hydropower sector.

Chapter 5 covers research question 3a) investigating whether a domestic charcoal industry is economically viable in Bhutan. Charcoal is needed as a carbon-reducing agent in Bhutan's metallurgical industries and ranks among the top ten import items accounting for almost 2% of total imports (MoF, 2013b). Past investment activities to establish a charcoal industry failed due to alleged labour shortages and prohibitive transportation costs (World Bank, 1992). Unlike the other simulation models included in this dissertation, this study does not rely on a CGE model, but on an investment and transportation model.

In Chapter 6, the research question 3b) is addressed by analysing the impact of forest policies that link rural households to the wood product value chain. Forests are often underestimated in their importance for rural livelihoods, but they provide significant potential to rural households to smoothen their income or even to fill seasonal income gaps (Sunderlin et al., 2005; Wunder, Angelsen, & Belcher, 2014). Due to the restrictive forest conservation framework, rural households in Bhutan are largely constrained to only extract timber for their own subsistence needs (RGoB, 2017), and commercial sale of wood products is usually prohibited. The approach in Chapter 6 builds on the earlier findings of Chapter 3 and 5, by incorporating seasonal underemployment and by including a marginal charcoal production activity in the 2012 SAM for Bhutan.

1.4 Outline of the Dissertation

Following the general background and research objectives presented above, this cumulative dissertation is structured as follows:

Chapter 2 provides the reader with the country context information of Bhutan describing the geography, political system, socio-economic development and agricultural sector of the country.

Chapter 3 investigates the core methodological research question of how relevant seasonal labour markets are for model outcomes in agrarian economies. This paper is prepared for submission to the Journal of Development Economics.

In *Chapter 4*, the empirical research question on the 100% organic agriculture policy conversion is addressed by developing a detailed CGE model for Bhutan with depiction of crop nutrients, agroecological zones and field operations. This study was published 2018 in PlosOne, Vol. 13, Issue 6, *https://doi.org/10.1371/journal.pone.0199025*.

Chapter 5 addresses the research question of whether a domestic charcoal industry can be reconciled with Bhutan's conservation framework. This study was published 2016 in Forest Policy and Economics, Vol. 73 *http://dx.doi.org/10.1016/j.forpol.2016.08.007*.

Chapter 6 builds on the findings of *Chapter 3* and *5* and investigates the research question on how innovative forest policy designs can contribute to rural livelihoods in Bhutan. This paper is prepared for submission to the Journal of Rural Studies.

The dissertation concludes with *Chapter 7,* which provides a synthesis of the research findings, highlights research limitations and highlights avenues for future research and briefly presents general policy implications.

Three technical appendices are included. Appendix A describes the theoretical framework developed to depict seasonal labour in a comparative static CGE model. Appendix B is the detailed technical documentation of the 2012 social accounting matrix of Bhutan, which was published in the working paper series of the Department of Agricultural Economics Humboldt-Universität zu Berlin in 2017 (see also: *https://doi.org/10.13140/rg.2.2.14554.85446).* 0 documents the extensions to the STAGE2 model, which were necessary for the studies included in this thesis.

1.5 References

Acs, S., Berentsen, P. B.M., & Huirne, R. B.M. (2007). Conversion to organic arable farming in The Netherlands: A dynamic linear programming analysis. Agricultural Systems, 94(2), 405–415. Retrieved from http://www.sciencedirect.com/science/article/pii/S0308521X06001697

Aeschbach-Hertig, W., & Gleeson, T. (2012). Regional strategies for the accelerating global problem of groundwater depletion. Nature Geoscience, 5(12), 853–861. https://doi.org/10.1038/ngeo1617

Ahamad, M. G., Khondker, R. K., Ahmed, Z. U., & Tanin, F. (2011). Seasonal Unemployment and Voluntary Out-Migration from Northern Bangladesh. Modern Economy, 02(02), 174–179. https://doi.org/10.4236/me.2011.22023

Alkire, S., & Foster, J. (2011). Counting and multidimensional poverty measurement. Journal of Public Economics, 95(7), 476–487. https://doi.org/10.1016/j.jpubeco.2010.11.006

Anand, S., & Sen, A. (1994). Human Development Index: Methodology and Measurement (Human Development Report Office Occasional Papers No. 12). New York, USA.

Arndt, C., Benfica, R., Maximiano, N., Nucifora, A. M. D., & Thurlow, James T. (2008). Higher fuel and food prices: impacts and responses for Mozambique. Agricultural Economics, 39(August), 497–511. https://doi.org/10.1111/j.1574-0862.2008.00355.x

Arndt, H. (1981). Economic Development: A Semantic History. Economic Development and Cultural Change, 29(3), 457–466. https://doi.org/10.1086/451266

Arrow, K. J., & Debreu, G. (1954). Existence of an equilibrium for a competitive economy. Econometrica: Journal of the Econometric Society, 265–290. Retrieved from http://www.jstor.org/stable/1907353

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M. J., Aviles-Vazquez, K., . . . Perfecto, I. (2007). Organic agriculture and the global food supply. Renewable Agriculture and Food Systems, 22(2), 86–108.

Banse, M., van Meijl, H., Tabeau, A., & Woltjer, G. (2008). Will EU biofuel policies affect global agricultural markets? European Review of Agricultural Economics, 35(2), 117–141. https://doi.org/10.1093/erae/jbn023

Barbier, Edward B. (2010). Poverty, development, and environment. Environment and Development Economics, 15(06), 635–660. https://doi.org/10.1017/S1355770X1000032X

Barbier, Edward B. (2012). Sustainability. The green economy post Rio+20. Science (New York, N.Y.), 338(6109), 887–888. https://doi.org/10.1126/science.1227360

Bardhan, P. K. (1984). Determinants of supply and demand for labor in a poor agrarian economy: an analysis of household survey data from rural West Bengal. In H. Binswanger & M. Rosenzweig (Eds.), Contractual Arrangements, Employment and Wages in Rural Labor Markets: A Critical Review. New Haven, CT: Yale University Press.

Bengtsson, J., Ahnström, J., & Weibull, A.-C. (2005). The effects of organic agriculture on biodiversity and abundance: a meta□analysis. Journal of Applied Ecology, 42(2), 261–269. https://doi.org/10.1111/j.1365-2664.2005.01005.x

Bernard, A., Haurie, A., Vielle, M., & Viguier, L. (2008). A two-level dynamic game of carbon emission trading between Russia, China, and Annex B countries. Journal of Economic Dynamics and Control, 32(6), 1830–1856. https://doi.org/10.1016/j.jedc.2007.07.001

Binswanger, H. P., & Rosenzweig, M. R. (1981). Contractual arrangements, employment, and wages in rural labor markets: a critical review (Studies in Employment and Rural Development No. 67). Washington D.C., USA. Retrieved from http://documents.worldbank.org/curated/en/412971467997610342/Contractual-arrangements-employment-and-wages-in-rural-labor-markets-a-critical-review

Böhringer, C., Carbone, J. C., & Rutherford, T. F. (2016). The Strategic Value of Carbon Tariffs. American Economic Journal: Economic Policy, 8(1), 28–51. https://doi.org/10.1257/pol.20130327

Breisinger, C., Thomas, M., & Thurlow, James. (2009). Social accounting matrices and multiplier analysis: An introduction with exercises: Intl Food Policy Res Inst.

Brooks, J. S. (2013). Avoiding the Limits to Growth: Gross National Happiness in Bhutan as a Model for Sustainable Development. Sustainability, 5(9), 3640–3664. https://doi.org/10.3390/su5093640

Brundtland, G. (1987). Our common future: Report of the 1987 World Commission on Environment and Development. United Nations, Oslo, 1, 59.

Calzadilla, A., Rehdanz, K., Betts, R., Falloon, P., Wiltshire, A., & Tol, R. S. J. (2013). Climate change impacts on global agriculture. Climatic Change, 120(1), 357–374. https://doi.org/10.1007/s10584-013-0822-4

Cassman, K. (2007). Can organic agriculture feed the world—science to the rescue? Renewable Agriculture and Food Systems, 22(02), 83–84. https://doi.org/10.1017/S1742170507001986

Castañeda, A., Doan, D., Newhouse, D., Nguyen, M. C., Uematsu, H., & Azevedo, J. P. (2018). A New Profile of the Global Poor. World Development, 101, 250–267. https://doi.org/10.1016/j.worlddev.2017.08.002

Chambers, R. (2012). Foreword. In S. Devereux, R. Sabates-Wheeler, & R. Longhurst (Eds.), Seasonality, rural livelihoods and development (xv-viii). Routledge.

Chambers, R., Longhurst, R., & Pacey, A. (1981). Seasonal dimensions to rural poverty: Frances Pinter. Retrieved from https://opendocs.ids.ac.uk/opendocs/bitstream/handle/123456789/136/rc166.pdf?sequence=2

Chiang, A. C., & Wainwright, K. (2005). Fundamental Methods of Mathematical Economics // Fundamental methods of mathematical economics (4th International Edition // 4. ed., internat. ed., [reprint.]). McGraw-Hill international edition. New York, USA: McGraw-Hill.

Christiaensen, L., Demery, L., & Kuhl, J. (2011). The (evolving) role of agriculture in poverty reduction—An empirical perspective. Journal of Development Economics, 96(2), 239–254. https://doi.org/10.1016/j.jdeveco.2010.10.006

Coady, D., Parry, I., Sears, L., & Shang, B. (2017). How Large Are Global Fossil Fuel Subsidies? World Development, 91, 11–27. https://doi.org/10.1016/j.worlddev.2016.10.004

Combes Motel, P., Choumert, J., Minea, A., & Sterner, T. (2014). Explorations in the Environment–Development Dilemma. Environmental and Resource Economics, 57(4), 479–485. https://doi.org/10.1007/s10640-013-9745-9

Dasgupta, S., Deichmann, U., Meisner, C., & Wheeler, D. (2005). Where is the Poverty–Environment Nexus? Evidence from Cambodia, Lao PDR, and Vietnam. World Development, 33(4), 617–638. https://doi.org/10.1016/j.worlddev.2004.10.003

Datt, G., & Ravallion, M. (1998). Farm productivity and rural poverty in India. Journal of Development Studies, 34(4), 62–85. https://doi.org/10.1080/00220389808422529

Dercon, S., & Krishnan, P. (2000). Vulnerability, seasonality and poverty in Ethiopia. Journal of Development Studies, 36(6), 25–53. https://doi.org/10.1080/00220380008422653

Dervis, K., Melo, J. de, & Robinson, S. (1982). General equilibrium models for development policy (No. 0521270308). New York, USA.

Devarajan, S., & Robinson, S. (2005). The Influence of Computable General Equilibrium Models on Policy. Frontiers in Applied General Equilibrium Modeling: in Honor of Herbert Scarf, 402.

Devereux, S., Sabates-Wheeler, R., & Longhurst, R. (Eds.). (2012). Seasonality, rural livelihoods and development: Routledge.

Dixon, P. B., & Jorgenson, D. W. (2013). Introduction. In Handbook of Computable General Equilibrium Modeling. Handbook of Computable General Equilibrium Modeling SET, Vols. 1A and 1B (Vol. 1, pp. 1–22). Elsevier. https://doi.org/10.1016/B978-0-444-59568-3.00001-8

Dixon, P. B., & Rimmer, M. T. (2011). You can't have a CGE recession without excess capacity. Economic Modelling, 28(1-2), 602–613. Retrieved from https://www.sciencedirect.com/science/article/pii/S0264999310001082

Dorosh, P., & Hazell, Peter. (2003). Growth Linkages, Price Effects and Income Distribution in Sub-Saharan Africa. Journal of African Economics, 12(2), 207–235. https://doi.org/10.1093/jae/12.2.207

Duraiappah, A. K. (1998). Poverty and environmental degradation: A review and analysis of the nexus. World Development, 26(12), 2169–2179. https://doi.org/10.1016/S0305-750X(98)00100-4

Ellis, F. (1998). Household strategies and rural livelihood diversification. Journal of Development Studies, 35(1), 1–38. https://doi.org/10.1080/00220389808422553

Evenson, R. E., & Gollin, D. (2003). Assessing the impact of the green revolution, 1960 to 2000. Science (New York, N.Y.), 300(5620), 758–762. https://doi.org/10.1126/science.1078710

Filipski, M., Aboudrare, A., Lybbert, T. J., & Taylor, J. Edward. (2017). Spice Price Spikes: Simulating Impacts of Saffron Price Volatility in a Gendered Local Economy-Wide Model. World Development, 91, 84–99. Retrieved from http://www.sciencedirect.com/science/article/pii/S0305750X16305204

Finnoff, D., & Tschirhart, J. (2008). Linking dynamic economic and ecological general equilibrium models. Resource and Energy Economics, 30(2), 91–114. Retrieved from http://www.sciencedirect.com/science/article/pii/S0928765507000450

Fisher, D. U., & Knutson, R. D. (2013). Uniqueness of Agricultural Labor Markets. American Journal of Agricultural Economics, 95(2), 463–469. https://doi.org/10.1093/ajae/aas088

Fitzherbert, E. B., Struebig, M. J., Morel, A., Danielsen, F., Brühl, C. A., Donald, P. F., & Phalan, B. (2008). How will oil palm expansion affect biodiversity? Trends in Ecology & Evolution, 23(10), 538–545. https://doi.org/10.1016/j.tree.2008.06.012

Flagg, J. A. (2015). Aiming for zero: what makes nations adopt carbon neutral pledges? Environmental Sociology, 1(3), 202–212. https://doi.org/10.1080/23251042.2015.1041213

GNHC. (2009). Tenth Five Year Plan 2008-2013: Volume 1: Main Document. Thimphu, Bhutan.

Haggblade, S., Hazell, Peter, & Reardon, T. (2010). The Rural Non-farm Economy: Prospects for Growth and Poverty Reduction. World Development, 38(10), 1429–1441. https://doi.org/10.1016/j.worlddev.2009.06.008

Hayden, A. (2015). Bhutan: Blazing a Trail to a Postgrowth Future? Or Stepping on the Treadmill of Production? The Journal of Environment & Development, 24(2), 161–186. https://doi.org/10.1177/1070496515579199

Hazell, Peter B. R., & Norton, R. D. (1986). Mathematical programming for economic analysis in agriculture: Macmillan New York. Retrieved from http://agrecon.mcgill.ca/courses/320/hazell/mathprogfront.pdf

Hertel, T. W. (1997). Global trade analysis: modeling and applications: Cambridge university press.

Hertel, T. W. (2002). Chapter 26 Applied general equilibrium analysis of agricultural and resource policies. In Handbook of Agricultural Economics : Agriculture and its External Linkages (pp. 1373–1419). Elsevier. https://doi.org/10.1016/S1574-0072(02)10008-9

ILO. (2015). ILOSTAT. Dataset. Genève, Switzerland. Retrieved from http://www.ilo.org/ilostat

Irz, X., Lin, L., Thirtle, C., & Wiggins, S. (2001). Agricultural Productivity Growth and Poverty Alleviation. Development Policy Review, 19(4), 449–466. https://doi.org/10.1111/1467-7679.00144

Jadin, I., Meyfroidt, P., & Lambin, Eric F. (2015). Forest protection and economic development by offshoring wood extraction: Bhutan's clean development path. Regional Environmental Change, 1–15. https://doi.org/10.1007/s10113-014-0749-y

Janvry, Alain, & Kanbur, R. (Eds.). (2006). Economic Studies in Inequality, Social Exclusion and Well-Being: Vol. 1. Poverty, Inequality and Development: Essays in Honor of Erik Thorbecke. Boston, MA: Springer Science+Business Media Inc.

Janvry, Alain de, & Sadoulet, E. (2010). Agricultural Growth and Poverty Reduction: Additional Evidence. The World Bank Research Observer, 25(1), 1–20. https://doi.org/10.1093/wbro/lkp015

Jarvis, L., & Vera-Toscano, E. (2004). Seasonal Adjustment in a Market for Female Agricultural Workers. American Journal of Agricultural Economics, 86(1), 254–266. https://doi.org/10.1111/j.0092-5853.2004.00576.x

Johansen, L. (1960). A multi-sector study of economic growth. Amsterdam, Holland: North-Holland Pub. Co,.

King, B. B. (1985). What is a SAM? A layman's guide to social accounting matrices. In G. Pyatt & J. I. Round (Eds.), Social Accounting Matrices, A Basis for Planning: A World Bank Symposium. A World Bank Symposium (pp. 12–29). Washington DC.

Kleinwechter, U., & Grethe, H. (2015). National Wage Trends and Migration in a Chinese Village Economy: A Micro Level Modeling Approach Based on a Composite Utility Function. American Journal of Agricultural Economics, 97(3), 701–726. https://doi.org/10.1093/ajae/aau070

Lélé, S. M. (1991). Sustainable development: A critical review. World Development, 19(6), 607–621. https://doi.org/10.1016/0305-750X(91)90197-P

Lindsey, P. A., Chapron, G., Petracca, L. S., Burnham, D., Hayward, M. W., Henschel, P., . . . Dickman, A. (2017). Relative efforts of countries to conserve world’s megafauna. Global Ecology and Conservation, 10, 243–252. https://doi.org/10.1016/j.gecco.2017.03.003

Lofgren, H., Harris, R. L., & Robinson, S. (2002). A standard computable general equilibrium (CGE) model in GAMS. Washington D.C., USA: Intl Food Policy Res Inst.

Lotze-Campen, H., Popp, A., Beringer, T., Müller, C., Bondeau, A., Rost, S., & Lucht, W. (2010). Scenarios of global bioenergy production: The trade-offs between agricultural expansion, intensification and trade. Ecological Modelling, 221(18), 2188–2196. https://doi.org/10.1016/j.ecolmodel.2009.10.002

Machlup, F. (1958). Equilibrium and Disequilibrium: Misplaced Concreteness and Disguised Politics. The Economic Journal, 68(269), 1. https://doi.org/10.2307/2227241

Matson, P. A. (1997). Agricultural Intensification and Ecosystem Properties. Science, 277(5325), 504–509. https://doi.org/10.1126/science.277.5325.504

McDonald, S. (2013). STAGE 2: A User Guide (version 2). Oxford, UK.

McDonald, S., & Thierfelder, K. (2015). A Static Applied General Equilibrium Model: Technical Documentation: STAGE Version 2: January 2015. Model Documentation.

McKenzie, Lionel. (1954). On equilibrium in Graham's model of world trade and other competitive systems. Econometrica: Journal of the Econometric Society, 147–161. Retrieved from http://www.jstor.org/stable/1907539

McKenzie, Lionel W. (1959). On the Existence of General Equilibrium for a Competitive Market. Econometrica, 27(1), 54. https://doi.org/10.2307/1907777

McShane, T. O., Hirsch, P. D., Trung, T. C., Songorwa, A. N., Kinzig, A., Monteferri, B., . . . O’Connor, S. (2011). Hard choices: Making trade-offs between biodiversity conservation and human well-being. Biological Conservation, 144(3), 966–972. https://doi.org/10.1016/j.biocon.2010.04.038

Meadows, Donella, Meadows, Dennis, Randers, J., & Behrens III, W. W.^. (1977). The limits to growth: A report for the Club of Rome's project on the predicament of mankind (2.ed., 4. print). A Potomac Associates book. New York NY: Universe Books.

Mitra-Kahn, B. H. (2008). Debunking the myths of computable general equilibrium models. Retrieved from http://www.academia.edu/download/2913349/4i5u50tdmoybjlj.pdf

MoAF. (2015). Bhutan RNR statistics 2015. Thimphu, Bhutan.

MoF. (2013). Bhutan Trade Statistics 2012. Thimphu, Bhutan.

Muller, A., Schader, C., Scialabba, N. E.-H., Brüggemann, J., Isensee, A., Erb, K.-H., . . . El-Hage Scialabba, N. (2017). Strategies for feeding the world more sustainably with organic agriculture. Nature Communications, 8(1), 1290. https://doi.org/10.1038/s41467-017-01410-w

Narain, U., Toman, M., & Jiang, Z. (2014). Note on Green Growth for Bhutan (World Bank License: CC BY 3.0 IGO). Washington DC, USA. Retrieved from World Bank website: https://openknowledge.worldbank.org/handle/10986/20402

Nelson, G. C., Valin, H., Sands, R. D., Havlík, P., Ahammad, H., Deryng, D., . . . Heyhoe, E. (2014). Climate change effects on agriculture: Economic responses to biophysical shocks. Proceedings of the National Academy of Sciences, 111(9), 3274–3279.

Pearce, D., Barbier, Edward, & Markandya, A. (2013). Sustainable Development: Economics and Environment in the Third World. Hoboken: Taylor and Francis.

Pingali, P. L. (2012). Green revolution: impacts, limits, and the path ahead. Proceedings of the National Academy of Sciences of the United States of America, 109(31), 12302–12308. https://doi.org/10.1073/pnas.0912953109

Ponisio, L. C., M'Gonigle, L. K., Mace, K., Palomino, J., Valpine, P. d., & Kremen, C. (2015). Diversification practices reduce organic to conventional yield gap. Proc. R. Soc. B, 282(1799), 20141396. https://doi.org/10.1098/rspb.2014.1396

Pyatt, G. (1988). A SAM approach to modeling. Journal of Policy Modeling, 10(3), 327–352. https://doi.org/10.1016/0161-8938(88)90026-9

Pyatt, G., & Round, J. I. (1985). Social Accounting Matrices for Development Planning. In G. Pyatt & J. I. Round (Eds.), Social Accounting Matrices, A Basis for Planning: A World Bank Symposium. A World Bank Symposium (pp. 52–69). Washington D.C., USA.

Reardon, T., Berdegué, J., Barrett, C. B., & Stamoulis, K. (2007). Household income diversification into rural nonfarm activities. Transforming the Rural Nonfarm Economy: Opportunities and Threats in the Developing World, 115–140.

Reardon, T., Stamoulis, K., Cruz, M. E., Berdegué, J., & Banks, B. (1998). Rural non-farm income in developing countries: Special Chapter (The state of food and agriculture No. 283-356). Rome, Italy. Retrieved from FAO website: http://www.fao.org/docrep/w9500e/w9500e00.htm

RGoB. (2008). The Constitution of the Kingdom of Bhutan. Thimphu, Bhutan.

RGoB. (2010). Economic development policy of the kingdom of Bhutan. Thimphu, Bhutan.

RGoB. (2012). Bhutan: In Pursuit of sustainable development: National report for the United Nations Conference on Sustainable Development 2012. Thimphu, Bhutan.

RGoB. (2017). Forest and Nature Conservation Rules and Regulations of Bhutan. Thimphu, Bhutan.

Robinson, E. (2016). Resource-Dependent Livelihoods and the Natural Resource Base. Annual Review of Resource Economics, 8(1), 281–301. https://doi.org/10.1146/annurev-resource-100815-095521

Robinson, S. (1991). Macroeconomics, financial variables, and computable general equilibrium models. World Development, 19(11), 1509–1525. https://doi.org/10.1016/0305-750X(91)90003-Z

Robinson, S. (2006). Macro Models and Multipliers: Leontief, Stone, Keynes, and CGE Models. In A. Janvry & R. Kanbur (Eds.), Economic Studies in Inequality, Social Exclusion and Well-Being: Vol. 1. Poverty, Inequality and Development: Essays in Honor of Erik Thorbecke (pp. 205–232). Boston, MA: Springer Science+Business Media Inc. https://doi.org/10.1007/0-387-29748-0_11

Robinson, S., & Lofgren, H. (2005). Macro models and poverty analysis: Theoretical tensions and empirical practice. Development Policy Review, 23(3), 267–283. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1467-7679.2005.00286.x/full

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F. S., Lambin, Eric, . . . Schellnhuber, H. J. (2009). Planetary boundaries: exploring the safe operating space for humanity. Ecology and Society, 14(2).

Rosenzweig, M. R. (1988). Chapter 15 Labor markets in low-income countries. In Handbook of Development Economics (pp. 713–762). Elsevier. https://doi.org/10.1016/S1573-4471(88)01018-6

Rutten, M., Shutes, L., & Meijerink, G. (2013). Sit down at the ball game: How trade barriers make the world less food secure. Food Policy, 38, 1–10. https://doi.org/10.1016/j.foodpol.2012.09.002

Scarf, H. (1967a). The approximation of fixed points of a continuous mapping. SIAM Journal on Applied Mathematics, 15(5), 1328–1343.

Scarf, H. (1967b). On the computation of equilibrium prices (Vol. 232): Cowles Foundation for Research in Economics at Yale University. Retrieved from http://dido.wss.yale.edu/~hes/pub/p0271.pdf

Scherr, S. J. (2000). A downward spiral? Research evidence on the relationship between poverty and natural resource degradation. Food Policy, 25(4), 479–498. https://doi.org/10.1016/S0306-9192(00)00022-1

Schofield, S. (1974). Seasonal factors affecting nutrition in different age groups and especially preschool children. The Journal of Development Studies, 11(1), 22–40.

Sen, A. (1988). Chapter 1 The concept of development. Handbook of Development Economics, 1, 9–26. https://doi.org/10.1016/S1573-4471(88)01004-6

Shoven, J. B., & Whalley, J. (1972). A general equilibrium calculation of the effects of differential taxation of income from capital in the U.S. Journal of Public Economics, 1(3-4), 281–321. https://doi.org/10.1016/0047-2727(72)90009-6

Shoven, J. B., & Whalley, J. (1973). General equilibrium with taxes: A computational procedure and an existence proof. The Review of Economic Studies, 40(4), 475–489. Retrieved from http://www.jstor.org/stable/2296582

Siebert, S. F., & Belsky, J. M. (2015). Managed fuelwood harvesting for energy, income and conservation: An opportunity for Bhutan. Biomass and Bioenergy, 74, 220–223. https://doi.org/10.1016/j.biombioe.2015.01.013

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., . . . Sörlin, S. (2015). Sustainability. Planetary boundaries: guiding human development on a changing planet. Science (New York, N.Y.), 347(6223), 1259855. https://doi.org/10.1126/science.1259855

Stevenson, J. R., Villoria, N., Byerlee, D., Kelley, T., & Maredia, M. (2013). Green Revolution research saved an estimated 18 to 27 million hectares from being brought into agricultural production. Proceedings of the National Academy of Sciences of the United States of America, 110(21), 8363–8368. https://doi.org/10.1073/pnas.1208065110

Stone, R. (1986). Nobel memorial lecture 1984. The accounts of society. Journal of Applied Econometrics, 1(1), 5–28. https://doi.org/10.1002/jae.3950010103

Sunderlin, W. D., Angelsen, A., Belcher, B., Burgers, P., Nasi, R., Santoso, L., & Wunder, S. (2005). Livelihoods, forests, and conservation in developing countries: An Overview. World Development, 33(9), 1383–1402. https://doi.org/10.1016/j.worlddev.2004.10.004

Taylor, J. E., Yunez-Naude, A., & Dyer, G. (1999). Agricultural Price Policy, Employment, and Migration in a Diversified Rural Economy: A Village-Town CGE Analysis from Mexico. American Journal of Agricultural Economics, 81(3), 653–662. https://doi.org/10.2307/1244030

Taylor, J. Edward, Charlton, D., & Yúnez-Naude, A. (2012). The End of Farm Labor Abundance. Applied Economic Perspectives and Policy, 34(4), 587–598. https://doi.org/10.1093/aepp/pps036

Thinley, J. Y. (2011). Making a Commitment to Organic Agriculture: Statement on Bhutan's organic policy by Prime Minister of Bhutan, Jigmi Y.Thinley. Thimphu, Bhutan.

Toman, M. (2012). "Green Growth": An Exploratory Review. Washington D.C., USA: The World Bank.

Troost, C., & Berger, T. (2015). Dealing with Uncertainty in Agent-Based Simulation: Farm-Level Modeling of Adaptation to Climate Change in Southwest Germany. American Journal of Agricultural Economics, 97(3), 833–854. https://doi.org/10.1093/ajae/aau076

Tuomisto, H. L., Hodge, I. D., Riordan, P., & Macdonald, D. (2012). Does organic farming reduce environmental impacts? – A meta-analysis of European research. Journal of Environmental Management, 112, 309–320. https://doi.org/10.1016/j.jenvman.2012.08.018

UN. (2016). Sustainable Development Goals Report 2016. New York, USA: UN.

Vaitla, B., Devereux, S., & Swan, S. H. (2009). Seasonal hunger: A neglected problem with proven solutions. PLoS Medicine, 6(6), e1000101. Retrieved from http://journals.plos.org/plosmedicine/article?id=10.1371/journal.pmed.1000101

Van der Mensbrugghe, D. (2005). LINKAGE Technical Reference Document. Washington DC, USA. Retrieved from http://documents.worldbank.org/curated/en/200941468322749541/pdf/468360WP0Box331LIC10LinkageTechNote.pdf

Wing, I. S. (2004). Computable General Equilibrium Models and Their Use in Economy-Wide Policy Analysis (Technical Note No. 6). Cambridge, USA. Retrieved from MIT Joint Program on the Science and Policy of Global Change website: http://web.mit.edu/globalchange/www/MITJPSPGC_TechNote6.pdf

Wodon, Q., & Beegle, K. (2012). Labor shortages despite underemployment? Seasonality in time use in Malawi. In M. C. Blackden & Q. Wodon (Eds.), World Bank Working Paper: Vol. 73. Gender, Time Use, and Poverty in Sub-Saharan Africa (pp. 97–116). Washington, DC: World Bank.

World Bank. (1992). Project Completion Report Bhutan Calcium Carbide Project (No. 11359). Washington DC, USA.

World Bank. (2018). World Development Indicators. Dataset. Washington DC, USA. Retrieved from http://data.worldbank.org/data-catalog/world-development-indicators

Wunder, S., Angelsen, A., & Belcher, B. (2014). Forests, Livelihoods, and Conservation: Broadening the Empirical Base. World Development, 64, S1-S11. https://doi.org/10.1016/j.worlddev.2014.03.007

Zhang, X., Yang, J., & Wang, S. (2011). China has reached the Lewis turning point. China Economic Review, 22(4), 542–554. Retrieved from http://www.sciencedirect.com/science/article/pii/S1043951X11000587

Chapter 2 Bhutan Country Context

This chapter provides a general background to Bhutan. It briefly presents the country's geographic conditions and constraints, describes its political system highlighting the role of GNH, presents an overview of the recent socio-economic development and lastly provides a brief profile of the agricultural sector

2.1 Geography, Climate and Population

Located in the Eastern Himalayas, Bhutan is a small and landlocked country with a land area comparable to Switzerland of 38,394 km2 (NSB, 2017b). The country shares its border with China (Tibet) in the North and with the Indian States Sikkim, West Bengal, Assam and Arunachal Pradesh in the West, South and East. Mountainous terrain and often steeply sloped valleys characterize the geography of Bhutan. 44.6% of the land area is located at altitudes higher than 3,000 meters above sea level (masl) (NSB, 2012). Lower altitudes as low as 160 meters are found in Bhutan's southern plains. In the North and Northwestern part, mountain peaks reach altitudes beyond 7,500 meters.

There are three different climatic zones, which are the alpine, temperate and subtropical zones. Winter starts in around late November and lasts until the end of February. Frost is observable throughout most of the country, and snowfall is to be expected at altitudes above 3,000 meters (NSB, 2017b). The beginning of spring, from March to mid of April, is dry and replaced by the onset of the monsoon rains, which last from mid of April over the entire summer until late September. Like in most other South Asian countries, the monsoon largely determines the annual precipitation and crop calendar. Bhutan can thus be considered a "monsoon economy" (Reardon et al., 2007). Due to the heavy rains, extreme weather events and natural disasters, such as flash floods and landslides, are likely during the monsoon time throughout the country (MoAF, 2016c). After the rainy season, autumn weather is rather dry and sunny days are frequent from late September until end of November.

Most of the land area is under forest cover (70% of land area) and shrubs (10%), while grassland and arable agricultural land account for only 5% and 3%, respectively (Gilani et al., 2015). Built-up area and barren, glaciers and areas under permanent snow account for the remaining 12%. Warm and cool broad-leaved forests are the most common forest types, comprising 18% and 26% of land area. Most of Bhutan's forest area provides crucial habitat for endangered flora and fauna. 105 species out of the 5,603 recorded vascular plants in Bhutan are endemic (RGoB, 2012). There are about 200 mammal species, of which many are endangered species such as the Bengali tiger, Asian elephant and red panda (IUCN, 2015). In order to conserve its wealth in biodiversity, Bhutan declared about 43% of the country area as protected area connected by biological corridors covering an additional 9% of the country (RGoB, 2012).

According to the latest population census in 2017, Bhutan has a population of about 735,000 of which 62% still live in rural areas (NSB, 2018b) . Due to its rugged terrain, the population density of Bhutan is relatively low (19 persons km-1) and rural settlements are often small, scattered and hard to access (Gosai & Sulewski, 2014).

2.2 Political System

Since 2008, Bhutan is a constitutional monarchy with a national identity embedded in Buddhism. Civil and monastic representatives crowned the first king, Ugyen Wangchuk, in 1907. Ugyen Wangchuk established a central power, which resulted in political stability and allowed for long-term development (NSB, 2017b). Until the 1960s, Bhutan remained under self-imposed isolation and trade with neighbouring country was impeded due to lack of road infrastructure. In 1958, Jawaharlal Nehru personally travelled to Bhutan on a horseback to convince the monarch to open up the country towards economic assistance from India (Penjore, 2004). India’s approaches towards Bhutan were made in the context of geopolitical tensions, such as the Sino-Indian border disputes and the 1959 Tibetan revolt. In the early 1960s, the first major achievement of the collaboration with India was the construction of the first motorable road, a highway connecting the capital city Thimphu and Paro with the Southern border town Phuentsholing (Karan, 1963). The 175 km long road reduced the travel time of formerly six days on a horseback to below 10 hours by a 4x4 vehicle. From Bhutan’s opening onward, it has been receiving development aid from India in form of grant support within the framework of five-year development plans.

Because of the strong cooperation with India and the geopolitical tension between India and China, Bhutan has no diplomatic relations with China and no official trade post. The only bordering trading partner is thus India, with whom Bhutan maintains a free trade agreement excluding any duties or quotas since 1972 (MoEA, 2012) . Within Bhutan, India’s presence is not only visible by the many Indian workers who are mostly employed in road construction, but also by military presence. It is estimated, that India stationed about 19,000 army troops, outnumbering the 18,000 soldiers of the Royal Bhutanese Army (Nyaupane & Timothy, 2010).

Bhutan's political system gradually transformed from an absolute monarchy to a constitutional monarchy. Political parties were banned until 2008, which was when Bhutan's first constitution came into force and when the first ever free and general elections took place. The country's legislative consists of the national assembly, the national council and the head of state, i.e. Bhutan's monarch, called *Druk Gyalpo* in the national language Dzongkha (RGoB, 2008). The national assembly and national council form a bicameral parliament with a total of 72 members following the Westminster Parliamentary system (NAB, 2018). The national council consists of 25 members of which five are appointed by the king and each of the remaining 20 members is an elected representative of the twenty "dzongkhags" (i.e., districts). All council members are apolitical, i.e. they are not affiliated with any of the political parties. The national assembly has 47 members, who are commonly affiliated with political parties and who are elected from the 47 constituencies over a term of five years (NAB, 2018). By the time of writing this chapter, the young democracy is preparing for its third National Assembly elections taking place in September and October 2018. A peaceful transfer of power already took place after the second elections in 2013, when the previous ruling party, the Bhutan Peace and Prosperity Party (or DPT), handed the government over to the People's Democratic Party (PDP).

The judicative power, the Royal Courts of Justice, comprise the Supreme Court, the High Court and further courts on the district and sub-district level (RGoB, 2008). The ruling party within the National Assembly nominates the Prime Minister, who presides the executive cabinet, also called the Council of Ministers (Lhengye Zhungtshog). The national government is located in the capital city, Thimphu. The political administration is divided into the 20 dzongkhags as shown in Figure 2.1 and 205 sub-districts called "gewogs". A gewog consists of a group of villages. The gewog council consists of elected local leaders headed by the "gup", i.e. the gewog headman (RGoB, 2009).

Figure 2.1. Map showing Bhutan and its administrative divisions

Source: CIA, 2012.

The executive cabinet is comprised of ten ministries, among them the Ministry of Agriculture and Forests (MoAF), Ministry of Economic Affairs (MoEA), Ministry of Finance (MoF) and Ministry of Labour and Human Resources (MoLHR). A variety of state institutions is independent from the executive body. These include the country's central bank, the Royal Monetary Authority (RMA), the National Environment Commission (NEC), the Anti-Corruption Commission, the Election Commission, and the Gross National Happiness Commission (GNHC).

The GNHC is a central government body that functions as the Planning Commission. It is responsible for the coordination of sectoral policies in order to ensure that they are in alignment with the overall development objectives of Gross National Happiness (GNH). Within this capacitiy, the GNHC provides guidance to the ministries for the policy formulation of five year development plans (henceforth FYP). Moreover, it reviews, endorses and allocates resources to proposed activities within the FYP, which underlines its influence within the policymaking process (GNHC, 2018). GNH was adopted as Bhutan's guiding development objective during the time of the fourth King of Bhutan, Jigme Singye Wangchuck based on the known shortcomings of conventional measures of economic growth such as the Gross Domestic Product (GDP) (Hayden, 2015; Verma, 2017). During the time of the 10^{th} FYP, GNH was defined to be based on four pillars, which are "1. Sustainable and equitable socio-economic development; 2. Environmental conservation; 3. The preservation and promotion of culture; and; 4- Good governance" (Ura, K., Alkire, S., Zangmo, T., & Wangdi, K, 2012, p. 7).

Over the last decades, GNH has attracted substantial research interest. The Centre of Bhutan Studies (CBS) has embedded GNH within a comprehensive framework, which made the concept more tangible. A multidimensional measure, the GNH index, was proposed, which should also allow policymakers to link GNH with policy and programme screening tools (Ura, K., Alkire, S., Zangmo, T., & Wangdi, K, 2012). The GNH index consists of nine domains (psychological wellbeing, time use, community vitality, ecological resilience, living standard, health, education and good governance), which are all equally weighted. Each domain comprises a number of indicators, 33 in total, and each indicator is measured by several variables, 124 in total.

2.3 Economic Development

Thanks to its mountainous geography, glaciers and monsoon rains, Bhutan is endowed with significant hydropower resources. Hydropower investments have been the main driver of the country's strong economic development over the last two decades (World Bank, 2014). The total hydropower potential is estimated at 30,000 Megawatts (MW) of which 1,600 MW have been developed so far in collaboration with the Government of India (Tortajada & Saklani, 2018)(Tortajada & Saklani, 2018). The last major hydropower plant (Tala, 1020 MW) was commissioned in 2007, resulting in a spike of hydropower export and economic growth (Figure 2.2). Currently five large-scale hydropower plants of a total capacity of 3,658 MW are under construction (RMA, 2017). Almost all of the projects experienced substantial delays and now they are all expected to be commissioned by 2023 (Lamsang, 2017). In 2016, the electricity sector's share in GDP was 16%. In addition, present expenditures related to hydropower investment contributed an estimated 28% of GDP; including the upcoming investments their contribution is even expected to reach 33% in 2020 (Boyreau & Rama, 2015; World Bank, 2014). Hence, hydropower will continue to be the main source of Bhutan's economic growth in the near future.

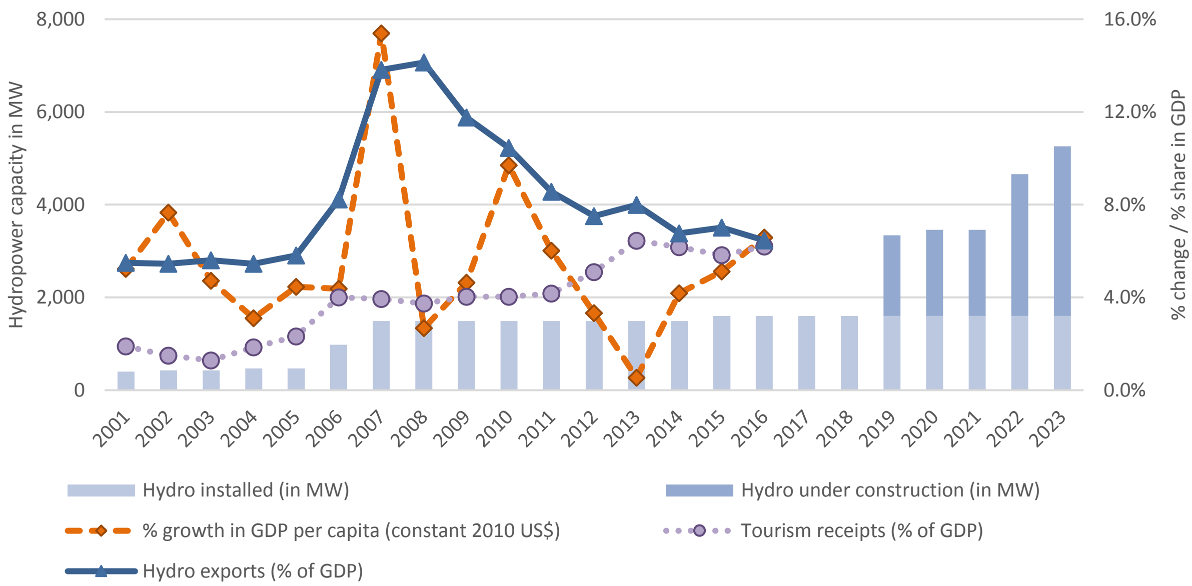

Figure 2.2. Development of Bhutan's economy as well as hydropower and tourism sector.

Note: Left axis shows hydropower capacity installed and under construction in MW accounting for completion delays. Right axis shows growth in GDP per capita (constant 2010 USD) and changes in hydropower exports and international tourism receipts as shares in GDP. Sources: RMA, 2017; World Bank, 2018.

Following the commissioning of the first large-scale hydropower project in Chhukha (368 MW) in 1986, energy-intensive industries co-financed by multilateral donors were established in Southern Bhutan close to the Indian border (World Bank, 1985). The rationale of such investments was to increase the use of hydropower as an intermediate-input in order to generate further employment and value added. However, the majority of hydropower (about 70%) is still exported to India (RMA, 2017) and the manufacturing sector still only has a moderate share in Bhutan's GDP (9% in 2016). In contrast, private services have experienced strong growth, particularly in the hotel & restaurants, transportation and wholesale and trade sector. These are the sectors benefitting from increasing tourist arrivals and rising income of urban households (Figure 2.2). Total services contributed 40% to GDP in 2016 (NSB, 2017a), but the share of public services (public administration, education and health) has been declining over the years.

Currently, Bhutan is still classified as a least-developed country, but is expected to “graduate” from this status within the near future (UN, 2018). The Human Development Index (HDI) ranks Bhutan 134rd among all countries, with an HDI of 0.612 (the average HDI for developing countries is 0.681) (UNDP, 2018). An important reason for the low rank is the very low mean years of schooling. The average Bhutanese aged 25 years or older has just received 3.1 years of schooling, which is largely because just about three decades ago the country was still very isolated and access to education was limited to the back then very small urban population. Now, the net enrollment rate in secondary schools has reached 84% in 2017, compared to just 24% in 1998. In the same time span, mean life expectancy at birth increased from 59.1 years to 70.2 years (World Bank, 2018)(World Bank, 2018).

Bhutan’s strong economic growth allowed to reduce the national poverty headcount ratio from 23.2% in 2007 to 12.0% in 2012 (World Bank, 2018). Yet, economic growth has largely bypassed the rural population and poverty has become almost exclusively a rural phenomenon, with 94% of the poor living in rural areas (NSB & World Bank, 2012; World Bank, 2018). There is a persistent trend of rural-urban migration, which in some regions has resulted in wide spread abandonment of farms (Gosai & Sulewski, 2014). The government has invested in road infrastructure and electrification as well as the provision of public services in order to mitigate the rural exodus, however, so far with unknown success.

2.4 Agriculture and Forestry

Despite the past economic growth driven by hydropower, Bhutan is still a peasant economy. About 50% of labour force is employed in agriculture and farming thus still represents the backbone of the majority of livelihoods in Bhutan, particularly in rural areas (NSB & ADB, 2012) . According to the national account statistics reported by the National Statistics Bureau (NSB) of Bhutan, the share of agriculture (i.e. crops, livestock and forestry) towards GDP increased slightly from 16.0% in 2012 to 16.5% in 2016 (NSB, 2017a). Estimating the sector’s contribution using a bottom-up approach, as it was done for the development of the 2012 SAM for Bhutan (Arndt Feuerbacher, C. Dukpa, & Grethe, 2017), the agricultural sector is found to have a substantially smaller share in GDP. Table 2.1 presents the major agricultural activities, their total output measured in million Ngultrum[4] and their share in value added. In total, the agriculture sector was found to only contribute 10.5% towards GDP.

[4] The average exchange rate in 2012, the reference year of this thesis, was 53.4 Bhutanese Ngultrum / 1 US-$.

The divergent estimates could possibly be explained by a difference in basic prices, which are not explicitly reported by the NSB and thus cannot be cross-checked. However, there are also other reasons for the discrepancy, which would require more detailed analysis. For instance, the NSB reports the forestry sector to have a 3.0% share in GDP in 2012 (NSB, 2014), while for the same year the bottom up approach only estimates a 1.6% share (see Table 2.1). According to the NSB, the activities of the Natural Resources Development Corporation (NRDCL) make up “almost 80 percent of the total forestry activities in the country” (NSB, 2013, p. 20).[5]

The NRDCL is a state owned enterprise with the almost exclusive responsibility of extracting timber. In 2012, the NRDCL reported gross sales of Nu. 438 million (NRDCL, 2013) of which Nu. 122 million were salaries and benefits to employees (proxy for return to labour) and Nu. 121 million were reported as operating profit (a proxy for returns to capital and land). However, the forestry sectors contribution to total GDP in 2012 in current prices (Nu. 97,453 million) was reported to be Nu. 2,926 million (NSB, 2014). Based on this estimate, the NRDCL would at most comprise 8.3% of forest activities (instead of the reported 80.0%), using the company’s reported gross value added, approximated by the returns to labour, land and capital. Some of the discrepancy is explained by rural households’ forest activities, which make up a considerable share of timber extraction, as estimated within this thesis. However, even if accounting for their output, there nevertheless remains a large discrepancy between the sector’s share estimated using the bottom-up approach and the NSB’s approach.

[5] The national account reports from 2012 to 2017 all include very similar, if not identical description, of how the forestry sector’s gross value added is estimated.

Table 2.1. Bottom-up estimation of output and value added of agricultural commodities

Commodity	Quantity produced	Cultivated area	Basic price	Output	Value added	Value added share	Share in GDP
	(metric tons)	(hectares)	(Nu./kg)	(million Nu.)	(million Nu.)	(in %)	(in %)
Paddy	54,876	16,678	26.3	1,445	1,256	86.9	1.3
Maize	59,993	23,866	14.9	891	750	84.2	0.8
Other cereals and oilseeds	12,201	9,204	26.7	328	280	85.4	0.3
Crop residues	168,680		1.0	169	147	86.9	0.2
Pulse	4,953	2,464	33.2	165	136	82.2	0.1
Low-value vegetables	30,951	5,078	15.7	484	436	90.0	0.4
High-value vegetables	9,814	2,770	60.7	596	561	94.2	0.6
Potato	59,004	6,181	14.4	847	656	77.4	0.7
Beverages and spices	4,569	2,652	129.8	593	546	92.1	0.6
Other nuts and fruit	16,888	2,319	21.3	360	315	87.5	0.3
Apples	6,905	703	33.4	231	223	96.5	0.2
Citrus fruits	41,809	3,265	19.9	833	826	99.1	0.8
Agriculture – crops				**6,942**	**6,131**	**88.3**	**6.3**
Milk	29,625		30.7	909	619.94	68.2	0.6
Beef	620		121.1	75	51.15	68.2	0.1
Cow manure	186,742		1.0	187.87	128.13	68.2	0.1
Cattle live animals				151.34	103.21	68.2	0.1
Bullock draught power				281	191.64	68.2	0.2
Dairy products	8,664		202.4	1,754	685	39.0	0.7
Chicken meat	909		159.5	145	60.76	41.9	0.1
Eggs	2,901		136.2	395	165.51	41.9	0.2
Chicken manure	3,377		1.0	3.40	1.42	41.9	0.0
Chicken live animals				4.36	1.83	41.9	0.0
Other animal products	1,337		120.9	162	117.13	72.3	0.1
Other animals manure	4,818		1.0	4.85	3.50	72.3	0.0
Other animals live animal				30.92	22.36	72.3	0.0
Agriculture - livestock				**4,104**	**2,151**	**52.4**	**2.2**
Milled rice	31,230		51.4	1,604	159	9.9	0.2
Milled other cereals	2,789		48.3	135	24	17.7	0.0
Processed rice	3,574		67.8	242	43	17.8	0.0
Processed maize	1,775		69.1	123	22	17.8	0.0
Vegetable oils	674		77.2	52	23	44.0	0.0
Ara	15,913		34.7	552	134	24.3	0.1
Agriculture - post-harvest				**2,708**	**405**	**14.9**	**0.4**
Logs (in m3)	216,784		4781.6	1,036	940	90.7	1.0
Firewood (in m3)	946,949		539.4	511	463	90.7	0.5
Non-wood forest products				157	157	100.0	0.2
Agriculture - forestry				**1,704**	**1,560**	**91.5**	**1.6**
Total agriculture				**15,458**	**10,247**	**66.3**	**10.5%**

Source: (Arndt Feuerbacher, C. Dukpa et al., 2017).

Crop activities play the most important role in Bhutanese agriculture, contributing 6.3% to GDP. The most important crops in valued added terms are paddy (contributing 1.3% towards GDP), maize (0.8%), potato (0.7%) and citrus (0.8%). The livestock sector is dominated by cattle, which in terms of livestock units (LU) accounts for 95% of all livestock in Bhutan (Arndt Feuerbacher, C. Dukpa et al., 2017). Despite the relatively high headcount of cattle (about 274,000 LU in 2012), the livestock's overall contribution towards GDP is only 2.2%. Cattle husbandry productivity is rather low due to the low milk yields of the local breeds, which account for 80% of the cattle population. Local breeds are in contrast very robust and thus more suited for the extensive livestock systems in Bhutan, which are characterized by free roaming cattle in mostly dense and hilly forests. Beef production has an almost negligible share in GDP, because slaughtering of cattle is a taboo, even though beef is commonly eaten, at least by households of Buddhist belief (Samdup, Udo, Eilers, Ibrahim, & van der Zijpp, 2010). As a result, most of the beef supply is imported from India (UN, 2015a).

Although more than 70% of the land area is under forest area, forestry accounts only for 1.6% of total GDP according to the bottom-up estimation in Table 2.1. Forest areas designated for commercial wood extraction, so called forest management units (FMU), make up about 5% of total forest area. The state-owned Natural Resource Development Corporation Limited (NRDCL) and commissioned sub-contractor firms operate FMUs. A further 10% of forest area is utilized directly by rural households. Rural households may only sell limited quantities of timber and fuelwood if they are members of community forests, which in total account for 2.5% of forest area (MoAF, 2015). Otherwise, Bhutan's forest policies restrict the extraction of timber by rural households for own subsistence use only (RGoB, 2017).

2.4.1 Agricultural Land Use

The majority of farmers in Bhutan are semi-subsistence smallholders with average landholdings of just 1.2 hectares (NSB, 2018b). The cultivation of land is generally constrained by the very mountainous terrain. About 99% of the land area in Bhutan is classified to be mountainous (Rodríguez-Rodríguez, Bomhard, Butchart, & Foster, 2011; UNEP-WCMC, 2013) . Most of the flat land area, if not yet used for urban settlements, is used for crop cultivation. However, in many cases farmers have to cultivate either steep slopes of irrigated rice terraces or steep and non-terraced rainfed land. Historically, swidden or slash-and-burn practices (called *Tseri* below altitude levels of 2500 m and *Pangshing* above 2500 m) were practiced largely in central and parts of eastern Bhutan (Siebert & Belsky, 2014), but ceased since the government passed a nation-wide ban in 1997 (T. Dukpa, Wangchuk, Rinchen, Wangdi K., & Roder, 2007). Permanent cropland consists largely of apple, citrus and areca nut orchards as well as the cultivation of perennial spices such as cardamom and ginger. Table 2.2 shows the total arable land area as measured by the 2012 agricultural sample survey differentiating by irrigated land (*Chhuzhing*), rainfed land (*Kamzhing*) and orchard land.

Table 2.2. Cultivated and fallow farmland in 2012

Land types	Cultivated land	Fallow land	Share fallow
	(in hectares)	(in hectares)	(in %)
Irrigated land	16,678	1,944	10.4
Rainfed land	49,532	16,552	25.0
Orchard land	8,971	491	5.2
Total land	75,180	18,987	20.2

Source: MoAF, 2013a.

By law, irrigated land is reserved for paddy-based cropping systems and only rarely farmers cultivate other crops in irrigated land during the paddy season (RGoB, 2007). Knowing how scarce arable land is within Bhutan, it is surprising to see that as much as 20.2% of all farmland was left fallow in 2012. Five years later, the share of irrigated and rainfed land left fallow even increased from 10.4% to 13.2% and from 25.0% to 32.0%, respectively (MoAF, 2018).[6] There are many factors causing farmers to leave land farmers and the exact dynamics and causal relationships are still not sufficiently well understood. Farming in Bhutan is very labour intensive and perceived as a drudgery. There are many farm constraints such as shortage of labour and human-wildlife conflicts, which are in interdependence with the overall trend of rural-urban migration and the low attractiveness of the farm sector among the youth.

2.4.2 Farming Constraints

Given the country's mountainous geography, smallholders in Bhutan are historically constrained by the limited availability of land, since only 3% of land area is arable. Moreover, climatic conditions also constrain farmers in the length of the growing season (FRMD, 2017).

[6] The actual share of land left fallow might be even much higher, since households that have abandoned farming are not covered anymore within the agricultural sample survey

Surprisingly, even though less than 3% of the land area is arable land, farmers do not perceive scarcity of land as the most severe constraint. Figure 2.3 shows the results of farming constraints enumerated during the representative agricultural sample survey rounds from 2012 to 2017. Shortage of land was a rather low-ranked constraint, faced by only about 15% of farmers.

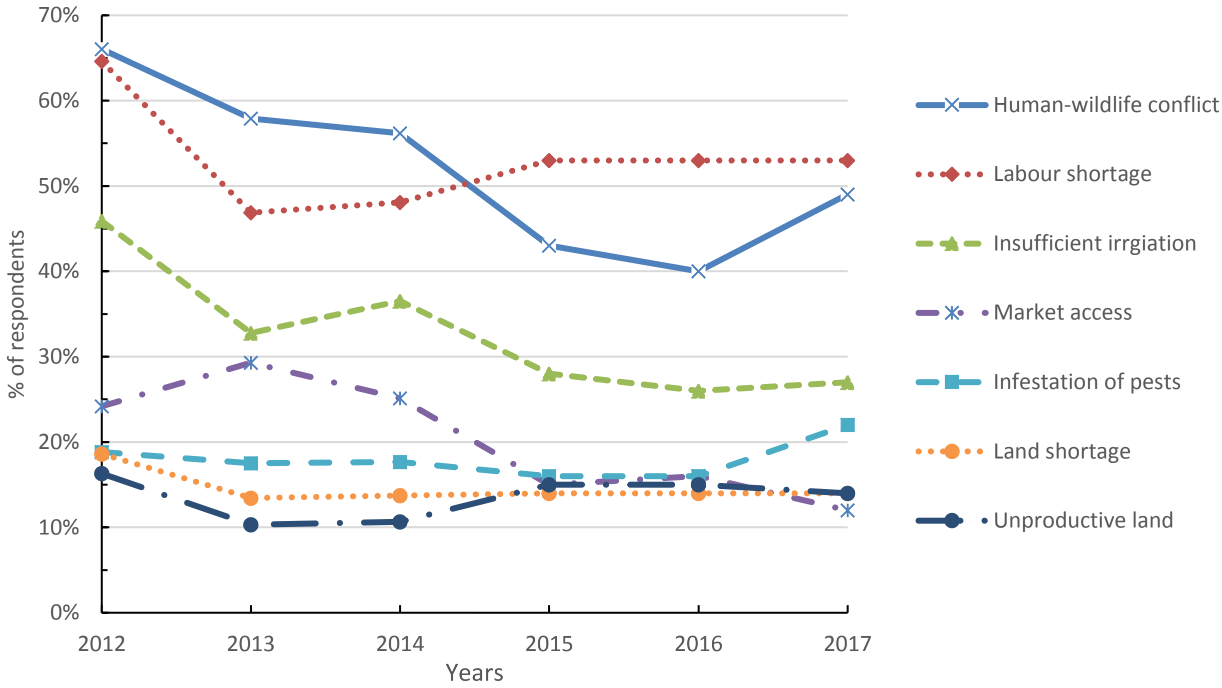

Figure 2.3. Farming constraints faced in Bhutan from 2012 - 2017

Source: Own compilation based on agricultural sample survey data 2012-2017 from the RNR Statistics Division of the Ministry of Agriculture and Forests, Bhutan.

The survey question in the agricultural sample survey does not allow for an assessment of the intensity of constraints. Nevertheless, it becomes clear that human wildlife conflict and labour shortage are by far the most frequently mentioned constraint by farmers over the last six years. Particularly human-wildlife conflicts resulting in crop damages and losses used to be most severe constraint. The strong investments in electric fencing likely contributed to a declining human-wildlife conflict, despite a slight rebound in 2017. Since 2015, labour shortages became the most frequently mentioned constraint. Labour shortages in Bhutan are seasonal and relate to specific periods within the year, such as during the transplanting or harvesting periods of paddy (Yeshey, 2012). Irrigation once was a frequently reported constraint, with about 45% of farmers mentioning it in 2012. The 11th five-year plan for the period 2013-2018 (GNHC, 2013) has allocated substantial resources towards the construction and rehabilitation of existing irrigation scheme, and since 2015 the share of farmers' complaining about insufficient irrigation has declined to below 30%.

Some of the farming constraints have been key themes of agricultural policy in Bhutan. The public research centres under the Ministry of Agriculture and Forests (MoAF) have developed a cost-effective electric fence relying on local components, which sees increasing adoption throughout the country (MoAF, 2017; Penjor et al., 2014). Yet, anecdotal evidence from the field also suggests, that fences have only limited effectiveness against certain type of wildlife such as monkeys (who use trees to jump over fences) and elephants (who were observed to use large branches to cause short-circuits). Addressing labour shortages is the mandate of the Agricultural Machinery Centre (AMC), which focuses on the provision of powertillers (GNHC, 2009). Powertillers primarily help to mitigate shortages during the land preparation periods, but mechanization of other field operations, such as transplanting and harvesting, is still underdeveloped and the economic feasibility is often questionable, given the small land sizes and problems of land fragmentation. Workers from India could mitigate labour shortages, but while they are allowed to work within most sectors inside Bhutan, predominantly construction, the agricultural sector is still excluded (Christensen, Fileccia, & Gulliver, 2012).

In addition to allowing Indian workers to work within agriculture, whether on a permanent or just seasonal basis, there are many further areas, which policymakers could tackle in order to possibly ease farmers' constraints and to improve rural livelihoods. While labour shortage has become the top ranked constraint, it is mostly limited to the cropping season. Particularly during the lean season, farmers often lack sufficient employment opportunities and the current agricultural policy does not adequately address this issue. Channelling tourists to rural areas as part of a community-based tourism strategy could yield substantial employment opportunities during the dry off-season. Also reforms of Bhutan's restrictive forest policies could provide the rural households with improved income opportunities during winter months, which is investigated in more detail within this thesis. One further constraint, which is deeply rooted within the country's culture and religion, is the low productivity of animal husbandry given the widespread stigma of slaughtering animals for meat consumption (Samdup et al., 2010). This question is not covered within the agricultural sample survey question. Any detailed investigation into this field would require a multidisciplinary approach that accounts for the cultural, religious and political dimensions as well as any relevant aspects of animal science.

2.4.3 Technology and Productivity

Generally, detailed data on farming practices and technology use is rare in Bhutan and most of the available data is from the Agricultural Sample Survey conducted in 2012 (MoAF, 2013a) and the 2008 Agricultural Census (MoAF, 2009). The use of agrochemicals in Bhutan is generally at a low level. While 37% of farmers use agrochemicals, chemical fertilizers or pesticides are only applied on 19% of arable land (MoAF, 2013a). Farmers use agrochemicals primarily for the cultivation of potato, paddy, maize and apple. Potato and apple are both cash crops exported to India, and paddy and maize are the main staple crops. Comparing yields between organic and conventional farmers in Bhutan, as done in Chapter 4, suggests that there is a considerable yield gap of 24% on average. Access to markets was found to be a main determinant for the adoption of agrochemicals (Minten & C. Dukpa, 2010b). A further determinant is the institutional setup of the agrochemical supply chain, which is entirely under the control of state agencies.

There are hardly any nationally representative data on what varieties farmers cultivate, but the government's efforts in breeding varieties adapted to the local climate seem to be increasingly fruitful. A study found that modern high yielding rice varieties were cultivated on 42% of total rice production area in 2012, compared to 35% in 2004 (Ghimiray, 2012). The adoption of improved maize varieties was even higher, making up 49% of the maize area in 2005 (Shrestha, Katwal Bdr., Ghaley et al., 2006). Ghaley and Christiansen (2010) conducted on-farm trials in Bhutan with traditional and improved rice varieties cultivated with and without mineral nitrogen (60 kg N ha-1) application. Both, the adoption of improved varieties and use of nitrogen had substantial positive effects on grain yield results.

The scope of mechanization is very limited in Bhutan, due to the very narrowly terraced wetland and the steeply sloped rainfed land. A further constraint for mechanization is land fragmentation and the general small sizes of farms. Agricultural machinery is mostly used for land preparation, for which powertillers are found to be most adequate. The terrain rarely allows for the use of tractors, which are only used in regions where farm land is located in wide and flat valleys, for instance in the Phobjika gewog in the Wangdue-Phodrang district. The government of Bhutan, with the assistance of donor funds from Japan, has invested substantially in improving farmers with better access to powertillers. Subsidies are offered for farmers purchasing their own powertillers (AMC, 2014) and through subsidizing leasing services. For the development of the 2012 SAM, using the available data, it was estimated that powertillers or tractors were used for the land preparation of about 38.7% of all cultivated farm land (Arndt Feuerbacher, C. Dukpa et al., 2017) . The use of other machinery, such as planters or reapers for paddy transplanting and harvesting, is still underdeveloped according to the reported machinery ownership surveyed in 2008 (MoAF, 2009).

2.4.4 Farming Systems

Due to the high variation in climate and altitudes farmers grow a large variety of crops. According to farm level data from 2012 (MoAF, 2013a), farmers grow about 14 crops on average. In the subtropical zone at altitude below 1,800 meters, the diversity is higher (15 on average) compared to the temperate zone, where farmers only grow 12 crops. More commercially oriented farmers have specialized into the cultivation of cash crops such as apples and potatoes in the temperate zones, and ginger, cardamom and citrus fruits in the subtropical areas. Cropping systems largely rely on three crops: rice, maize and potato (Katwal, 2013). Given the high variation in agroecological and climatic conditions, agroecological zones (AEZs) are suitable to characterize farming systems in Bhutan in more detail (Table 2.3).

The alpine and cool temperate zones are home to about 7% of all farmers, whose livelihoods largely depend on yak herding, dairy products and cultivation of temperate crops. While slaughtering cattle is discouraged in Bhutan, yaks are an exception to the benefit of yak herders (Samdup et al., 2010)(Samdup et al., 2010). Cropping is limited by the short vegetation period and only about 5% of cultivated land is located at altitudes above 2,600 meters. Due to its commercial potential, the potato was integrated into the traditional wheat-buckwheat-barley rotation system (Walter Roder, Nidup, & Chettri, 2008). Over the last decade, collection of non-wood forest products, especially the astronomically priced Cordyceps (sold at prices up to 7,500 USD kg^{-1}), became a major source of cash income for the highlanders (MoF, 2013b; Winkler, 2008).

In the warm temperate zone, farming systems are largely based on rice and potato cultivation. Particularly in the Western and Central districts of Chhukha, Paro, Wangdue and Bumthang, there are commercially oriented farmers with disproportionately high degrees of mechanization and agrochemical use. Potato is the most important cash crop in the temperate zone, followed by high-value vegetables such as chilies and apples. Rice is largely cultivated for subsistence purposes, with the exception of farmers with good market access and growing conditions, e.g., rice farmers within the proximity of Thimphu and Paro. Due to low levels of rainfall, rice can only be grown once a year and the growing season has a low-high-low temperature pattern similar to conditions in Japan, Korea and Northern China (Ghimiray et al., 2008). Livestock systems are mostly dependent on cattle husbandry for the production of dairy and manure as well as draught power.

The majority of agricultural households and farmland is found in the subtropical zones below 1,800 meters. Smallholder systems are either based on rice, given the availability of irrigation facilities, or rainfed maize. Important rice production regions between 1,200 and 1,800 meters of altitude are the Punakha-Wangdue valley and Trashigang (with the sub-district Radhi, "the rice bowl of the East") and below 1,200 meters the gently sloped rice areas below in Samtse, Sarpang and Samdrup-Jongkhar (Ghimiray, Chhetri, & Dukpa, 2009). Double-cropping of rice is possible, but rarely practiced due to shortages in irrigation and labour (Ghimiray et al., 2008). Maize is predominantly grown in Eastern Bhutan in single and double-cropping systems. Only a small share of Maize is actually directly consumed as food and the largest shares are processed (roasted, popped or flaked), used for Ara brewing (a local alcoholic beverage) or fed to livestock. Cattle plays a similarly important role in the subtropical zones, for the supply of milk, manure and draught power. Many farmers in the subtropical zones are descendants of immigrants from Nepal and practice Hinduism. Hence, they also refrain from slaughter cattle, but they are more likely to slaughter other animals, mostly pigs, goats and poultry. Medium to large-scale layer and broiler poultry farms are largely based in the subtropical areas, supplying chicken meat and eggs to the urban centers. A well-known example is the Tsirang egg production cooperative that sells its products on the Centenary Farmers Market in the capital city Thimphu.

In the subsequent studies, the AEZ classification is reduced from six to three agroecological zones. Areas at an altitude above 1,800 masl are grouped together to form AEZ3, the *temperate AEZ*. Areas between altitude levels of 1,800 and 1,200 masl are AEZ2, the *dry subtropical AEZ* and all areas below 1,200 masl are grouped in AEZ1, the *humid subtropical AEZ*.

Table 2.3. Agro-ecological zones and farming systems in Bhutan

Agro-ecological zone (AEZ)	Altitude range	Annual rainfall (mm)	Air temperature °C			Agri. households	Arable land	Animal husbandry and crop production (shares in total harvested area in parenthesis)	Farming systems
			Max	Min	Mean	(% share)	(% share)		
Alpine	3,600 – 4,600	<650	12.0	-0.9	5.5	1.2	0.2	Semi-nomadic people, yak herding for dairy products, wool and meat. Barley (58%), wheat (6%), turnips (22%), potato (10%), and other vegetables.	Barley single-cropped. Potato single cropped or rotated with turnips or wheat
Cool temperate	2,600 – 3,600	650 – 850	22.3	0.1	9.9	5.8	4.8	Yak, cattle and sheep husbandry for dairy products, wool and meat. Upland paddy (2%), wheat (17%), buckwheat (12%), potato (31%), turnips (15%), apple (4%) and other temperate fruits and vegetables.	Potato rotated single cropped or rotated with wheat, buckwheat or mustard. Turnips rotated with intercropped barley and mustard.
Warm temperate	1,800 – 2,600	650 – 850	26.3	0.1	12.5	32.5	26.8	Cattle husbandry for dairy products, draught power and manure. Irrigated rice (21%), maize (27%), wheat (4%), potatoes (18%), chili (4%) and other vegetables. Cardamom (2%), apple (3%) and other temperate fruit trees.	Rice single cropped or rotated with wheat fodder, oats, chilies or vegetables. Maize single cropped or rotated with wheat or potato. Potato rotated with wheat, turnips or mustard.
Dry subtropical	1,200 – 1,800	850 – 1,200	28.7	3.1	17.2	32.2	31.4	Cattle husbandry for draught power and manure. Irrigated rice (25%), maize (35%), buckwheat (4%), millet (3%), pulses (3%), chilies (2%) and other vegetables. Cardamom (2%), citrus (4%) and other subtropical fruit trees.	Rice single cropped or rotated with wheat, chilies and vegetables. Maize single or double cropped, or rotated with legumes, millet or potatoes.
Humid subtropical	600 – 1,200	1,200 – 2,500	33.0	4.6	19.5	15.4	20.5	Cattle husbandry for draught power and manure. Poultry, goats and pigs for meat and other animal products. Irrigated rice (18%), maize (37%), millet (4%), buckwheat (4%) and vegetables. Ginger (2%), cardamom (4%), citrus (8%) and other subtropical tropical fruit trees.	Rice single cropped or rotated with maize, wheat, mustard or vegetables. Maize single or double cropped, or rotated with legumes, millet or potatoes.
Wet subtropical	150 – 600	2,500 – 5,500	34.6	11.6	23.6	13.0	16.4	Cattle husbandry for draught power and manure. Poultry, goats and pigs for meat and other animal products. Irrigated rice (26%), maize (34%), millet (6%), mustard (1%) and other vegetables. Ginger (3%), cardamom (2%), areca nut (11%), citrus (8%) and other subtropical tropical fruit trees.	Rice single cropped or rotated with maize, wheat, mustard or vegetables. Maize single or double cropped, or rotated with legumes, millet or potatoes.

Source: AEZ classification is based on GNHC, 2009. Percentage distribution of agricultural households and arable land across AEZs is based on data from MoAF (2013a), Farming system characterization is based on (Ghimiray et al., 2008; Katwal, 2013, 2016; Walter Roder et al., 2008).

2.5 References

AMC. (2014). *Machinery Price List*. Paro, Bhutan. Retrieved from Agriculture Machinery Centre (AMC) Paro website: http://www.amc.gov.bt/index.php?r=product/index

Boyreau, G., & Rama, M. (2015). *Bhutan Macroeconomic and Public Finance Policy Note: Hydropower Impact and Public Finance Reforms towards Economic Self-Reliance*. Washington DC, USA. Retrieved from https://openknowledge.worldbank.org/handle/10986/24581

Christensen, G., Fileccia, T., & Gulliver, A. (2012). *Bhutan - Agricultural sector review: Issues, institutions and policies*. Rome.

CIA. (2012). *Bhutan Administrative Divisions 2012*. Washington D.C., USA: U.S. Central Intelligence Agency. Retrieved from http://legacy.lib.utexas.edu/maps/middle_east_and_asia/txu-pclmaps-oclc-780922902-bhutan_admin-2012.jpg

Dukpa, T., Wangchuk, P., Rinchen, Wangdi K., & Roder, W. (2007). Changes and innovations in the management of shifting cultivation land in Bhutan. In M. Cairns (Ed.), *Voices from the Forest: Integrating Indigenous Knowledge into Sustainable Upland Farming* (pp. 692–699). London: Earthscan.

Feuerbacher, A., Dukpa, C., & Grethe, H. (2017). *A 2012 Social Accounting Matrix (SAM) for Bhutan with a detailed representation of the agricultural sector: Technical Documentation* (Working Paper No. 94). Berlin. Retrieved from Department of Agricultural Economics, Faculty of Life Sciences, Humboldt-Universität zu Berlin website: https://www.agrar.hu-berlin.de/de/institut/departments/daoe/publ/wp/wp94.pdf

Ghaley, B. B., & Christiansen, J. L. (2010). On-farm assessment of mineral nitrogen and cultivar effects on rice productivity in Bhutan highlands. *Acta Agriculturae Scandinavica, Section B - Plant Soil Science*, *60*, 460–471. https://doi.org/10.1080/09064710903156295

Ghimiray, M. (2012). An analysis of rice varietal improvement and adoption rate by farmers in Bhutan. *Journal of Renewable Natural Resources Bhutan*, *8*, 13–24.

Ghimiray, M., Chhetri, M., & Dukpa, W. (2009). *Rice Production Practices for Low Altitude Belt: Field Manual*. Retrieved from Council for RNR Research Bhutan website: http://rcbajo.gov.bt/wp-content/uploads/2016/03/Rice-production-guide-for-south.pdf

Ghimiray, M., Dorji, K. D., Katwal Bdr., T., Penjore, U., Dorji, S., Pem, S., . . . Pradhan, K. (2008). *Rice in Bhutan: A Source Book*. Thimphu, Bhutan.

Gilani, H., Shrestha, H. L., Murthy, M. S. R., Phuntso, P., Pradhan, S., Bajracharya, B., & Shrestha, B. (2015). Decadal land cover change dynamics in Bhutan. *Journal of Environmental Management*, *148*, 91–100. https://doi.org/10.1016/j.jenvman.2014.02.014

GNHC. (2009). *Tenth Five Year Plan 2008-2013: Volume 1: Main Document*. Thimphu, Bhutan.

GNHC. (2013). *Eleventh Five Year Plan 2013-2018: Volume 1: Main Document*. Thimphu.

GNHC. (2018). Mandate. Retrieved from https://www.gnhc.gov.bt/en/?page_id=524

Gosai, M. A., & Sulewski, L. (2014). Urban attraction: Bhutanese internal rural–urban migration. *Asian Geographer*, *31*, 1–16. https://doi.org/10.1080/10225706.2013.790830

Hayden, A. (2015). Bhutan: Blazing a Trail to a Postgrowth Future? Or Stepping on the Treadmill of Production? *The Journal of Environment & Development*, *24*, 161–186. https://doi.org/10.1177/1070496515579199

IUCN. (2015). *IUCN Red List of Threatened Species.*

Karan, P. P. (1963). Geopolitical Structure of Bhutan. *India Quarterly: a Journal of International Affairs*, *19*, 203–213. https://doi.org/10.1177/097492846301900301

Katwal, T. B. (2013). *Multiple cropping in Bhutanese agriculture: Present status and opportunities*. Thimphu. Retrieved from http://www.nbc.gov.bt/wp-content/uploads/2010/06/Multiple-Cropping-Paper-Bhutan-for-SAC-1.pdf

Katwal, T. B. (2016). *Cropping calendar for cereals across various agroecological zones*. Email. Thimphu, Bhutan.

Lamsang, T. (2017, April 3). Punatsangchu I to be delayed to Dec 2022 and Punatsangchu II till Sept 2019. *The Bhutanese*. Retrieved from https://thebhutanese.bt/punatsangchu-i-to-be-delayed-to-dec-2022-and-punatsangchu-ii-till-sept-2019/

Minten, B., & Dukpa, C. (2010). *Technology adoption, agricultural productivity, and road infrastructure in Bhutan*. Thimphu, Bhutan.

MoAF. (2009). *Agricultural Census 2008 - Microdata*. Thimphu, Bhutan.

MoAF. (2013). *Agricultural Sample Survey 2012 - Dataset*. Thimphu, Bhutan.

MoAF. (2015). *Bhutan RNR statistics 2015*. Thimphu, Bhutan.

MoAF. (2016). *State of Climate Change Report for the RNR Sector*. Thimphu, Bhutan. Retrieved from Ministry of Agriculture & Forests website: http://www.moaf.gov.bt/download/Publications/State-of-the-Climate-Change-Report-2016_FINAL.pdf

MoAF. (2017). *Electric fence inventory*. Thimphu, Bhutan.

MoAF. (2018). *Agriculture Statistics 2017*. Thimphu, Bhutan.

MoEA. (2012). *Diagnostic Trade Integration Study*. Thimphu, Bhutan.

MoF. (2013). *Bhutan Trade Statistics 2012*. Thimphu, Bhutan.

NAB. (2018). About National Assembly of Bhutan: Overview. Retrieved from http://www.nab.gov.bt/en/about/overview-national-assembly

NRDCL. (2013). *Annual Report 2012*. Thimphu, Bhutan.

NSB. (2012). *Statistical Yearbook 2012*. Thimphu, Bhutan. Retrieved from www.nsb.gov.bt

NSB. (2013). *National Account Statistics 2013*. Thimphu, Bhutan.

NSB. (2014). *National Account Statistics 2014*. Thimphu, Bhutan.

NSB. (2017a). *National Accounts Statistics 2017*. Thimphu, Bhutan. Retrieved from National Statistics Bureau website: http://www.nsb.gov.bt/publication/download.php?id=1268

NSB. (2017b). *Statistical Yearbook of Bhutan 2017*. Thimphu, Bhutan. Retrieved from National Statistics Bureau (NSB) of Bhutan website: http://www.nsb.gov.bt/publication/download.php?id=1386

NSB. (2018). *2017 Population and Housing Census of Bhutan: National Report*. Thimphu, Bhutan. Retrieved from National Statistics Bureau (NSB) of Bhutan website: http://www.nsb.gov.bt/publication/download.php?id=1352

NSB, & ADB. (2012). *Bhutan Living Standard Survey 2012 - dataset*. Thimphu, Bhutan.

NSB, & World Bank. (2012). *Bhutan Poverty Analysis 2012*. Thimphu, Bhutan. Retrieved from National Statistics Bureau; World Bank website: http://www.nsb.gov.bt/publication/files/pub6pg3078cg.pdf

Nyaupane, G. P., & Timothy, D. J. (2010). Power, regionalism and tourism policy in Bhutan. *Annals of Tourism Research*, *37*, 969–988. https://doi.org/10.1016/j.annals.2010.03.006

Penjor, T., Dorji, L., Nima, C., Yangzom, D., Chhetri, P. B., Norbu, T., & Dorki, L. (2014). *Fabricated electric fencing (FEF) System: A new approach to mitigate human-wildlife conflict in Bhutan* (Human-Wildlife Conflict Resolution in the Mountains of SAARC - Success Stories). Thimphu, Bhutan.

Penjore, D. (2004). Security of Bhutan: Walking Between the Giants. *Journal of Bhutan Studies*, *10*, 108–131. Retrieved from http://www.dspace.cam.ac.uk/handle/1810/227045

Reardon, T., Berdegué, J., Barrett, C. B., & Stamoulis, K. (2007). Household income diversification into rural nonfarm activities. *Transforming the Rural Nonfarm Economy: Opportunities and Threats in the Developing World*, 115–140.

RGoB. (2007). *The land act of Bhutan 2007*. Thimphu, Bhutan.

RGoB. (2008). *The Constitution of the Kingdom of Bhutan*. Thimphu, Bhutan.

RGoB. (2009). *The Local Government Act of Bhutan 2009*. Thimphu, Bhutan. Retrieved from http://www.mohca.gov.bt/download/LGAct2018Final.pdf

RGoB. (2012). *Bhutan: In Pursuit of sustainable development: National report for the United Nations Conference on Sustainable Development 2012*. Thimphu, Bhutan.

RGoB. (2017). *Forest and Nature Conservation Rules and Regulations of Bhutan*. Thimphu, Bhutan.

RMA. (2017). *Annual Report 2016/17*. Thimphu, Bhutan.

Roder, W., Nidup, K., & Chettri, G. (2008). *The Potato in Bhutan*. Thimphu, Bhutan.

Rodríguez-Rodríguez, D., Bomhard, B., Butchart, S. H.M., & Foster, M. N. (2011). Progress towards international targets for protected area coverage in mountains: A multi-scale assessment. *Biological Conservation*, *144*, 2978–2983. https://doi.org/10.1016/j.biocon.2011.08.023

Samdup, T., Udo, H. M.J., Eilers, C., Ibrahim, M. N.M., & van der Zijpp, A. J. (2010). Crossbreeding and intensification of smallholder crop–cattle farming systems in Bhutan. *Livestock Science*, *132*, 126–134. Retrieved from http://www.sciencedirect.com/science/article/pii/S1871141310001915

Shrestha, S., Katwal Bdr., T., Ghaley, B. B., Pulami, T. M., Chophyll, K., Wangchuk, S., & Wangdi, N. (2006). *Adoption and Impact Assessment of Improved Maize Technologies in Bhutan Resource: First draft report*. Thimphu, Bhutan.

Siebert, S. F., & Belsky, J. M. (2014). Historic livelihoods and land uses as ecological disturbances and their role in enhancing biodiversity: An example from Bhutan. *Biological Conservation*, *177*, 82–89. https://doi.org/10.1016/j.biocon.2014.06.015

Tortajada, C., & Saklani, U. (2018). Hydropower-based collaboration in South Asia: The case of India and Bhutan. *Energy Policy*, *117*, 316–325. https://doi.org/10.1016/j.enpol.2018.02.046

UN. (2015). *UN comtrade database*. New York, USA. Retrieved from United Nations website: http://comtrade.un.org/

UN. (2018). Least Developed Country Category: Bhutan Profile. Retrieved from https://www.un.org/development/desa/dpad/least-developed-country-category-bhutan.html

UNDP. (2018). Human Development Index and its components. Retrieved from http://hdr.undp.org/en/composite/HDI

UNEP-WCMC. (2013). *Mountain Area per country*. Washington DC, USA.

Ura, K., Alkire, S., Zangmo, T., & Wangdi, K. (2012). *A short guide to gross national happiness index*. Thimphu: Centre for Bhutan Studies.

Verma, R. (2017). Gross National Happiness: meaning, measure and degrowth in a living development alternative. *Journal of Political Ecology*, *24*, 476. https://doi.org/10.2458/v24i1.20885

Winkler, D. (2008). Yartsa Gunbu (Cordyceps sinensis) and the Fungal Commodification of Tibet's Rural Economy. *Economic Botany*, *62*, 291–305. https://doi.org/10.1007/s12231-008-9038-3

World Bank. (1985). *Staff appraisal report Bhutan Calcium Carbide Project* (No. 5430-BHT). Washington DC, USA.

World Bank. (2014). *Bhutan Country Snapshot*. Washington DC, USA.

World Bank. (2018). *World Development Indicators*. Dataset. Washington DC, USA. Retrieved from http://data.worldbank.org/data-catalog/world-development-indicators

Yeshey. (2012). Economics of mechanizing rice cultivation at RNRRDC Bajo. *Journal of Renewable Natural Resources Bhutan*, *8*, 42–52.

Chapter 3 Rural Livelihoods and Seasonal Labour Supply

This chapter consists of the corresponding manuscript "Rural Livelihoods and Seasonal Labour Supply", which is prepared for submission to the Journal of Development Economics.

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Abstract

Agriculture is a biological process where the demand for labour varies with the seasons and weather. Whole economy models, such as computable general equilibrium (CGE) models, have neglected the influence of seasons on labour markets and rural livelihoods, with the implicit assumption of separability of seasonal labour demand and supply. This study relaxes that restrictive assumption using a CGE model. The results demonstrate that ignoring the influence of seasons on rural labour markets systematically biases the results. Assuming homogeneity of labour units, i.e., allowing substitution across season, systematically understates the impacts of policy changes on rural wage rate and overstates agricultural output responses. The magnitude of the biases can be summarised as, effective, changes in the labour endowments. The results have important implications for understanding the implications of domestic and global policy changes for agriculture, and welfare in rural communities, in developing economies.

Keywords: Seasonal labour; Rural labour markets; Economy-wide modelling; CGE; Model bias; Policy analysis; Rural development; Bhutan

3.1 Introduction

Agricultural production is a biological process that is governed by weather and the seasons: the demand for inputs follows the seasons and sequencing of agricultural operations, e.g., soil preparation, planting, weeding and harvesting. Seasonal fluctuations in labour demand in agriculture are a feature of agriculture in all economies. In low-income agrarian economies, the seasonal fluctuations are substantial, which reflects the labour-intensive methods of production and the limited options for investment in labour saving technologies. In middle to high-income economies, the fluctuations are muted by, *inter alia*, the use of labour saving technologies. With "agriculture being a seasonal operation, it is somewhat misleading to speak in terms of a homogeneous unit of labour. A unit of labour at the time of harvesting is not replaceable by a unit of labour at a slack period" (Amartya K. Sen, 1966, p. 440). This insight is important for an understanding of rural labour markets; seasonal labour bottlenecks are constraints for agricultural output "regardless of the degree of [apparent] underemployment" (Ruthenberg, 1971, p. 78).

Empirical studies have recorded evidence of seasonal labour shortages and underemployment in economies as divergent as China (Zhang et al., 2011), Malawi (Wodon & Beegle, 2012)(Wodon & Beegle, 2012) and the U.S. (Fisher & Knutson, 2013; J. Edward Taylor, Charlton, & Yúnez-Naude, 2012)(Fisher & Knutson, 2013; J. Edward Taylor et al., 2012). Seasonal underemployment rather than open unemployment is the prevalent observation in rural areas, since farmers find some level of employment in non-farm activities during slack periods (Binswanger & Rosenzweig, 1981; Reardon et al., 1998)(Binswanger & Rosenzweig, 1981; Reardon, Stamoulis, Cruz, Berdegué, & Banks, 1998). Seasonal underemployment disproportionately affects women (Bardhan, 1984; Jarvis & Vera-Toscano, 2004)(Bardhan, 1984; Jarvis & Vera-Toscano, 2004), is a driver of seasonal migration (Ahamad, Khondker, Ahmed, & Tanin, 2011; Kleinwechter & Grethe, 2015)(Ahamad et al., 2011; Kleinwechter & Grethe, 2015) and a target of public employment schemes (Basu, 2013; Devereux, 2016).

The seasonality of labour demand is a common feature in farm and multi-agent models (e.g. Acs et al., 2007; Troost & Berger, 2015). Ignoring the seasonality of labour demand will distort model outcomes, since it allows the use of more resources than those available (Hazell & Norton, 1986, pp. 42–46). These micro-level models do not capture forward or backward linkages within economies nor do they depict the operations of labour markets. But, economy-wide models, which are extensively used for policy analysis in the agrarian economies

(Devarajan & S. Robinson, 2005), have neglected the seasonality of labour demand in agricultural production. With some 32% of the labour force in low- and middle-income countries employed in agriculture (World Bank, 2018), and incomes from labour being a primary determinant of welfare, the neglect of seasonal labour demand may bias the results from economy-wide models.

Only two studies that incorporate seasonal demands for labour in a general equilibrium framework are known. The Alaskan labour market was studied in a model that coupled an economic and ecological general equilibrium models, with the labour market segmented into two periods, a fishing and an off-season (Finnoff & Tschirhart, 2008). Similarly, a village-level CGE-model for rural Morocco segmented gendered labour within and outside the saffron growing season (Filipski et al., 2017). Neither studies focussed on the implications of seasonality of labour on model outcomes.

In economy-wide models the standard implicit assumption is that seasonal labour demand and supply are separable, i.e., that labour types are measured in 'homogenous units'. This annualized setup of the labour market is illustrated in Figure 3.1a, which we henceforth refer to as the annual model. Households supply a pool of labour units, which independent of its temporal composition is demanded as aggregated labour units by economic and leisure activities. The annual model sidesteps the reality of the seasonal fluctuations of labour demand in agriculture addressed in micro-level models. The separability assumption is relaxed in the seasonal model illustrated in Figure 3.1b. An empirical seasonal CGE model for Bhutan is developed in this study. The simulation demonstrate that ignoring seasonal labour demand systematically biases the results; the analyses demonstrate that this is a general result.

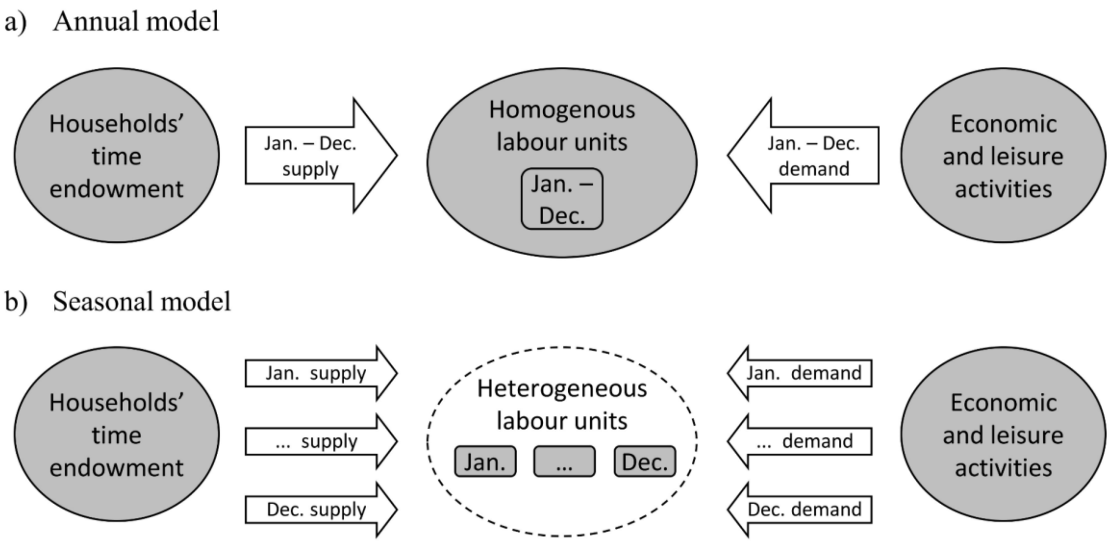


Figure 3.1. Illustration of labour markets with annual and seasonal setup

The paper is organised as follows. The next section, 3.2, demonstrates that the modelling seasonality of labour demand is overwhelmingly a data issue. A brief description of the Bhutanese economy is provided in section 3.3. In section 3.4 the database for Bhutan used in this study is described (see Arndt Feuerbacher, C. Dukpa et al., 2017 for greater detail), and the adaptation of the CGE model for this study is explained. The formulation of the policy shocks and the macroeconomic closure and market clearing conditions are reported in section 3.5. Section 3.6 presents the results and analyses, which are discussed in section 3.7. The paper closes with suggestions for further developments of the method and an assessment of the implications of the results for agrarian policy analyses in developing countries.

3.2 Seasonal Labour

In the following, a theoretical framework is elaborated how seasonality of labour (and leisure) is reflected within labour demand, supply and the market clearing conditions. A much more detailed presentation of this theoretical framework is also provided in Appendix A.

3.2.1 Labour Demand

Production is defined as a function of inputs $\boldsymbol{x}_a = f(\boldsymbol{l}, \boldsymbol{k}, \boldsymbol{n}, \boldsymbol{i}, \boldsymbol{\sigma}, \boldsymbol{\gamma})$ where $\boldsymbol{x}_a$ is a vector of outputs of activity a, $\boldsymbol{l}, \boldsymbol{k}$, and $\boldsymbol{n}$ (labour, capital and land) are vectors of primary inputs, $\boldsymbol{i}$ is a vector of intermediate inputs, $\boldsymbol{\sigma}$ is a vector of substitution elasticities and $\boldsymbol{\gamma}$ a vector of efficiency factors. The labour inputs can be defined using skill types, e.g., by education or occupation categories, and seasonal types, e.g., by months. Nested CES functions allow flexibility in substitution possibilities such that, for instance, the substitution possibilities between labour of different skill types are greater than the substitution possibilities between labour of different seasonal types within each skill type.[7] The associated first order conditions (FOC) identify the factor returns, and allow wage rates for each type of labour to vary across seasons reflecting the seasonal patterns of labour demand.

The elasticities of substitution of seasonal labour depend on the economic activity. Cropping activities, e.g., paddy rice, must follow sequences defined by nature, as noted by Sen (1966), which implies no, or limited, substitution possibilities. Non-farm activities may provide complimentary employment options for rural labour with a counter seasonal pattern relative to cropping activities (Reardon *et al.*, 1998). For manufacturing activities, the degree of substitution of labour across seasons will be greater.

Agricultural capital goods, e.g., ploughs, sprayers and reapers, may only be used during specific seasons, and hence have limited scope to substitute for labour. This may be particularly relevant in (recursive) dynamic models when new technologies may be embodied in new capital items (Solow neutral technical progress). This study uses a comparative static version of the CGE model with fixed technology. The nuances of multiple types of capital are set aside.

3.2.2 Labour Supply

Modelling of the supply-side is more complex because it is necessary to allow for the observed periods of apparent underemployment and those periods when there are high demands for labour, e.g., harvesting and weeding

Typical factor market clearing conditions in CGE models fix the supplies of each factor, but that factors can be fully employed or in surplus (underemployed). Economic theory argues that individuals maximize utility by trading off consumption and leisure - $\boldsymbol{u}_h = u(\boldsymbol{x}_{c,h}, \boldsymbol{lei}_{c,h})$, where $\boldsymbol{u}_h$ is a vector of household utilities, $\boldsymbol{x}_{c,h}$is a vector of consumption of commodities, c, by household, h, and $\mathbf{lei}_{c,h}$ is a vector of household specific domestic services and commodities used for social reproduction and leisure, that are produced outside the production boundary of

[7] Regular nested CES functions "are globally well-behaved and can provide a local approximation to any globally well-behaved cost function" Perroni and Rutherford (1995).

the SNA (see UN, 2009, para 1.41, p. 64).[8] By defining activities that produce commodities outside the production boundary[9] as household specific, i.e., they can only be produced and consumed by the household, the model generates uniquely defined prices for commodities and activities within and without the production boundary (see Aragie et al., 2017).[10]

The production activities of households outside the production boundary require the use of labour, with opportunities for substitution of labour across skill and seasonal type. If activities are less time dependent, i.e., the degree of substitutability between time periods is greater, the availability of labour for production activities is less time critical.

The time dependency of labour used to produce leisure is, arguably, more flexible than labour used for social reproduction. Substituting time use across periods allows for taking less leisure during periods of peak labour demand with compensating increases in leisure during periods of slacker labour demand: these choices are made in response to changes in the seasonal wage rates for labour.[11] Such patterns of labour demand across production cycles is a feature of agricultural production in both developed and developing economies and provides a rational explanation for "[apparent] underemployment" in developing countries (Ruthenberg, 1971, p. 78).[12]

3.2.3 Labour Market Clearing

Most CGE models (e.g., Thomas Hertel, 1997b; Lofgren et al., 2002; Scott McDonald & Thierfelder, 2015) clear factor markets at the factor level, i.e., the market clearing condition requires that total factor demand is less than or equal to the fixed factor supply. The inclusion of household specific production activities requires that factor markets are cleared at the institution level, i.e., $\sum_a FD_{f,a} \leq \sum_{ins} FSI_{ins,f}$, where $FD_{f,a}$ is the factor, f, demand by activity, a, and $FSI_{ins,f}$ is the factor supply by institution, ins.

With market clearing at the level of the institution, labour used by activities within and without the production boundary cannot exceed those available to the household. Labour used within

[8] Because domestic services and commodities used for social reproduction and leisure are household specific, the possibility of non-unique prices that underpins the definition of the SNA's production boundary is avoided.
[9] These activities can include carer services, domestic chores, e.g., cooking, cleaning, water collection, etc., resting/sleeping and leisure.
[10] The method is a development and generalisation of the method used by Fontana and Wood (2000).
[11] Another form of adjustment in developing, and developed, economies is seasonal labour migration; slack periods in some areas coincide with peak periods in other areas. The geography of Bhutan largely precludes this option.
[12] In high-income countries agriculture farmworkers, historically, worked shorter weeks during slack (winter) seasons and longer weeks in peak seasons and worked more overtime during peak seasons. Other examples of adaptation to seasonal workloads include the use of contractors, e.g., the harvest teams that work their way north harvesting wheat in the U.S.

the production boundary, for social reproduction and leisure cannot exceed the total supply by a household. This formulation also endogenises the functional distribution of income.[13]

3.3 Country Background to Bhutan

Bhutan has a population of about 735,000 of which 62% are residing in rural areas (NSB, 2018a). Landlocked in the mountainous Eastern Himalayas, Bhutan has historically been isolated and constrained in its development. In 1958, India's premier minister Jawaharlal Nehru travelled to Bhutan on horseback to initiate close bilateral cooperation, which catalysed Bhutan's rapid economic growth over recent decades (Penjore, 2004).

Bhutan is known for its unique development philosophy of Gross National Happiness. The poverty headcount ratio declined from 23% to 8% between 2007 and 2017 (NSB & World Bank, 2017). Yet, economic development largely benefitted the growing urban population and poverty became a rural phenomenon, particularly in the Southern and Eastern districts of Bhutan. Bhutan scores well among most nutrition indicators with only 2.8% of the population living under the food poverty line of 2,124 kcal in 2012 (NSB & World Bank, 2012). Stunted growth in children younger than five years old and anaemia, which affects women and children, remain serious challenges (Atwood, Nagpal, Mbuya, & Laviolette, 2014).

Bhutan remains a peasant economy, despite increasing investments in the formal economy, with about 50% of the labour force working in agriculture (NSB & ADB, 2012) – similar to other South Asian countries (World Bank, 2018). Agriculture is dominated by semi-subsistence smallholders cultivating, on average, 1.2 hectares (NSB, 2018a). Three percent of Bhutan's land area is available for farming, but this is driven by labour and capital scarcity rather than land scarcity (Boserup, 2005). This reflects the very low population density (19 persons km^{-1}) (NSB, 2018a) and the limitations on the scope for mechanisation, e.g., powertillers for land preparation, due to the very steep slopes of rainfed land and narrow rice terraces. The share of fallow land has increased in recent years. Labour shortages are identified as the main farming constraint mentioned by farmers (MoAF, 2016b).

Bhutan is a "monsoon economy" (Reardon et al., 1998). The onset of monsoon rains determines the cropping pattern of rice, with seasonal labour bottlenecks observed during the transplanting and harvesting periods of rice. Farm labour demand is relatively low in slack periods, i.e.,

[13] Most CGE models define the functional distribution of (factor) incomes to households using a matrix of parameters.

outside the main cropping seasons, when farmers pursue non-farming activities such as textile weaving and forestry. There are considerable regional differences in monsoon rain patterns and climatic conditions. There are three major agroecological zones (AEZs): the humid subtropical zone (AEZ1, below 1200 m of altitude), the dry subtropical zone (AEZ1, 1200 – 1800 m) and the temperate zone (above 1800 m). Agricultural households and cultivated land are almost equally distributed across these zones.

Rural settlements are scattered and difficult to access, despite a growing rural road network. There is little evidence of rural-rural seasonal migration with the exception of transhumant pastoralists migrating between summer and winter camps. Rural livelihoods are mostly dependent on crop agriculture. Cattle husbandry, which dominates livestock agriculture, is land extensive, but labour intensive; reflecting low productivity and widespread discouragement of slaughtering due to Buddhist beliefs (Samdup et al., 2010).

Agricultural households in the temperate zones (AEZ3) are closer to urban centres (particularly Thimphu and Paro in Western Bhutan). They have more diversified income sources, particularly the landless agricultural households. Per capita incomes decline with decreasing altitude and increasing distance from the Western urban areas. While the climate at higher altitudes is a constraint, it is also a seasonal advantage for farmers to supply produce to India and Bangladesh (MoEA, 2012). The main cash crop exports are vegetables, potatoes and apples from the temperate regions (AEZ3), and citrus, cardamom and ginger from the subtropical zones. The cultivation of cereals, particularly rice and maize, occupies two-thirds of cropland. Cereal yields are low compared to other South Asian countries, reflecting low adoption levels of agrochemicals (Arndt Feuerbacher, Luckmann, Boysen, Zikeli, & Grethe, 2018).

Bhutan maintains a free trade agreement with India. Since subsistence consumption absorbs the largest share of farmers' cereal production, Bhutan became heavily reliant on cereal imports from India, comprising 35% of total cereal demand (Arndt Feuerbacher, C. Dukpa et al., 2017). Recently, India has imposed export bans on cereals, but exempted Bhutan. Nevertheless, increasing the degree of food self-sufficiency is a political priority in Bhutan.

3.4 Data and Method

3.4.1 Data

The data used for this study is a Social Accounting Matrix (SAM) for Bhutan in 2012 (Arndt Feuerbacher, C. Dukpa et al., 2017)(Arndt Feuerbacher, C. Dukpa et al., 2017) with satellite accounts for quantities of factors and elasticities.[14] The season demands for labour were estimated from primary data, from seasonal calendars, secondary data from the (national) 2012 agricultural sample survey (MoAF, 2013a), crop calendars and cost of production studies (see Appendix 3B).

The database distinguishes between farm and non-farm labour, with the supply and demand of farm labour split into 12 regular monthly periods. Farm labour dominates the rural labour market, although non-farm workers, e.g., teachers, shop owners, etc., also reside in rural areas. Bhutan is characterised by large variations in climate and altitude with associated differences in growing conditions, so the rural labour market is further segmented by the three AEZs. Non-farm labour is classified as unskilled and skilled labour. Farm labour is demanded by agricultural activities, food processing and off-farm activities. Non-farm labour is demanded by manufacturing and service activities. Households are classified as non-farm and farm, with farm households sub-divided by AEZs and access to land, i.e., farm and landless households.

There are five land accounts (rainfed, irrigated, orchard, pasture and forest land), which are sub-divided by AEZs. There are four capital factors: two livestock capital accounts (cattle and other animals), and two physical capital factors by ownership (farm and landless household and incorporated business enterprise owned).

3.4.1.1 Seasonal Activities

The shares in total output, required person-days and type of labour demand by activities that use seasonal labour are reported in Table 3.1; the characteristics of the seasonal labour demand are also identified. Cropping activities have ‘rigid’ labour demands, i.e., operations such as transplanting or harvesting of paddy are performed in specific time windows. Other activities

[14] The economic structure of Bhutan as represented in the SAM is presented in Appendix 3A.

such as livestock husbandry or textile weaving of farm households are performed with flexibility of labour demand.

Some crops, in Bhutan, are cultivated in different seasons or with different cropping patterns, e.g., double or single cropping of maize; these activities were disaggregated accordingly. Cropping activities account for 52% of output, by value, and 43% of total person-days. The high labour intensity of rice production - 250 person-days per hectare[15] – means that rice cultivation accounts for ~38% of cropping labour. There are 37.9 million person-days provided by about 170,000 farmers, i.e., an average of 225 working days per person; this excludes labour used for social reproduction and leisure. Overall, employment in seasonal activities accounts for 48.3% of Bhutan's labour days.

[15] Maize has half the labour intensity per hectare.

Table 3.1. Seasonal activities represented in SAM

Activity	Share in total seasonal output value	Person-days (in thousand)	Share in total person-days employed in production	Type of seasonal labour demand	Seasonal labour substitution elasticity[a] $\sigma_{a,t}$
Milled, rice	12.7%	6,065	16.0%		
Double cropping of maize	1.8%	1,102	2.9%		
Single cropping of maize	5.2%	2,971	7.8%		
Other cereals and oilseeds	2.5%	1,100	2.9%		
Vegetables - first season	4.5%	786	2.1%	Rigid	0
Vegetables - second season	4.5%	1,107	2.9%		
Potato - first season	5.9%	1,411	3.7%		
Potato - second season	0.2%	96	0.3%		
Spices	4.3%	453	1.2%		
Fruits	10.1%	1,032	2.7%		
Total cropping activities	51.6%	16,124	42.5%		
Cattle husbandry	9.6%	8,249	21.8%		0.1
Other animals	5.3%	2,049	5.4%	Flexible	0.1
Dairy production	12.5%	3,914	10.3%		0.2
Total livestock activities	27.4%	14,212	37.5%		
Cereal milling[c]	1.0%	146	0.4%		1.5
Cereal processing	2.6%	345	0.9%		1.5
Ara[b] production	4.0%	786	2.1%		1.5
Total food proc. activities	7.6%	1,277	3.4%		
Community forestry	8.6%	4,164	11.0%	Flexible	1.5
Textile weaving	4.8%	2,123	5.6%		1.5
Total non-farm activities	13.4%	6,287	16.6%		
Total seasonal activities	100.0%	37,899	100.0%		
Total seasonal leisure		14,655		Flexible	0.2

Please note: Each seasonal activity is further disaggregated by agroecological zone.
[a] Set *a* identifies activities, set *t* the seasonal periods
[b] Excludes milling of paddy, which is included in the “Milled, rice” activity
[c] Ara is a traditional home-brewed alcoholic beverage made from cereals

3.4.1.2 Leisure and Social Reproduction in the Database

The available data do not allow meaningful separation of the accounts for social reproduction and leisure; they are therefore treated as a single account – leisure. Each household can consume leisure commodities that are produced by the household using labour only provided by that household.[16] For all (farm and landless) agricultural households, the time endowment is six

[16] This is a reasonable assumption in the case of Bhutan and other developing economies. In developed economies, and/or for rich households, social reproduction may use employed labour, e.g., cleaners, nannies, etc. In all economies, leisure accounts can only use household specific labour.

days per week, or 312 days a year. Hence, there are 87 days (312 - 225) for leisure and social reproduction, i.e., a time endowment ratio of 1.4 (312 / 225). The seasonal demands for labour vary; the resultant seasonal patterns of leisure are reported in Figure 3.2. The time endowment ratio (1.4) implies income elasticities of labour supply, $\varepsilon_{L,Y}$, of -0.28 (Ballard, 2000; Boeters & Savard, 2013) for (farm and landless) agricultural households.[17] This elasticity is close to point estimates for low-middle income countries (Danzer, 2013), but high compared to estimates from high-income countries, which range between -0.10 and -0.19 (Ballard, 2000; Borjas, 2000, p. 47). Sensitivity analyses are conducted to test the robustness of model results. For non-agricultural households, the leisure endowments are estimated for an elasticity of -0.15.

3.4.1.3 Distribution of Seasonal Labour-Leisure

The use of person-days for seasonal labour and leisure for the three AEZs are reported in Figure 3.2. The number of person-days required for rigid and flexible demand and leisure are summarised for each month. The patterns of demand differ markedly across activities, particularly for cropping activities with rigid demand. The potential seasonal labour bottlenecks are driven by the paddy transplanting and harvesting seasons, which vary by AEZ, e.g., in AEZ1 transplanting is in June-July and harvesting in November-December. Livestock activities have constant, but slightly flexible labour demand, comprising more than a third of total seasonal labour (Table 3.1). Non-farm activities have highly flexible labour demand and follow a counter-cyclical pattern. The share of seasonal labour employed by activities with flexible demand is lowest during peak periods and highest during lean seasons, such as during the winter months in AEZ3.

[17] The time-use survey for Bhutan conducted by the Centre for Bhutan Studies & GNH Research (2015), reports an average time endowment of 15.2 hours, consisting of 8 hours working and about 7.2 hours for leisure and social reproduction, leaving 8.8 hours for sleep. These estimates yield an income elasticity of labour supply, $\varepsilon_{L,Y}$, of -0.48. This is unrealistic given that leisure and social reproduction are not separately quantified, and the ability to substitute away from social reproduction is far lower than from leisure.

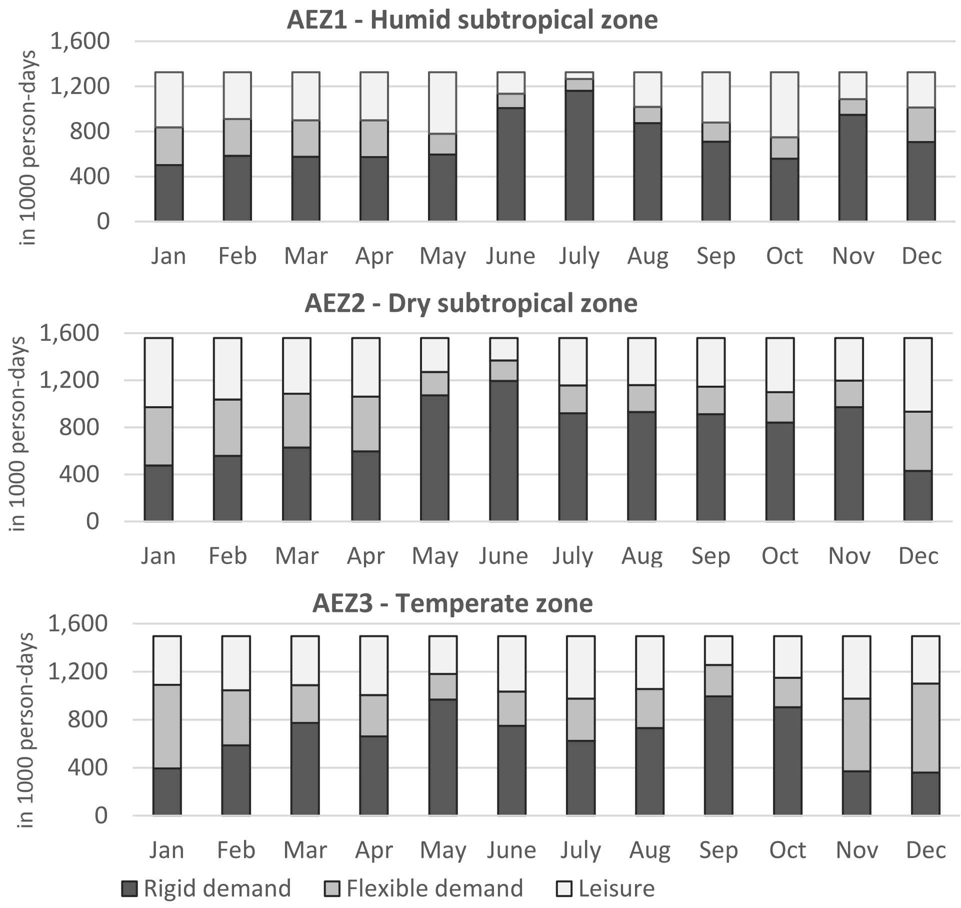


Figure 3.2. Aggregated distribution of seasonal labour demand in 1000 person-days per month across AEZs

3.4.2 The Model

The Bhutan model is a single country comparative-static CGE model developed from STAGE2 (Scott McDonald & Thierfelder, 2015). The nesting of the production is extended to incorporate seasonal labour and fertiliser – a land saving intermediate input (the production structure is illustrated in Figure 3.3). Non-seasonal inputs are not shaded, and seasonal inputs are shaded. At the top level of the nest, aggregate non-land saving intermediate inputs and value-added components are aggregated with CES or Leontief technologies. At the second level, Leontief technologies are used to aggregate non-land saving intermediate inputs and CES technologies are used to combine the fertilizer-land and capital-labour aggregates. The third level combines land and aggregate fertilisers, where aggregate fertilisers are a combination of chemical and organic fertilisers (manure) from the fourth level; both use CES technologies.[18] The capital-labour aggregate is a combination of capital and aggregate labour, with aggregate labour being a combination of seasonal and permanent labour (level 4). Permanent labour is a combination of skilled and unskilled labour, while seasonal labour is an aggregate of labour from all 12 months. All the capital and labour components are aggregated with CES technologies. The point estimates for the CES elasticities, used at each level of the production system, are detailed in Table 3.2 together with the sources used; the simulation exercises include sensitivity analyses with respect to these point estimates.

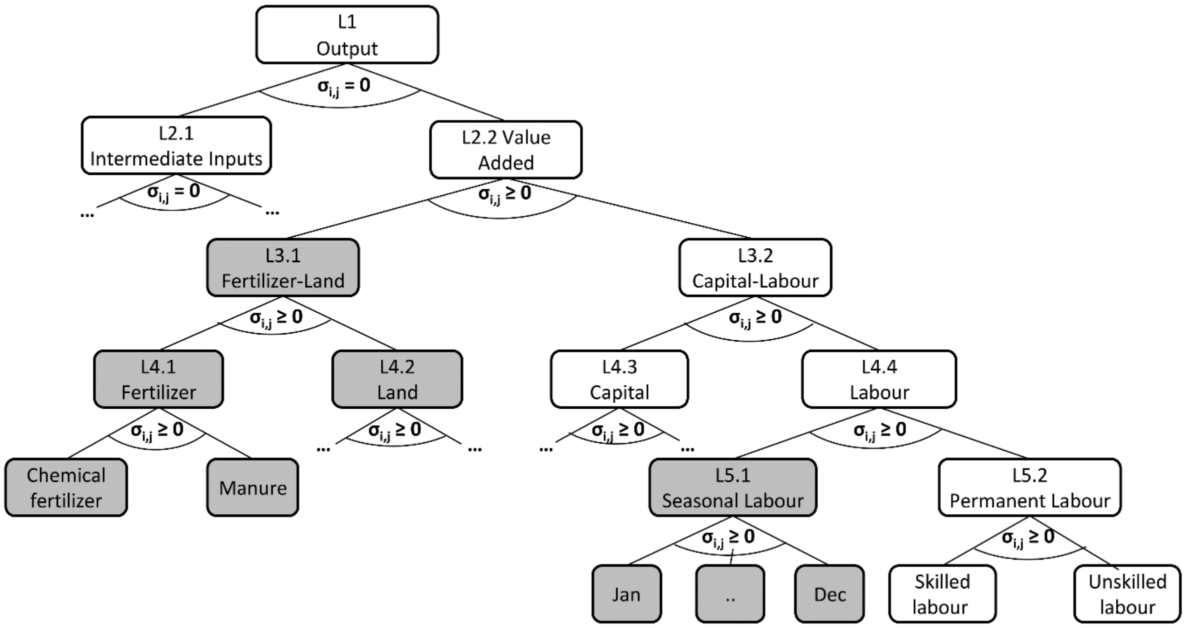


Figure 3.3. Production structure incorporating seasonal labour

3.4.3 Demand System for Leisure and Consumption

The model's demand system is implemented as a CES-LES-CES nest. In the first nest, households trade-off aggregate leisure and aggregate consumption, allowing for labour supply along the intensive margin (working hours). The CES substitution elasticity at the labour-leisure trade-off is computed as: $\sigma_{lei,X} = 1 - \frac{\varepsilon_{L,Y}}{\varepsilon_{L,W}}$, i.e., it is calibrated in consistence with the income elasticity of labour supply, $\varepsilon_{L,Y}$, and wage elasticity of labour supply, $\varepsilon_{L,W}$ (Boeters & Savard, 2013). Wage elasticity of labour supply is set to 0.15 following Goldberg (2016), who estimated

[18] Leontief technologies are options at all levels of the production system.

the wage elasticity in rural Malawi applying field experiment methods in the day labour market.[19] The resultant elasticities of labour-leisure substitution, $\sigma_{lei,X}$, are 1.54 for agriculture and 2.00 for non-agriculture households.

Household specific leisure is a CES aggregate of leisure from permanent and seasonally employed workers.[20] There are no known estimates of intra-household substitution of leisure across working household members. An elasticity of 0.5 is assumed, i.e., imperfect substitution. Total seasonal leisure is also a CES aggregate allowing households to substitute seasonal leisure across different periods subject to an intertemporal elasticity of substitution (IES). The substitution of seasonal leisure can be regarded as analogous to the intertemporal substitution of labour supply due to short-term (or transitory) wage changes, which is grounded in the life-cycle labour supply theory (Lucas Jr and Rapping, 1969). Estimates for IES range between 0.00 – 0.50 (Card, 1994; Connolly, 2008; Heckman & MaCurdy, 1982; Skoufias, 1996). Studies applying field experiments, e.g., Fehr & Goette, 2007, point towards higher elasticities. Given the wide range in the literature, and an absence of estimates for Bhutan, an IES of 0.2 is used (see Table 3.1).

Households demand aggregate commodity groups in a Linear Expenditure System. The income elasticities of commodity groups were estimated using cross-sectional secondary household data from the 2012 Bhutan Living Standard Survey (NSB & ADB, 2012) (see Appendix 3C). Each commodity group is comprised of similar commodities, which are aggregated using a CES specification. The CES parameters to aggregate the commodity groups is documented in Appendix 3D.

[19] According to a meta-analysis of empirical estimates of $\varepsilon_{L,w}$ the average of literature values is 0.07 and 0.34 for men and women, respectively Evers, Mooij, and van Vuuren (2008). The vast majority of the surveyed studies have, however, been conducted in industrialized countries. Furthermore, since our study does not differentiate between male and female labour, we deem the estimate of Goldberg most adequate for our purpose.

[20] Technically, household specific leisure is implemented by defining the share of leisure in the total time endowment of a household's workers as labour. For each household type, this additional labour is used in an economic activity to "produce" household specific leisure applying the same production structure as described in Figure 3.2. Hence, each household consumes its leisure as a commodity (e.g. skilled household leisure), but the leisure commodity is substituted with aggregate consumption.

Table 3.2. Overview of parameters used in the model framework

System	Nest / Functional form	Parameter value	Description	Source
Production system structured as regular nested CES functions (as in Figure 3.3)	L1	Leontief (σ = 0)	Aggregation of intermediate-inputs and value added	Assumption
	L2.1	Leontief (σ = 0)	Aggregation of intermediate-inputs	
	L2.2	$0.1 \leq \sigma \geq 1.7$	Aggregation of value added	Thomas Hertel, McDougall Robert A., Narayanan G., & Aguiar, 2016
	L3.1	0.4	Land extensification margin	Bouët, Femenia, & Laborde, 2014
	L3.2	$0.1 \leq \sigma \geq 1.7$	Capital-labour aggregation	Thomas Hertel et al., 2016Thomas Hertel, McDougall Robert A., Narayanan G., & Aguiar, 2016
	L4.1	1.1	Chemical fertilizer and animal manure aggregation	Ali & Parikh, 1992
	L4.2	NA	Aggregation of land-types	[a]
	L4.3	1.5	Agricultural capital aggregation	Assumption
	L4.4	NA	Permanent and seasonal labour aggregation	[a]
	L5.1	$0 \leq \sigma \geq 1.5$	Aggregation of monthly seasonal labour[b]	See assumptions in Table 3.1
	L5.2	1.5	Aggregation of skilled and unskilled labour	Assumption
Demand System	CES	$1.5 \leq \sigma \geq 2$	Labour-leisure trade-off [b]	See section 4.3.1
	LES	$0.5 \leq \eta_{ih} \geq 1.8$	Linear expenditure system (LES) for commodity groups	Estimation documented in Appendix 3C
	CES	$0.8 \leq \sigma \geq 1.5$	Aggregation of single commodities to groups	Assumptions
Trade regimes	CES	$0.9 \leq \sigma \geq 4.4$	Armington aggregation of imports	Thomas Hertel, McDougall Robert A., Narayanan G., & Aguiar, 2016Thomas Hertel et al., 2016
	CET	2	Constant elasticity of transformation (CET) of exports	Assumption
Land supply	Asymptotic	0.8	Land supply curve[b]	Eickhout, van Meijl, Tabeau, & Stehfest, 2009

[a] Not applicable, because nest aggregates only one single land type (L4.2) or only seasonal or permanent labour (L4.4)
[b] Robustness of model results against variation in this parameter were checked conducting sensitivity analysis

3.5 Model Scenarios

3.5.1 Model Setups and Closure

The impacts of various changes in cereal import prices on Bhutan's economy are simulated with two different behavioural specifications; a model with seasonal labour data and a model with annual labour data. The seasonal model depicts seasonality as described in the model structure, with twelve monthly farm labour accounts per AEZ (as in nest L5.1 in Figure 3.3). In contrast, the annual model has *one* farm labour account per AEZ: this excludes seasonality and reflects the assumption of homogenous labour.

Trade is modelled using Armington's insight. Imports are imperfect substitutes for domestically produced goods and services (CES) as are exports (CET). Details for the chosen elasticities are reported in Table 3.2. In CGE models there are manifold factors determining the degree of price transmission (Devarajan, Lewis, & Robinson, 1990; Melo & S. Robinson, 1989). Two determinants are worthwhile to highlight: (1) The Armington elasticity that governs the ease of substitution of foreign and domestically produced goods via a CES nest; and (2) the import intensity that is measured as the share of imports in total domestic demand reflecting the degree of import linkages. The Armington elasticity for milled rice is 4.23 computed as a weighted average of the elasticities for paddy (incl. Basmati rice) and processed rice documented in Hertel et al. (2016). In case of maize and other cereals, we assumed a moderately high Armington elasticity of 2.00.

Macroeconomic Closure

The small country assumption is used, i.e., fixed world market prices, and the external balance (foreign savings) is cleared by a flexible exchange rate.[21] We assume a medium-term horizon for the capital and factor market closures. The models are investment-driven; the investment-savings account is cleared by flexible (additive) household saving rates. Government savings are fixed in real terms and income taxes vary (additively) to clear the government account.

Factor Market Clearing

A medium-term horizon is imposed for clearing the factor accounts. The supplies of each type of capital are fixed and perfectly mobile across activities.[22] All labour accounts, skilled, unskilled and seasonal labour, are perfectly mobile across activities: they are segmented by characteristics (skill-level, AEZ and time period) which cannot be altered, i.e., no labour mobility across characteristics. Alternative macroeconomic closure are evaluated as a component of sensitivity analyses: these are a flexible exchange rate and a savings-driven closure variant.

[21] Bhutan's currency is pegged against the Indian Rupee, the country's main trade partner; this might justify a fixed exchange-rate closure. The peg to the Indian rupee is a result of a close economic cooperation with India, which is undermined by the model scenarios. An alternative closure with a fixed exchange rate is included in the sensitivity analysis in section 6.3.
[22] Capital is only mobile between activities that employ capital in the base SAM.

Land is perfectly mobile across cropping activities. Due to high prevalence of fallow land in Bhutan, about 21% of arable land is left fallow, a land supply curve is implemented following Eickhout et al. (2009). Land supplies depend on the land rental rate and approaches an asymptote of maximum land supply as the factor price for land goes towards infinity. An inelastic supply of land, with a price elasticity, $\varepsilon_n^{AL} = 0.8$, is used, which equals the price elasticity that Eickhout et al. (2009) report for the South Asian region.[23]

3.5.2 Scenario Description

The scenario is stylised but rooted in a possible policy change: the imposition of a ban on cereal exports by India to Bhutan that requires that Bhutan purchases cereals on the world market, i.e., from countries other than India. There are no border crossing with Bhutan's Northern neighbour, China, so imports must arrive, at least in the medium terms, by land through India or by air. The average import cost per ton from the world market to Bhutan is estimated to be 117 USD/ton (World Bank, 2018), which is assumed as the absolute mark-up on the import cost in Table 3.3. The cost of imported cereals would increase by 25% to 52%, depending on the absolute unit price of imports. To evaluate the sensitivity of the results to the direction of the price change the simulations use increases and decreases in the border price of cereals.[24]

Table 3.3. Overview of simulated changes in import cost of cereals

Commodity	Base					*SimIncrease*	*SimDecline*
	Share in total cereal demand	**Import intensity**	**Import Unit Price (2012)**	**Quantity imported (2012)**	**Share imported from India**	**Chg. in import price[a] (in foreign currency)**	**Chg. in import price (in foreign currency)**
	(%)	(%)	(USD/ton)	Tons	(%)	(%)	(%)
Milled rice	67	43	325	72,297	100	36	-36
Maize	22	3	225	2,257	100	52	-52
Other cereals[b]	11	41	277	5,967	100	25	-25

[a] Computed by dividing the increase in import cost of 117 US-\$ ton^{-1} by the import unit price in column four.
[b] Wheat imports of India make up 60% of total imports of other cereals and the increase in import cost is adjusted accordingly

Source: Author's calculation based on 2012 Bhutan SAM and World Bank, 2017.

[23] The sensitivity of results towards variation in this parameter is checked in section 6.3.
[24] We also simulate further variants of both *SimIncrease* and *SimDecline* in order to assess the nature of bias caused by seasonality (see section 3.6.1) and to check the robustness of results against variations in model parameters (see section 3.6.3).

3.6 Results

We first explain the effects of the *SimIncrease* and *SimDecline* scenarios at the macro-level (Table 3.4). Subsequently, we present the micro-level results of the *SimIncrease* for their empirical relevance and in order to dissect the mechanisms of the seasonal labour market that determine the difference in model outcomes.

3.6.1 Macro-level Results

The *SimIncrease* scenario boosts domestic cereal production, increasing demand for arable land, agricultural capital and farm labour. In the seasonal model, labour shortages during the cereal cropping periods become the bottleneck resulting in spikes of seasonal wages and a substantially lower farm labour supply response when compared to the annual model (Figure 3.4). Assuming perfect intertemporal substitution of labour and leisure, the annual model has effectively more usable labour available for crop production. Consequently, absorption, GDP and welfare decline at lower rates than in the seasonal model.

In the opposite case (*SimDecline*), cereal imports increase and domestic cereal production declines, releasing farm labour during the cropping periods. In the seasonal model, seasonal wages now strongly drop during months formerly characterized by labour shortages. This dampens the decline in cereal production and leads to an even stronger drop in crop prices than in the annual model. Due to the assumption of perfect intertemporal substitution, the formerly absorbed labour in cereal production becomes equally available to all other seasonal activities, independent of the (usual) timing of their operations. Since more activities can use the labour, farm wages do not decline as strongly.

Table 3.4. Changes in macro-level and agriculture sector indicators and household income

	Base Year	***SimIncrease***		***SimDecline***	
Macro indicators	**Share of GDP (%)**	**Change from base year (%)**			
		Annual model	**Seasonal model**	**Annual model**	**Seasonal model**
GDP	100.0	-0.04	-0.09	-0.37	-0.21
Absorption (C+I+G)	131.5	-0.27	-0.31	0.71	0.79
Consumption (C)	45.2	-0.76	-0.88	2.02	2.23
Investment (I)	67.0	0.00	0.00	0.00	0.00
Government (G)	16.2	0.00	0.00	0.00	0.00
Exports (E)	34.7	-0.63	-0.57	1.00	0.87
Imports (M)	66.2	-0.78	-0.77	2.46	2.29
Exchange rate (*Domestic currency/ foreign currency*)		-1.55	-1.58	2.38	2.30
Producer price index (PPI)		-1.12	-1.16	1.76	1.71
Agriculture sector indicators	**(%)**				
Cereal self-sufficiency (in %)	65.2	80.13	79.00	39.91	42.91
Crop producer prices		2.40	3.11	-2.94	-4.14
Crop production		2.75	1.53	-6.29	-3.94
Farm labour wages		2.15	3.79	-3.86	-5.36
Farm labour supply		0.55	-0.14	-1.10	0.15
Arable land rent		5.4	3.4	-1.2	-1.0
Arable land supply		3.1	2.5	-7.9	-5.8
Welfare (Slutsky approximate)	**Share total pop. (%)**				
Average household	100.0	-0.53	-0.56	1.51	1.56
Non-agricultural households	52.9	-0.99	-0.99	2.03	1.99
Farm households	43.8	0.46	0.35	0.39	0.66
Landless households	3.4	-0.48	-0.23	1.38	1.22
Household income					
Average household	100.0	-0.71	-0.79	1.18	1.21
Non-agricultural households	52.9	-1.53	-1.56	2.43	2.33
Farm households	43.8	1.31	1.09	-1.88	-1.49
Landless households	3.4	-0.13	0.02	0.04	-0.03

Source: Own model results.

Seasonality of labour has a strong impact on rural factor markets in both scenarios, independent of whether cereal import costs increase or decline. Due to higher increases (decreases) in farm wages, land prices increase (decrease) less strongly in case of increasing (decreasing) import cost of cereals. Consequently, the seasonal model reports very different changes in income for landless and farm households owning land. These findings indicate that there is a systematic bias if seasonality of labour is neglected. Simulating scenarios, in which the intensity of the shock of *SimIncrease* and *SimDecline* is varied in 25% intervals from 25% to 150%, we observe that changes in farm wages are consistently higher in the seasonal than in the annual model, corroborating the systematic nature of our findings (Figure 3.4).

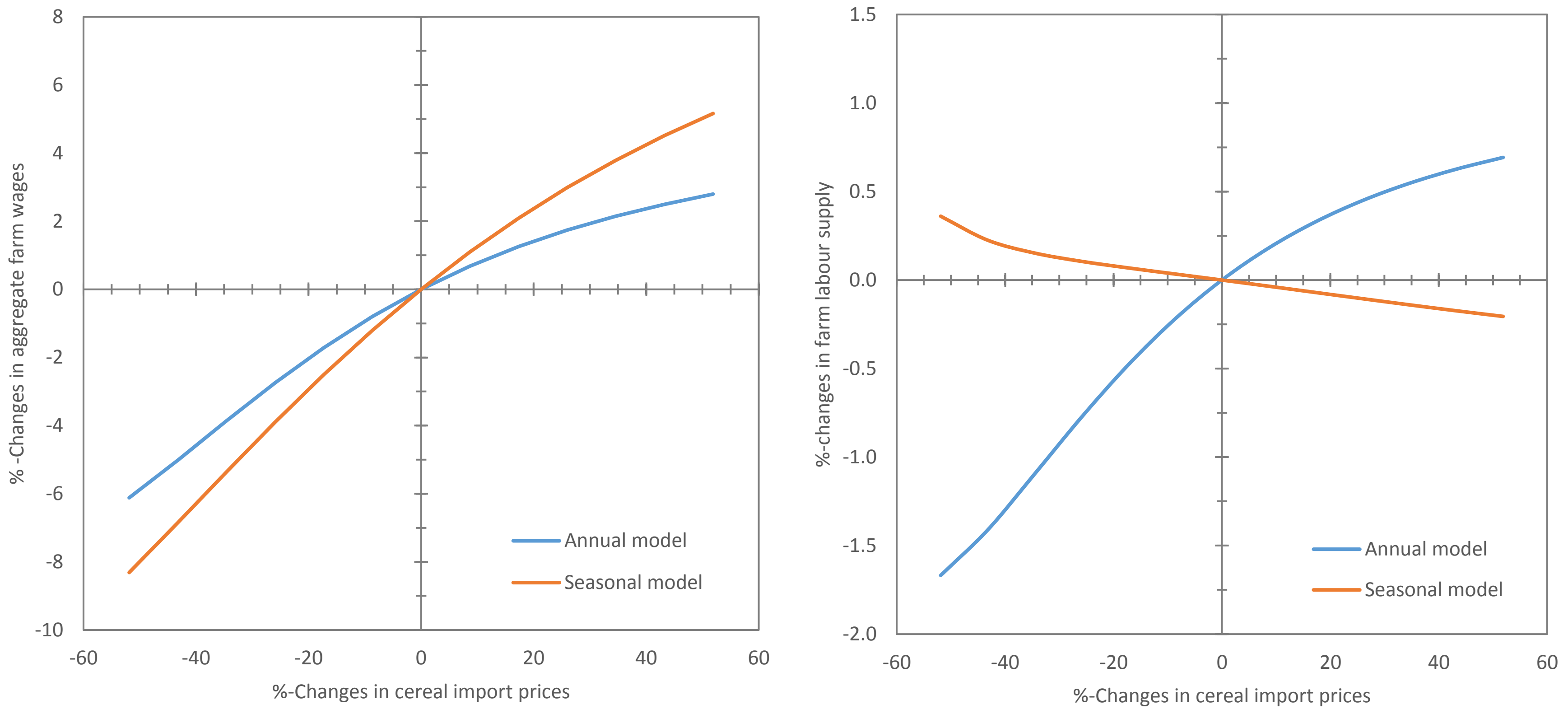


Figure 3.4. Changes in aggregate farm wages depending on changes in import prices of cereals

Source: Own model results

Agriculture accounts for about 12% of Bhutan's GDP and cereal imports comprise only 2.4% of imports. The impacts on the secondary and tertiary sectors are thus rather moderate and differences in model outcomes are less pronounced for changes in most macro indicators (e.g., the exchange rate) and average household income. Important to highlight is, that the consumption of leisure is neither included in aggregate consumption nor GDP. Hence the impacts on the macro-level turn-out less adverse in case of increasing (decreasing) labour supply.

3.6.2 Micro-level Results

Given its real-world relevance, we will only discuss the micro-level impacts of the *SimIncrease* scenario in detail in the following.

3.6.2.1 Agricultural Sector

The commodity accounts rice and other cereals are affected most by the Indian export ban, due to their high import intensities, measuring how much of domestic demand is met by imports (Table 3.5). This explains why about 50% from the increase in rice and other cereal import prices is transmitted to the consumer level. Maize has a very low import intensity (3.1%) and thus exhibits a low price transmission.

The seasonal labour constraints lead to spikes in seasonal wages and higher producer prices for most crops in the seasonal model, hampering the seasonal model's supply responsiveness. The agricultural output increases by only 0.2% compared to 1.1% in the annual model (Table 3.5). In case of rice the supply response of the annual model is 40.0% higher than in the seasonal model. Maize production changes only very slightly since it is hardly traded. In the annual model output increases (0.2%), but declines in the seasonal model (0.6%), where it is competing with the paddy sector for labour during the peak seasons. The output of other cereals increases slightly more in the seasonal model (5.1%) than in the annual model (4.9%), because it is an aggregate of various cereals predominantly cultivated in the off-season (e.g., wheat, barley, millet),

In both models, farmers shift from the production of other crops (vegetables, potatoes, spices and fruits) to cereals. Vegetables and potatoes are labour intensive and grown on rainfed land, just as maize and other cereals. As both factor prices increase strongly, their cost of production increases, yet output declines amidst an appreciating exchange rate and lower domestic demand.

Spices and fruits are less labour intensive and grown on permanent land, which does not compete with cereal cultivation.

Table 3.5. Percentage changes in food prices at various levels of the food value chain

SAM sectors	Sector or group name	Import intensity (%)	%-changes									
			Import price in foreign currency	Import price in domestic currency		Producer price		Consumer price		Output	
				Annual Model	Seasonal model	Annual Model	Seasonal model	Annual Model	Seasonal model	Annual Model	Seasonal model
1-10	Agriculture	30.2	12.0	10.2	10.2	1.7	2.1	3.1	3.4	1.1	0.2
1-7	Crops	41.4	23.2	20.9	20.9	2.4	3.1	5.5	6.1	2.7	1.5
1-3	Cereals	34.6	34.6	32.5	32.4	6.6	8.4	12.3	13.7	10.5	7.5
1	Rice, milled	42.7	35.9	33.8	33.8	8.8	11.2	15.5	17.2	16.7	12.0
2	Maize	3.1	51.7	49.4	49.3	3.4	4.8	3.5	4.6	0.2	-0.6
3	Other cereals	41.4	24.8	22.9	22.8	3.2	3.4	10.6	10.6	4.9	5.1
4-7	Other crops	42.7		-1.5	-1.6	-0.4	-0.4	-0.6	-0.6	-2.3	-2.4
8-10	Livestock	18.7		-1.5	-1.6	0.5	0.3	-0.4	-0.5	-2.1	-2.2
11-12	Forestry	35.1		-1.5	-1.6	0.3	-0.9	0.1	-0.9	-0.7	-0.1
13	Mining	7.8		-1.5	-1.6	-1.6	-1.6	-1.6	-1.6	0.1	0.2
14-19	Food processing	59.6		-1.5	-1.6	0.9	0.9	0.0	0.0	-5.5	-5.8
20-21	Textile weaving	59.6		-1.5	-1.6	-0.7	-1.3	-1.1	-1.4	-1.2	0.0
17-22	Other manufacturing	50.0		-1.5	-1.6	-1.5	-1.6	-1.5	-1.6	0.0	0.2
23	Electricity	38.4		-1.5	-1.6	-1.6	-1.6	-1.7	-1.7	0.3	0.4
24	Construction	0.3		-1.5	-1.6	-1.5	-1.6	-1.5	-1.6	0.0	0.0
26-32	Services	38.4		-1.5	-1.6	-1.5	-1.5	-1.5	-1.5	0.0	0.0

Note: As a response to the appreciating exchange rate, export prices decline by 1.6% in both scenarios across exported commodities.
Source: Model results.

3.6.2.2 Household Consumption

Among all households in Bhutan, agricultural households spend the highest share of income (55%) on food; increasing food prices thus disproportionately affect their cost of living. However, they also benefit from higher agricultural income, which is the dominating effect. Except for landless households in AEZ3, who highly depend on non-agricultural income, household expenditure ("HHexp") increases for agricultural households (Figure 3.5). With higher wages and lower land rents in the seasonal model (Table 3.7), landless households' expenditure increase more, to the disadvantage of farm households, whose increase in expenditure is relatively lower.

The impacts of the import price shock in terms of food security, approximated by food consumption, are more adverse according to the seasonal model, which also reports higher food prices. Most striking is the difference in consumption of leisure. Since wages drop in most months in the seasonal model, all agricultural households increase leisure consumption. Yet, being able to perfectly substitute leisure and labour across season, leisure consumption is consistently reduced in the annual model. Consequently, households in the annual model consume more of the “real” commodities, particularly food, while in the seasonal model the increase in real consumption is lower, due to higher leisure consumption.

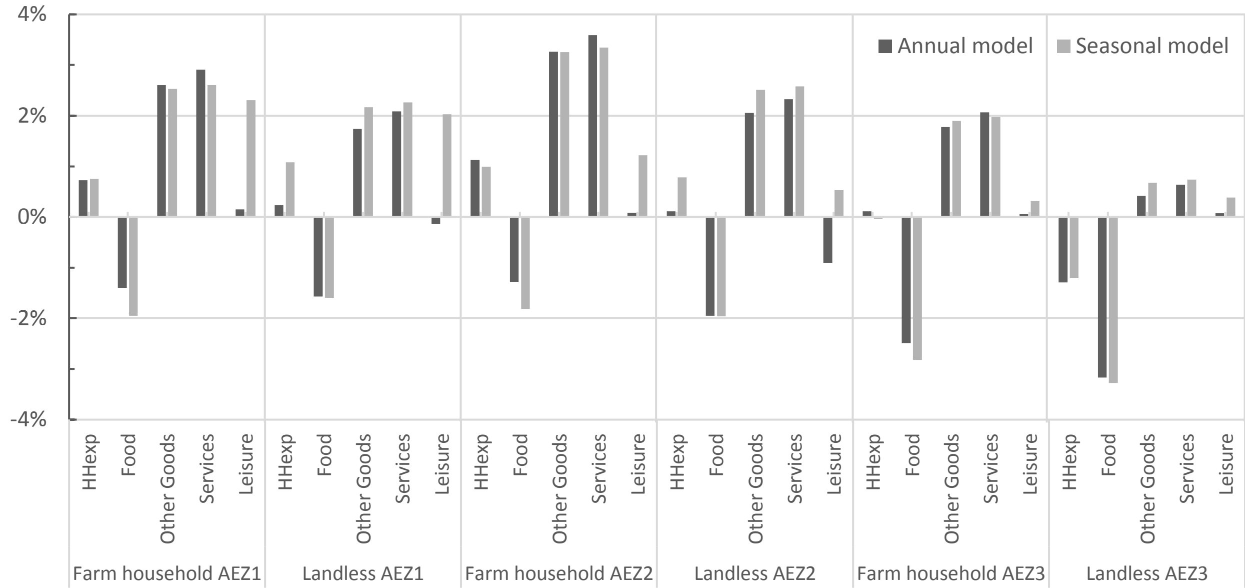


Figure 3.5. Changes in agricultural household consumption

Source: Own model results.

3.6.2.3 Farm Wages and Farm Labour Supply

Since the *SimIncrease* scenario stimulates the production of cereals, the alterations in seasonal wages are asymmetric and largely reflect the pattern of labour requirement for cereal cultivation, predominantly rice (Figure 3.6a). For example, the strong increases in seasonal wages in the low altitude zone (AEZ1) during June, July and November, coincide with the periods of land preparation, transplanting and harvesting of rice. Due to the colder climate, rice field operations occur roughly a month earlier in AEZ2 vis-à-vis AEZ1, and another month earlier in AEZ3. Hence, the pattern of seasonal increases in farm wages occur in phase shifts of just one month across the three AEZs.

Additional labour demand for maize production further exacerbates seasonal labour shortages. Both single and double cropping of maize are represented as activities in the model. Of the two systems, double-cropping of maize overlaps most with the rice transplanting period. Consequently, output of double-cropping of Maize drops at higher rates in AEZ1 and AEZ2 in the seasonal model and in AEZ2 output of single cropped Maize even increases in AEZ2.

The results correspond well with field observations and records of farmers complaining about labour shortages in the rice transplanting and harvesting season. Unfortunately, we cannot contrast the model results with empirical data on seasonal wages. Actual farm labour transactions (i.e. hiring labour in and out) only take place in months of labour demand peaks. However, in the majority of months, particularly in the lean season, there is no spot market for farm labour as farmers hardly hire any workers. Thus, typical in the context of semi-subsistence agriculture, we predominantly have to interpret the seasonal wages as shadow wages.

Seasonal wages decline in those months, in which there is low or no labour demand by cereal activities (Figure 3.6a). Non-cereal activities largely reduce their demand for seasonal labour facing lower consumer demand and a decline in competitiveness against imports. Furthermore, non-cereal crop activities also have to reduce labour demand in months in which they face less or no competition with cereal activities, due to the rigid demand pattern in cropping.

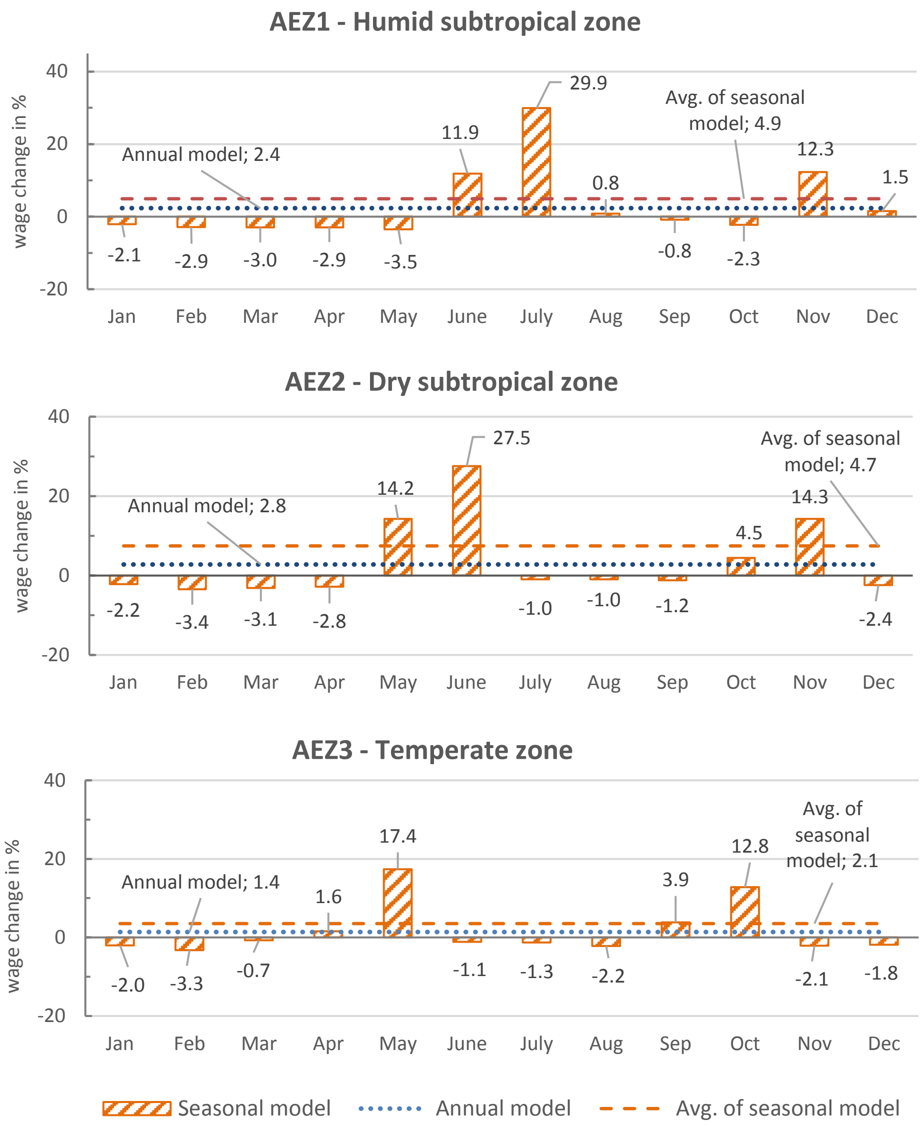


Figure 3.6.a Changes in farm wages

Source: Own model results.

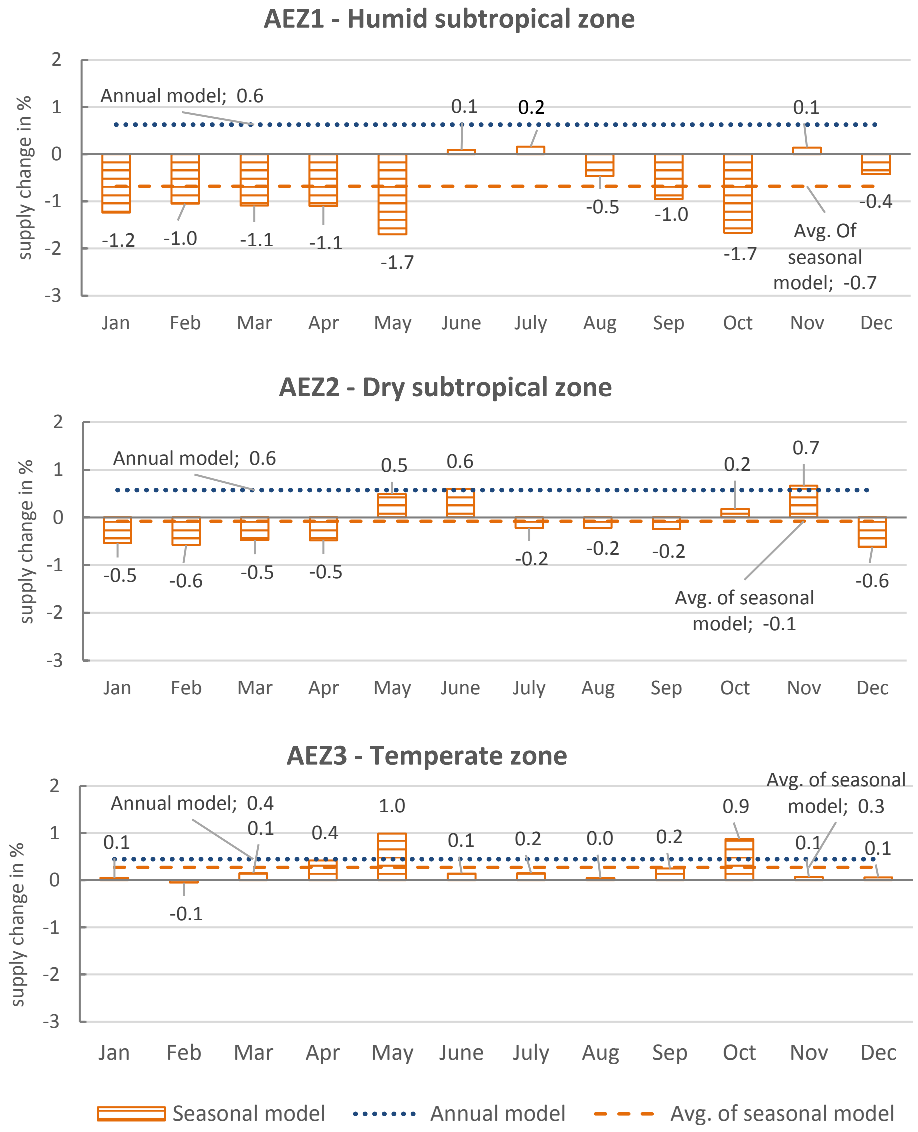


Figure 3.6.b Changes in farm labour supply

Source: Own model results

In the annual model, changes in farm wages correspond to the entire year and are lower than the annual average in the seasonal model (Figure 3.6a). However, changes in aggregate farm labour supply are higher in the annual model (Figure 3.6b). The difference between both models is explained by how the assumption of perfect intertemporal substitution affects the mechanisms of farm labour mobility and supply in the annual model. Firstly, it allows for a perfect mobility of farm labour across activities, independent of the periods in which labour is supplied or demanded. Secondly, the changes in the aggregate price of leisure for agricultural households is mostly determined by the annual change in farm wage as shown in Table 3.6.[25] Since agricultural household income increases at a substantially lower rate, there are strong incentives to increase labour, which, unlike in the seasonal model, is supplied to an annual pool of farm labour.

Table 3.6. Change in households' aggregate price of leisure and farm supply

Households		% change in the aggregate price of leisure		% change in households farm labour supply	
		Annual model	Seasonal model	Annual model	Seasonal model
AEZ1	Farm household	1.3	-0.5	0.6	-0.7
	Landless	0.8	-0.7	1.0	-0.5
AEZ2	Farm household	1.9	0.9	0.5	-0.1
	Landless	1.5	0.6	1.1	0.3
AEZ3	Farm household	0.8	0.5	0.4	0.2
	Landless	-0.3	-0.5	1.0	0.7
Skilled households		-1.6	-1.6	-0.2	-0.2
Unskilled households		1.3	-1.6	-0.2	-0.2
Other income households		0.8	-1.6	-0.2	-0.3

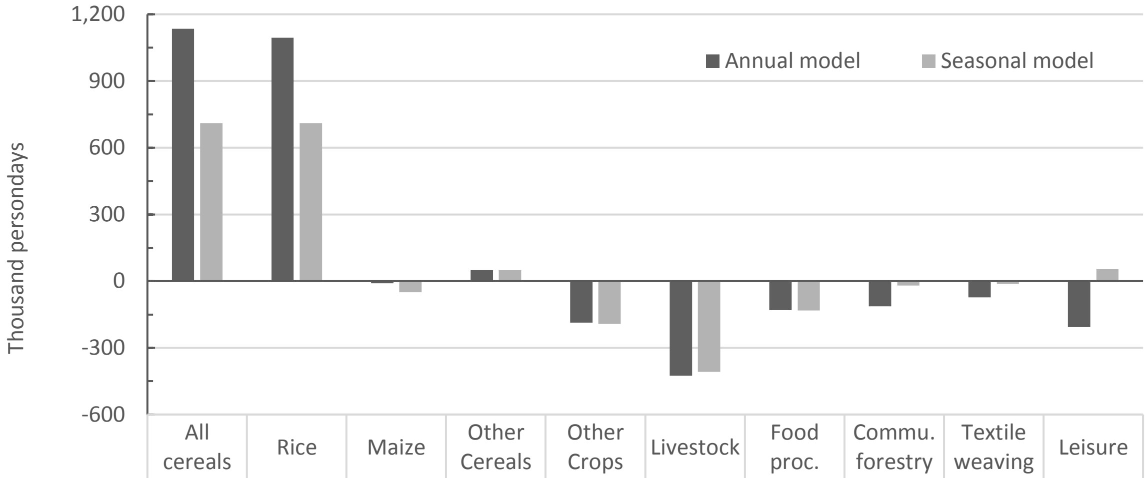
Understanding the effects of the labour-leisure trade-off is less straightforward in case of the seasonal model. The change in the aggregate price of leisure (Table 3.6) strongly differs from the average annual change in farm wages, because there are different weights of seasonal leisure (as shown in Figure 3.2). The composite prices of seasonal leisure either drop (for all agricultural households in AEZ1 and for the landless in AEZ3) or increase between 0.5% and 0.9% (Table 3.6), even though the average annual farm wages increase at much higher rates. In periods of labour shortages, households face scarcity of seasonal leisure, since most of their time is already absorbed in activities within the production boundary. Conversely, in lean months a disproportionately high amount of leisure time is available to households. The high

[25] There is a slight discrepancy, because agricultural households' labour endowment includes small shares of non-seasonal labour.

share of leisure from lean months is reflected by the high share parameters in the CES aggregation of leisure. With a low degree of intertemporal substitution of leisure, households can substitute the consumption of leisure in periods with strong increases in wages by consuming more leisure in periods of declining seasonal wages, which is precisely what we observe in the results presented in Figure 3.6b.

3.6.2.4 Reallocation of Farm Labour

The bias in model results becomes particularly obvious when investigating the differences in allocation of farm labour across activities. The perfect mobility across activities allows for a substantial reallocation of labour from counter-cyclical activities like forestry and textile production to cereal production (Figure 3.7). While similar in absolute terms, flows of labour from livestock to cereal activities play a much more important role in the seasonal model, accounting for 45% of labour flows compared to 37% in the annual model. Yet, most striking is the difference of labour supply from leisure. In consistence with Sen's observation, the annual model leads to an effective increase of labour endowment. Assuming perfect intertemporal substitution allows for an increase in labour units supplied in peak periods by reducing leisure in slack periods. This unrealistic effect accounts for 18% of the reallocated labour in the annual model. In contrast, assuming heterogeneity of labour over time, there is hardly any additional labour supplied during peak periods, but increases in leisure consumption lead to a slight positive absorption of total reallocated labour (6%) in the seasonal model. In sum, the above factors explain the much higher reallocation of labour in the annual model, 3.0% of farm labour flows to cereal activities, which is only 1.9% in the seasonal model.



	All cereals	Rice	Maize	Other Cereals	Other Crops	Livestock	Food proc.	Commu. forestry	Textile weaving	Leisure
Annual model	1,135	1,095	-10	50	-186	-425	-130	-113	-73	-207
Seasonal model	711	711	-49	49	-192	-409	-131	-19	-12	53

Figure 3.7. Net reallocation of farm labour

Note: Measured in thousand person-days across seasonal activities and leisure aggregated at the national level)

3.6.2.5 Activity-specific Price of Composite Farm Labour

In the seasonal model, each seasonal activity has a specific pattern of labour demand. Since the changes in seasonal wages differ it follows that the price changes of composite farm labour are activity specific. Composite price changes of agricultural labour are highest for activities that largely depend on labour supplied during bottleneck periods such as for rice and maize in AEZ1 (Figure 3.8). Activities that predominantly demand labour during periods counter-cyclically to the cultivation of paddy and maize (i.e. early cultivation of vegetables, community forestry and textile weaving) even benefit from a falling composite price of seasonal labour. Consequently, in the seasonal model the decline of aggregate output of forest products (0.1%) and textiles (0.0%) is substantially lower compared to the decline in the annual model (-0.7% and -1.2%, respectively).

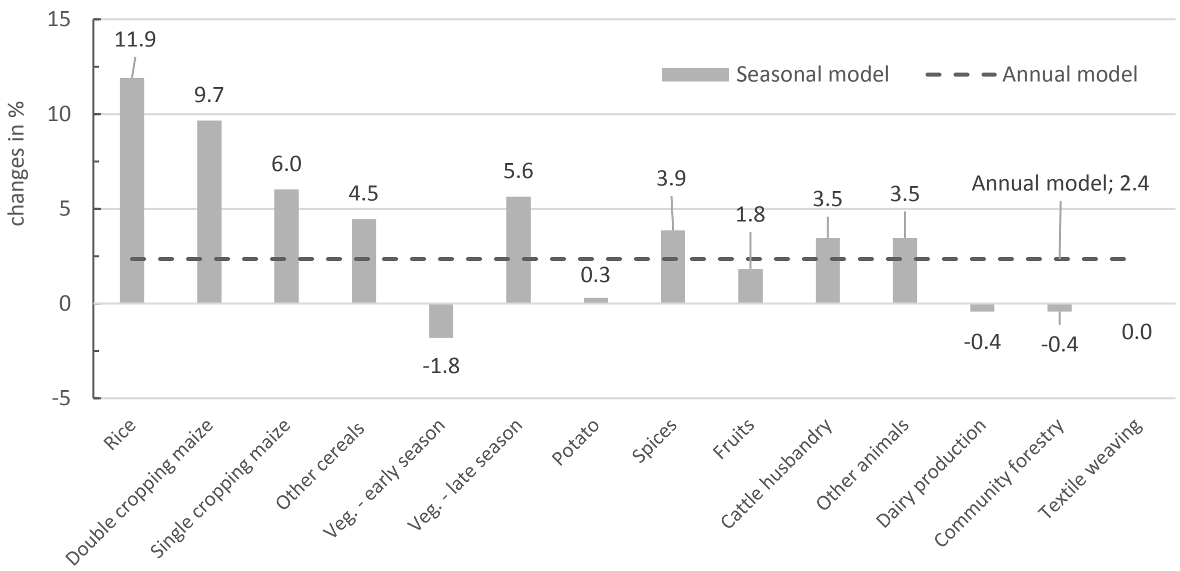


Figure 3.8. Changes in the activity specific price of composite seasonal labour within AEZ1

3.6.2.6 Factor Market

The secondary and tertiary sectors face a reduction in domestic demand, due to a loss of purchasing power. Furthermore, the appreciation in the exchange rate additionally reduces the competitiveness of export-oriented sectors. Consequently, the factor prices of non-farm labour and incorporated capital decline (Table 3.7).

Conversely, factor prices for farm labour, irrigated and rainfed land, as well as agricultural capital increase due to the shock. Land prices increase strongly and in case of irrigated land much more than labour. Interestingly, since the activity specific wage for rice is much higher in the seasonal model than in the annual model (see previous section 3.6.2.5), there is also a lower substitution of land through labour taking place in the seasonal model. Land expansion via the asymptotic land supply curve is dependent on the change in real land prices (deflated by the PPI), explaining the increases in rainfed land supply despite low or slightly negative changes. Due to lower availability of labour for cereal production, total arable land increases only by 2.5% in the seasonal model, compared to 3.1% in the annual model. The strong rise in farm wages and land prices also drive up the returns for agricultural capital used for mechanization, such as machinery and draught animals for land preparation. This means, that the benefits of mechanization would be underestimated if seasonality is neglected in economy-wide analyses.

Table 3.7. Changes in factor prices and factor supply

Factor accounts	Change in factor price (%)		Changes in factor supply (%)	
	Annual	Seasonal	Annual	Seasonal
Skilled labour	-1.6	-1.6	-0.2	-0.2
Unskilled labour	-1.5	-1.6	-0.3	-0.3
Farm labour – national*	2.1	3.8	0.5	-0.1
Farm labour - AEZ1	2.4	4.9	0.6	-0.7
Farm labour - AEZ2	2.8	4.7	0.6	-0.1
Farm labour - AEZ3	1.4	2.1	0.4	0.3
Arable land national	5.4	3.4	3.1	2.5
Rainfed land - national	-0.9	-1.1	0.2	0.0
Rainfed land - AEZ1	-1.0	-1.8	0.1	-0.5
Rainfed land - AEZ2	-1.2	-0.6	-0.1	0.4
Rainfed land - AEZ3	-0.5	-0.9	0.5	0.2
Irrigated land - national	25.8	17.8	12.0	9.7
Irrigated land - AEZ1	23.1	14.8	13.0	9.7
Irrigated land - AEZ2	26.5	17.0	10.8	8.8
Irrigated land - AEZ3	28.2	22.9	12.3	11.2
Orchard land – national	-2.2	-2.2	-0.9	-0.9
Pasture land - national	-5.7	-4.9		
Forest land - national	-1.9	-1.4	-0.7	-0.2
Livestock - national	6.2	2.8	0.0	0.0
Unincorporated capital	12.1	7.8	0.0	0.0
Incorporated capital	-1.6	-1.6	0.0	0.0

* Changes in aggregate farm labour computed based on farm labour used within productive boundary, excluding leisure

3.6.3 Sensitivity Analysis

Economy-wide models, such as CGE models, sometimes face criticism regarding the econometric foundation of their model parameters and functional forms. For most parameters in our model we have either used empirically estimated parameters reported in the literature or own estimates in case of the income elasticities used for the Linear Expenditure System. For some of the model parameters, which may have a large impact on the difference between the two model setups, no estimates were available and we used own assumptions instead. To test the robustness of our analysis, we therefore conduct ceteris paribus sensitivity analyses with the following variants in model setups:

± *50% Sigmasea*: Varying the seasonal labour substitution elasticity, $\sigma_{a,t}$,by ± 50%[26]

± *50% Intertemp*: Varying the intertemporal substitution (IES) of seasonal leisure by ± 50%

± *50% Inclab*: Varying the income elasticities of labour supply, $\varepsilon_{L,Y}$, by ± 50%

Fixed ER: Macro-closure with fixed instead of flexible exchange rate. The external balance remains fixed and the import duties adjust multiplicatively.

Savings Driven: Macro-closure using a savings driven instead of investment driven closure.

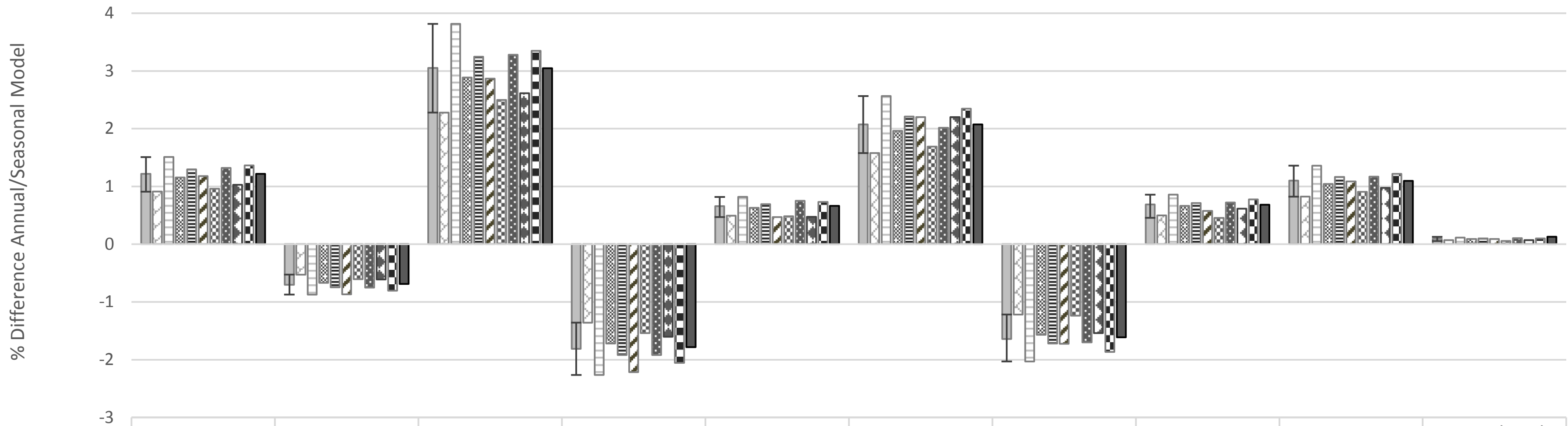
± *50% Landela*: Varying the land supply elasticity ε_n by ± 50%

The results of the sensitivity analysis are presented for the main indicators in Figure 3.9. The differences in those indicators between the seasonal and annual model (expressed in absolute percentage points) is only changing moderately upon large changes in central model parameters or closures. The error bars on the reference model results reflect the total span of deviations across all variants.

The largest deviations of differences are observed for changes in the seasonal labour substitution elasticity. Rigid activities in the reference setup are demanding seasonal labour according to Leontief technology (i.e., fixed shares). If this is changed to an inelastic substitution elasticity equal to 0.1, cropping activities can substitute labour originally required in peak periods with labour from other periods in which wages either increase at lower rates or even decline. In reality, some substitution is possible among field operations. For example, farmers could reduce the labour demand for transplanting paddy (“sloppier transplanting”), but instead dedicate more time to harvesting, which would compensate their earlier sloppiness. , for which we had to rely on plausible ad-hoc specifications.

The importance of the seasonal labour substitution elasticity for differences in model results is quite obvious, as it concerns the most distinct feature of both model setups. Assuming a perfect substitution elasticity would make the models undistinguishable, which would imply perfect homogeneity of labour units on the labour demand side. Research on estimating the substitution elasticity of seasonal labour is needed, but probably a daunting task, given the high data requirements. Our sensitivity analysis shows that even if changing this parameter by ±50%, there are no drastic changes and the results remain in line with our main findings.

[26] Formerly rigid activities (i.e., with a seasonal labour substitution elasticity of zero) remain rigid when decreasing the elasticity and are set equal 0.1 when increasing the elasticity.



	Crop Output	Crop Prices	Cereal Output	Cereal Prices	Arable land supply	Land prices	Agricultural wages	Farm labour supply	Reallocated labour	Agricultural household welfare
Reference	1.22	-0.70	3.05	-1.81	0.66	2.08	-1.64	0.69	1.10	0.09
Sigmasea +50%	0.91	(0.53)	2.28	(1.36)	0.49	1.58	(1.22)	0.50	0.82	0.07
Sigmasea -50%	1.51	(0.87)	3.82	(2.27)	0.82	2.57	(2.03)	0.86	1.36	0.11
Intertemp +50%	1.15	(0.67)	2.89	(1.72)	0.63	1.96	(1.57)	0.66	1.04	0.09
Intertemp -50%	1.30	(0.75)	3.25	(1.92)	0.69	2.21	(1.72)	0.71	1.17	0.10
Inclab +50%	1.18	(0.87)	2.87	(2.22)	0.47	2.20	(1.72)	0.58	1.08	0.09
Inclab -50%	0.96	(0.61)	2.50	(1.54)	0.48	1.69	(1.24)	0.46	0.91	0.05
Landela +50%	1.32	-0.75	3.28	-1.92	0.75	2.02	-1.70	0.72	1.17	0.10
Landela -50%	1.03	-0.61	2.61	-1.60	0.48	2.20	-1.54	0.61	0.97	0.07
Fixed ER	1.37	-0.81	3.35	-2.06	0.73	2.35	-1.87	0.78	1.22	0.10
Savings Driven	1.22	-0.69	3.05	-1.78	0.66	2.07	-1.61	0.69	1.10	0.13

Figure 3.9. Sensitivity analysis of changes in differences of main model results

Note: Error-bars show the maximum range of deviations across all sensitivity scenarios.

3.7 Discussion

Given its empirical relevance, we briefly discuss the implications of the *SimIncrease* scenario on Bhutan's economy. In the second part, we discuss the relevance of seasonal labour markets for economy-wide models and highlight limitations and avenues for further development of the method.

3.7.1 Impacts on Bhutan's Economy

The long-standing and fruitful Bhutan-India relationship make it unlikely that Bhutan could face an export ban on cereals imposed by India, but concerns about it have increased recently. During the latest border show-down between China and India on Bhutanese territory, the Bhutanese administration's crisis management has displayed features of a gradual emancipation process from its traditional role of being a mere bystander sandwiched by the two geopolitical giants (Mitra and Thaliyakkattil, 2018). However, Bhutan's foreign policy is closely watched by India. Just shortly before the second free elections in July 2013, India provoked by Bhutan's diplomatic advances towards China cut subsidies on kerosene cooking fuels exported to Bhutan, which caused turmoil among consumers and allegedly contributed to the very unexpected victory of the opposition party (Taneija, 2013).

Our model results suggest that a hypothetical export ban on cereals would only have modest impacts on Bhutan's economy. The assessment of the severity of the shock certainly hinges particularly on the assumption of the adjustment horizon and the land supply elasticity. Taking a short-term horizon perspective, reallocation of land would not be perfect, as assumed in our approach, but sluggish, leading to a generally lower increase in cereal supply and higher cereal prices. Conducting the analysis with a lower land supply elasticity further reduces the ability to increase domestic cereal production, leading to higher welfare losses, as modelled in our reference case. Yet, the vast amount of fallow land has also been abandoned in the past due to the declining ability of Bhutanese farmer's to compete with cereal imports. It is thus reasonable that a strong exogenous increase in cereal prices would revive farmers' interest in cultivating cereals, as suggested by the model results. The impacts are also less severe as one may have expected, due to Bhutan's past strong growth in non-agricultural sectors, such that the share of agriculture in GDP is only about 10% and the fact that cereal imports only account for 2.5% of total imports.

The effects on household welfare and income are largely in line with findings of the literature on food-price impacts (e.g. Arndt *et al.*, 2008a). Average welfare would decline by about 0.5% with most of the welfare losses born by urban households, which are net-food consumers but in the context of Bhutan can be considered the least vulnerable. In contrast, agricultural households largely benefit due to increasing income from farm labour and land. The impacts on food security are arguably higher with average food consumption declining between 2.5% and 2.8% (in the annual and seasonal model, respectively), but still modest compared to the high increase in cereal prices. An important limitation of our analysis is that we cannot assess the magnitude of impacts on the most vulnerable groups, i.e. those that are already food insecure before the shock. This would require a more refined model, which can capture more of the heterogeneity of rural livelihoods in Bhutan.

3.7.2 Seasonality of Labour in Economy-Wide Models

3.7.2.1 Relevance of Findings

Our results show that not accounting for seasonality causes potentially relevant distortions of results in how rural labour markets are depicted in economy-wide models. A model with only annual labour markets effectively increases the endowment of usable labour during periods characterized by seasonal labour shortages. The assumption of perfect intertemporal substitution affecting the mechanisms of labour mobility and supply thus results in biased results of supply responses and welfare changes. Simulating a range of scenarios with positive and negative cereal import prices, we find evidence for a systematic nature of this bias. Economy-wide models have become widely applied frameworks, particularly in the context of low-income countries, where agriculture employs not only most of the labour force, but the majority of the extreme poor (Castañeda *et al.*, 2018). Hence, we consider our findings to be an important contribution, particularly since the depiction of labour markets is considered one of the weaknesses in CGE modelling (Dixon and Jorgenson, 2013).

The analysis was based on a database with a detailed representation of the Bhutanese agricultural sector. The results support the importance of adequate disaggregation when seasonality varies due to regional differences in agroclimate, farming systems or socio-economic characteristics. For example, the low-altitude zone in Bhutan (AEZ1) is characterized by particularly low cereal yields and labour intensive cultivation systems. This zone also has the most pronounced labour peak, which results in severe labour bottlenecks and a much lower supply flexibility compared to the other zones with less extreme seasonal patterns.

Arguably, seasonality of labour plays a less relevant role for the analysis of symmetric shocks. Simulating scenarios with a ± 10% exogenous change in the land productivity, the flow of farm labour between activities is rather minimal (0.2% and 0.1% in the annual and seasonal model, respectively), because all crop activities are affected similarly. This does not contradict our findings, which have shown that seasonality of labour matters mostly in case of structural change leading to substantial movements of labour across sectors and across the production and non-production (leisure and reproduction) boundary. Structural changes are particularly relevant for the assessment of trade-agreements, whether it concerns bilateral or global agreements such as the Doha Round, but they are also relevant in other contexts such as dynamic changes driven by economic processes within a region or country.

Depicting seasonality in economy-wide models increases the data demands for an adequate database development. However, there are many types of scenarios, which would benefit from an economy-wide analysis with seasonal labour markets. Public employment schemes are for instance designed to counter seasonal underemployment, but can also have more complex effects once seasonality of labour is comprehensively accounted for (Devereux, 2016). Large-scale land acquisitions and foreign direct investments can result in either an amplification or dampening of seasonality (Kleemann and Thiele, 2015). A large-scale contract farming scheme for hazelnut plantations is currently being implemented in Bhutan covering almost 10% of farmland, which potentially could increase seasonal labour shortages during the hazelnut harvest time. Also, technological disruptions can alter the labour intensity of seasonal activities, such as Bhutan’s 100% organic policy, which would increase seasonal labour demand for weeding and manuring operations (Feuerbacher *et al.*, 2018).

3.7.2.2 Limitations and Avenues for Further Research

The sensitivity analyses show that our findings are highly robust against variation in central model parameters. However, our model is limited in that it neither allows to specifically account for substitution possibilities of labour inputs between operations (yet also the data is not available to determine the substitution degree) nor does it allow to account for sequential decision making. Transplanting of rice, for example, to some degree could also done at an earlier time, which would trigger a consequent shift in timing of the field operations thereafter. To some degree this flexibility is reflected in our model by reflecting seasons in monthly intervals. More sophisticated models could be developed down this line, for instance in dynamic frameworks, which - however - would hinge on data availability.

Farm labour supplied by the elderly and children was not explicitly depicted in our model due to data limitations. According to field observations, the elderly are predominantly involved in less intensive work such as crop guarding. Child labour is officially banned in Bhutan, but children are engaged in simple activities such as cattle herding. Without reliable data, it is not possible to gauge how much labour these groups could supply, particularly during peak periods. However, we estimated the labour employed in agriculture using a bottom-up approach based on labour requirement per cultivated area. Hence, any labour supplied is reflected in the model. If these age groups could provide substantially more labour, than the differences between both model setups would be even higher, as the annual model could freely allocate the additional labour units of children and the elderly throughout the year.

Gender plays an important role for seasonal labour due to the traditional division of work between women and men. Wages of women in our analysis are likely to have increased most, as they are predominantly for transplanting of rice. Also, women's traditionally higher involvement in reproduction activities would feed back to their labour supply and migration decision. The gender dimension and the role of seasonal migration has not been considered in our approach. In the former due to data limitations and in the latter, due to the specific country context. Future research may also address other phenomena of seasonality, such as seasonal incidences of hunger and diseases, and specifically those that affect gendered time-use, such as the seasonality of births.

3.8 Conclusions

We develop the first economy-wide database and model incorporating seasonal labour markets and find that it has highly relevant implications for the agricultural sector's adaptability towards exogenous shocks. Neglecting seasonality causes biased results regarding the simulated supply responses and welfare changes. Our results provide evidence that these biases are systematic in the event of asymmetric shocks provoking structural changes, such as the simulated changes in cereal import prices, but also in the event of many other possible scenarios. The study contributes to the sparse literature of depicting labour markets in economy-wide model frameworks and represents a novelty by addressing the role of seasonal labour. Arguably, the seasonality of labour markets has so far been neglected in economy-wide models due to data paucity. But our findings suggest that this data is crucial to improve the depiction of labour mobility and supply within the rural economy and to prevent unrealistic model outcomes. While this study relied on data from Bhutan, a unique country with respect to many characteristics, the findings are nevertheless transferable to many similar peasant economies.

3.9 Appendix

Appendix 3A Economic Structure of Bhutan

Table 3.8. Economic structure of Bhutan

SAM sectors	Sector or group name	GDP share (%)	Production share (%)	Export share (%)	Export intensity	Import share (%)	Import intensity
1-14	Agriculture	9.4	8.2	4.0	9.4	7.5	29.2
1-7	Crops	6.9	4.2	3.9	16.4	1.6	15.0
1-3	Cereals	2.8	1.7	0.0	0.0	0.4	8.3
1	Paddy	1.5	0.9	-	-	-	-
2	Maize	0.9	0.6	-	-	0.0	3.1
3	Other cereals	0.3	0.2	0.0	0.3	0.3	41.4
8-10	Livestock	2.0	2.3	0.0	0.0	3.3	37.9
11-14	Post-harvest	0.4	1.6	0.1	1.5	2.6	43.1
11	Rice, milled	0.2	1.0	0.0	0.4	2.0	43.5
15-16	Forestry	1.6	1.0	0.3	5.7	0.2	7.8
16	Community Forestry	1.2	0.7	0.2	5.7	0.2	7.8
17	Mining	2.0	1.6	5.6	60.7	2.5	58.6
18-23	Manufacturing	8.4	16.7	44.4	44.1	73.5	72.8
18-20	Food processing	1.0	1.7	1.4	11.3	4.7	48.0
22	Textiles - by farm households	1.0	1.0	0.0	1.2	1.0	37.3
23	Textile - by others	0.6	0.6	0.0	1.2	0.6	37.3
24	Electricity	12.5	8.6	26.0	65.5	0.0	0.3
25	Construction	23.7	27.7	-	-	4.5	5.9
26-32	Services	42.5	36.2	19.6	11.6	11.8	12.3

Source: 2012 Social Accounting Matrix for Bhutan.

Appendix 3B Compilation of a Seasonal Accounting Matrix

The seasonal Social Accounting Matrix (SAM) is based on a national 2012 SAM for Bhutan that was developed by Arndt Feuerbacher, C. Dukpa et al. (2017). The 2012 SAM was disaggregated into the three agroecological zones (AEZs) using the agricultural sample survey datasets from 2012 to 2014 (MoAF, 2014) and altitude data of the 204 gewog centres (i.e., the centre of sub-districts) (NLC, 2014). The disaggregation of farm labour according to seasonal labour accounts is based on the development of a labour calendar containing information on how much person-days an activity absorbs within each month of a year. Due to the extreme differences in altitude that are prevalent throughout Bhutan, climates and crop cycles differ substantially across AEZs. Instead of developing a national labour calendar representative for the whole of Bhutan, we developed a labour calendar for each of the three AEZs and thus preserve important characteristics of the seasonality of regional labour markets.

Data sources

Unfortunately, there is no data available on households' time use across the whole year in Bhutan. The Gross National Happiness (GNH) survey is the only data source in Bhutan that has collected time-use data from a large sample of households (sample size of 7,153 respondents) (Centre for Bhutan Studies & GNH Research, 2015). However, their survey relies on a 24-hour recall period and respondents were only interviewed within a part of the year (January to May 2015), which has left out most of the cropping season. Hence, the data would not allow to derive seasonal time-use (and thus labour) patterns for the whole year.

Instead, we developed seasonal labour calendars relying on two categories of data: (1) Data on labour requirement of seasonal activities published in either specific cost of production (CoP) studies or as part of other research output. This data for instance reports how much labour is needed in person-days per hectare field operations such as land preparation, weeding or harvesting of rice. (2) Data on the calendar of seasonal activities, either published e.g. specifically as cropping calendars or as part of other research output. Table 3.9 lists the various data sources used to estimate the labour requirement of seasonal activities within each AEZ.

Table 3.9. Underlying data sources to estimate labour requirement of seasonal activities

Author(s) and Year	Title	Purpose
C. Dukpa & Arndt Feuerbacher, 2018	Participatory compilation of seasonal calendars in ten (out of twenty) Bhutanese districts	Labour intensity of household activities
N. Dorji, Flinn, & Maranan, 1990	Rice Production in the Wangdiphodrang-Punakha Valley of Bhutan	Cost of production (CoP) on rice
Arndt Feuerbacher, C. Dukpa et al., 2017	A 2012 Social Accounting Matrix (SAM) for Bhutan with a detailed representation of the agricultural sector	Labour requirement estimation for non-cropping activities
Ghimiray et al., 2008	Rice in Bhutan – A source book	CoP rice
Mann & Hobbs, 1988	Wheat and wheat development in Bhutan	CoP wheat
Mehta, Rabgyal, & Acharya, 2015a	Commodity Chain Analysis of Ginger in Bhutan	CoP ginger
Mehta, Rabgyal, & Acharya, 2015b	Commodity Chain Analysis of Large Cardamom in Bhutan	CoP cardamom
MoAF, 2006	Baseline Survey	CoP vegetables and fruits
MoAF, 2009	Agricultural census 2008	Data on machinery and animal manure use on farm level
MoAF, 2012a	Cost of rice production in different agro-ecological zones	CoP rice
MoAF, 2013a	Agricultural sample survey 2012	Crop level data on pesticide and chemical fertilizer use
MoAF, 2013e	Cost of production studies on vegetables	CoP vegetables
MoAF, 2014	Agricultural sample survey 2013	Labour-intensity of crop-guarding per crop
Phuntsho, S., Schmidt, K., Kuyakanon, R.S. and Temphel, K.J., 2011	Community Forestry in Bhutan: Putting People at the Heart of Poverty Reduction.	Labour-intensity of forestry activities
RC Khangma, 2003	RNR Technical recommendations	CoP wheat and maize
Walter Roder et al., 2008	The Potato in Bhutan	CoP potato
Röhrig, 2016	Adoption of Sustainable Land Management technologies among smallholder farmers in Eastern Bhutan	CoP of various crops, labour intensity for manual manuring
Shrestha, Katwal Bdr., & Ghalley BB., 2006	Adoption and Impact Assessment of Improved Maize Technologies in Bhutan	CoP maize
Tashi & K. Wangchuk, 2016	Organic vs. conventional rice production: comparative assessment under farmers' condition in Bhutan	CoP rice
D. Wangchuk & Katwal Bdr., 2014	Promoting hybrid maize as a spring crop under rice-fallow systems: success and lessons learnt	CoP maize
C. Zangmo, personal communication, November 7, 2016	Labour input, cropping calendar and agricultural practices in apple cultivation	CoP apple
Yeshey, 2012	Economics of mechanizing rice cultivation at RNR-RDC Bajo	CoP rice

Secondary data sources used to estimate the calendar of activities within each AEZ listed in Table 3.10 below.

Table 3.10. Underlying data on calendar of activities

Authors	Title	Purpose
T. Dochen, personal communication, July 28, 2016	Potato cropping calendar	Cropping calendar for potato across the three AEZs
M. Ghimiray, personal communication, July 26, 2016	Rice cropping calendar	Cropping calendar for rice across the three AEZs
T. Gurung, 2011	Comparative analysis of the companion model use to facilitate the adaptive management of irrigation in Bhutan	Cropping patterns of cereals and vegetables in seven Bhutanese villages
Katwal Bdr., 2016	Cropping calendar for cereals across various AEZs	Cropping calendar for cereals including crop-rotation variants
W. Lakey, personal communication, March 13, 2015	Cropping calendar and agricultural practices of citrus production in Bhutan	Cropping patterns of citrus production
L. Phuntsho, personal communication, August 3, 2016	Wheat cropping calendar	Cropping calendar for wheat across the three AEZs
RC Wengkhar, 2015	Cropping calendar for fruits and vegetables	Cropping calendar for fruits and vegetables across various AEZs
Sariyev, Gurung, Feuerbacher, & Loos, 2017	Study on intra-household decision-making and food security	Cropping calendar of various and time use of non-cropping activities

In addition, primary data on the calendar of activities was collected across nine districts of Bhutan by the first author of this article and Chencho Dukpa in order to cross-check and if necessary to complement the available secondary data (C. Dukpa & Arndt Feuerbacher, 2018). Within a participatory setting, 23 farm households across nine districts of Bhutan and at different altitude levels (Figure 3.10) were asked to compile their own seasonal calendar of farm activities.

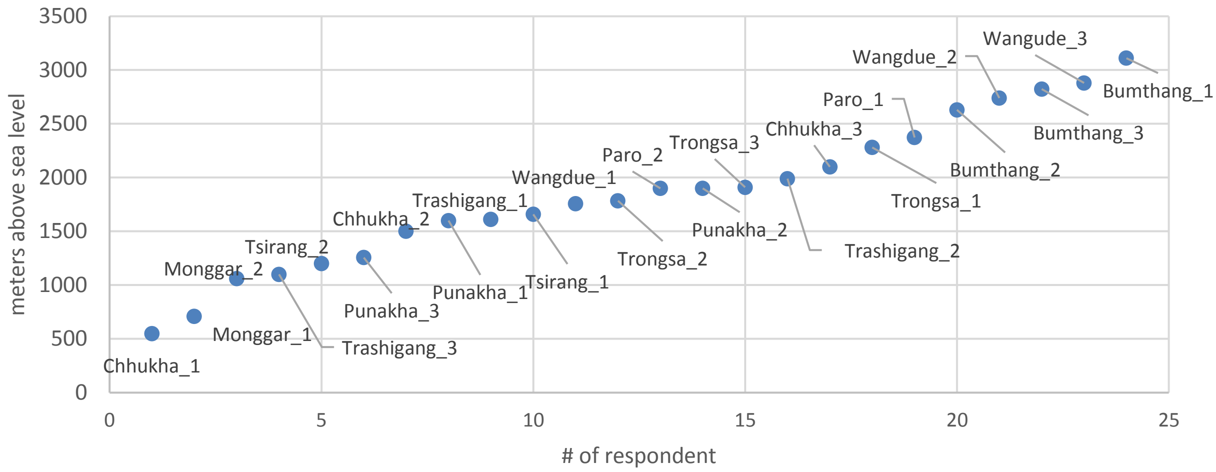


Figure 3.10. Location and altitude of respondents included in seasonal calendar survey

At the beginning of the interview, a short set of questions about the sex and age of household members, land and livestock ownership, etc. was asked. Afterwards, households described their cropping activities. This marked the beginning of the seasonal calendar exercise, as the interviewer asked for more details about the various field operations involved in their cropping activities. Households described their monthly cropping activities with reference to the Bhutanese lunar calendar (in which March represents the first month) by placing a card on an empty map on the household's floor. Either the cards were used by the households to draw the activity on them or they were already pre-printed with a symbol of the activity (e.g., ploughing of land for paddy cultivation). After describing the cropping activities, the procedure was repeated for all non-cropping activities (e.g. cooking and caring for household members, leisure time, textile weaving, firewood collection, fodder collection, off-farm works).

Once the household has described all relevant activities, the interviewer took a first picture of the map. Afterwards, the respondents received a jar of white beans, of which they placed beans on cards in order to visualize how much time they spent per activity. Again a picture was taken. In the final step, households were asked to replace the white beans by either yellow or brown beans to show what approximate share of the time was provided by female (yellow maize) or male (brown beans) household members to perform a specific activity (Figure 3.11).

Figure 3.11. Respondents compiling their seasonal calendar of activities

Note: Photo in the top shows respondents from Radhi, Trashigang in Eastern Bhutan (~1,100 m altitude). The bottom photo shows respondents from Rukubji, Wangdue in Central Bhutan (~2,700 m altitude).
Photo credit: Arndt Feuerbacher

Households were told that the sum of yellow and brown beans should not exceed the previous number of white beans. However, as the beans should only serve as a rough indication of the absolute workload per activity and share between female and male household members, a small deviation was allowed for. After the respondents replaced all white beans accordingly, they were asked to inspect their personal seasonal calendar for any potential inconsistencies. Once the household did the final change, the interviewer took a last picture of the seasonal calendar marking the end of the seasonal calendar survey.

Compilation procedure

Seasonal activities of farm households can be distinguished into activities involving various operations within a rigid time pattern (i.e., cropping activities) and activities with a lower variety of operations involved and high flexibility of timing (i.e. processing of cereals, forestry activities, textile weaving). Given this clear distinction, we decided to first develop a seasonal labour calendar for cropping activities which involved information on various field operations and which had inevitable ramifications on the timing of other, non-cropping activities. Afterwards, the seasonal labour calendar for non-cropping activities was developed. The estimation procedure for the labour calendar for cropping activities is illustrated in Figure 3.12 below. Farm labour was disaggregated into seasonal labour according to monthly intervals, such that each period t represents one month.

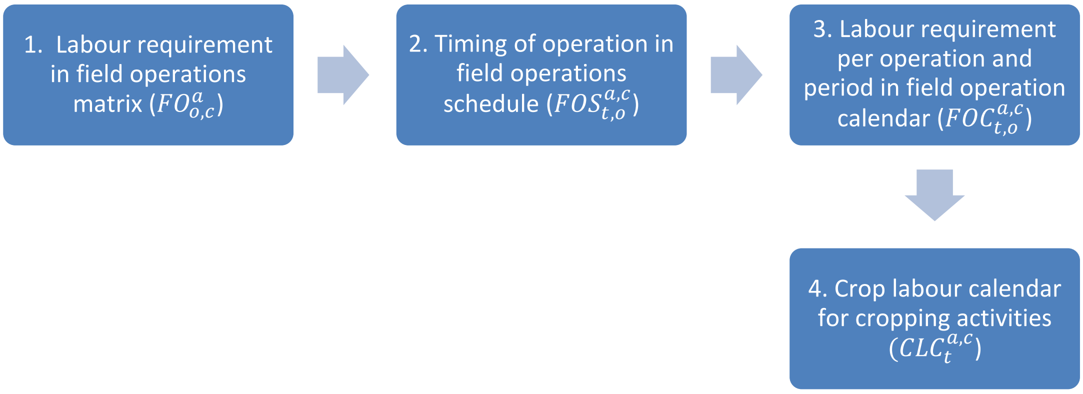


Figure 3.12. Procedure to estimate the labour calendar for cropping activities

Source: Author's own compilation.

Data on field operations were available for 24 different crops, which together account for 94.2% of total cultivated area in 2012 (MoAF, 2013a). In case information for a specific crop (e.g. turnip) was missing, it was assumed that the seasonal labour requirement is similar to a closely related crop (e.g. radish) for which data is available. Some crops are grown in summer and winter (e.g. maize and many pulses and vegetables), which is particularly the case in the humid and dry subtropical zones below 2,400 masl. In such cases, a crop labour calendar was compiled separately for each cultivation season. An overview of all crops, their respective cultivated areas per agroecological zone and the final mapping to the commodity structure in the seasonal SAM is provided in the Table 3.11.

Table 3.11. Cultivated area in hectares and relative distribution across AEZs of crops (set c)

SAM commodity croup	Crop name	AEZ1	AEZ2	AEZ3	Total
Paddy	Paddy	5,632	6,876	4,170	16,678
		33.8%	41.2%	25.0%	100.0%
Maize - first season	Maize - First Season	3,983	2,593	5,193	11,768
		33.8%	22.0%	44.1%	100.0%
Maize - second season	Maize - Second Season	5,246	6,851	-	12,098
		43.4%	56.6%	0.0%	100.0%
Other cereals and oilseeds	Wheat	329	566	1,198	2,092
		15.7%	27.1%	57.2%	100.0%
	Barley	174	539	512	1,225
		14.2%	44.0%	41.8%	100.0%
	Buckwheat	672	966	736	2,373
		28.3%	40.7%	31.0%	100.0%
	Mustard	299	439	394	1,132
		26.4%	38.8%	34.8%	100.0%
	Millet	1,341	752	140	2,233
		60.0%	33.7%	6.3%	100.0%
Vegetables - first season	Beans - First season	350	1,016	418	1,785
		19.6%	56.9%	23.4%	100.0%
	Eggplant	42	45	28	115
		36.3%	39.5%	24.2%	100.0%
	Broccoli	39	98	39	176
		22.2%	55.6%	22.2%	100.0%
	Onion/Garlic	112	309	225	646
		17.3%	47.9%	34.8%	100.0%
	Chili - First season	247	709	850	1,805
		13.7%	39.2%	47.1%	100.0%
Vegetables – second season	Beans- Second Season	148	-	-	148
		100.0%	0.0%	0.0%	100.0%
	Peas	27	88	155	271
		10.1%	32.5%	57.4%	100.0%
	Cabbage	163	213	355	730
		22.3%	29.1%	48.6%	100.0%
	Radish	280	350	604	1,234
		22.7%	28.4%	48.9%	100.0%
	Cauliflower	70	107	72	249
		28.3%	42.8%	28.9%	100.0%
	Chili - Second season	71	-	-	71
		100.0%	0.0%	0.0%	100.0%
Potato - first season	Potato - First season	460	771	4,411	5,642
		8.2%	13.7%	78.2%	100.0%
Potato - second season	Potato - Second season	-	369	-	369
		0.0%	100.0%	0.0%	100.0%
Spices	Ginger	601	112	1	715
		84.2%	15.7%	0.2%	100.0%
	Cardamon	806	568	465	1,840
		43.8%	30.9%	25.3%	100.0%
Fruits	Areca nut	1,412	1	-	1,413
		99.9%	0.1%	0.0%	100.0%
	Guava	35	43	-	78
		44.5%	55.5%	0.0%	100.0%
	Plum	-	-	16	16
		0.0%	0.0%	100.0%	100.0%
	Orange	2,174	1,091	-	3,265
		66.6%	33.4%	0.0%	100.0%
	Apple	-	-	695	695
		0.0%	0.0%	100.0%	100.0%
All crops of set c		61,603	63,679	51,691	176,973
		34.8%	36.0%	29.2%	100.0%
Total area cultivated in hectares		64,741	67,768	55,442	187,952
% share included in set c		95.2%	94.0%	93.2%	94.2%

The data sources on field operations were consolidated to a total of 13 field operations (see Table 3.12 for an overview), which are denoted by set *o* in the following. The field operation matrix $FO_o^{z,c}$ contains the total labour requirement in person-days per hectare for each agroecological zone (set *z*) and crop (set *c*). In the second step, using data on crop calendar recorded the field operations schedule, $FOS_{t,o}^{z,c}$, is compiled in which a binary code determines whether an operation is performed for a crop in period *t* or not.

Table 3.12. Overview of field operations

Field Operation	Description
Nursery	Nursery operations needed in paddy and vegetable cultivation
Mechanical land preparation	Mechanical land ploughing and puddling using powertiller or tractor
Draught power land preparation	Ploughing and puddling using bullock draught power
Manual land preparation	Manual ploughing and puddling
Sowing and planting	Sowing and planting of seeds or seedlings.
Organic fertilization	Organic fertilization using animal manure
Chemical fertilization	Chemical fertilizing
Other operations	Other operations including grass cutting, pruning and fence maintenance
Irrigation	Irrigation
Organic plant protection	Organic plant protection consisting of manual weeding and usage of organic pesticides
Chemical plant protection	Chemical plant protection
Crop guarding	Crop guarding
Harvesting	Harvesting including treshing and winnowing of paddy, dehusking of maize, transport of harvest to farmstead, packing and grading of fruits

In step 3, the crop-specific field operation calendar for a crop *c* in a zone *z*, $FOC_{t,o}^{a,z}$, is computed the following:

$$FOC_{t,o}^{z,c} = FOS_{t,o}^{z,c} * FO_o^{z,c} * \left[\sum_t FOS_{t,o}^{z,c} \right]^{-1} \tag{3.1}$$

Lastly, the crop-labour calendar, $CLC_t^{z,c}$, is determined by adding up the labour requirement within each time period across all eleven operations as described in equation (3.2):

$$CLC_t^{z,c} = \sum_o FOC_{t,p}^{z,c} \tag{3.2}$$

The crop-labour calendar is multiplied with the annual cultivated area per crop to arrive at total labour requirement per crop and period. This information is then aggregated to match the commodity account structure of the seasonal 2012 SAM and multiplied with the mean agricultural wage per AEZ. Data on seasonal wages is not available and wages are assumed to be constant across time periods instead. It is acknowledged that this limitation in data could potentially result in an underestimation of seasonal labour patterns in value terms, as during peak periods higher wages are to be expected while lower wages during lean periods.

While the above outlined approach allows for the systematic estimation of seasonal labour demanded by cropping activities, different approaches and rationales were applied for the remaining activities. Analysing the primary data from the seasonal calendars, it was found that livestock activities such as animal husbandry and dairy production activities have rather constant labour demand. Exceptions are times in which mother cows are calving and when farmers make hay, collect fodder and bedding materials from the forests or periods. Yet, most of these irregular and additional activities do not follow a constant pattern and also cancel out among farmers if aggregated at a higher level (e.g. periods of calving and availability of milk). Hence, we assumed a constant pattern of labour demand.

Forestry activities play an important role in rural areas in order to collect fuelwood, timber for construction purposes and non-wood forest products (NWFPs) such as mushrooms and Cordyceps (also called the caterpillar funghi, which is used in traditional Chinese medicine and sold at astronomically high prices). By field observations and accounts of most experts in Bhutan (Sears et al., 2017), forestry activities and particularly those connected to the extraction of timber, are predominantly performed in the winter months. This is confirmed by our primary seasonal calendar data for AEZ3, which shows that 92% of forestry activities take place between November and April. Collection of NWFPs largely take place in the monsoon months between May and September. In lower altitudes, predominantly in AEZ1, we find that households spend time on forestry activities a little bit more regularly. Due to the small sample size and the high likelihood of underrepresenting time spent on the collection of NWFPs, we assume that 30% and 20% of forestry activities in AEZ1 and AEZ2, respectively, is done between May and November, with the remainder done in the winter months. In AEZ3, we assume that forestry activities are 77% of the time performed in the months from November to April.

Our seasonal calendar survey resulted in an unclear picture as regards the timing of cereal milling. Some households report to do milling throughout the year, with a slight focus on the months following the harvest time. Others report to store paddy and to mill it only in times it is needed for own consumption or for selling it on nearby markets to finance inputs of the next cultivation. As we cannot identify a clear pattern, we decided instead to use a flat distribution of seasonal labour demand for the milling of cereals.

In months of low labour requirement, i.e. periods during winter and between planting and harvesting, farm households reported to do activities such as processing of cereals (e.g. preparation of puffed rice), brewing of traditional alcohol (Ara) and weaving of textiles. According to the seasonal calendar data that we collected from the households, these time periods are strongly dependent on the household's individual pattern of activities. Yet, what they had in common was that they all followed a counter-cyclical pattern, i.e. they rarely if never coincided with periods of peak labour demands (i.e. planting or harvesting months). We therefore estimate the relative monthly labour distribution of these activities assuming a counter-cyclical pattern as described in equation (3.3).

$$shrCA_t = \left(\max_{t'}\left(LC_{t'}\right) - LC_t\right) * \left[\left(12 * \max_{t'}\left(LC_{t'}\right)\right) - \sum_t LC_t\right]^{-1} \qquad (3.3)$$

Where $shrCA_t$ is an coefficient expressing the share of labour demand of counter-cyclical activities per period t such that $\sum_t shrCA_t = 1$; $\max_{t'}\left(LC_{t'}\right)$ is the maximum aggregated labour demand of the vector LC_t that contains the aggregated seasonal labour demand per period *t* of all seasonal activities except for the counter-cyclical activities.

Appendix 3C Estimation of Linear Expenditure System (LES)

The Linear Expenditure System (LES) is a commonly applied demand system to depict consumer theory within CGE models. The LES is based on the Stone-Geary utility function (Sadoulet & Alain de Janvry, 1995) presented in equation (3.4):

$$U = \prod_{i=1}^{n} (q_i - c_i)^{b_i} \tag{3.4}$$

With the conditions:

1.) $q_i - c_i > 0$; 2) $0 < b_i < 1$; 3) $\sum_i b_i = 1$

Where U denotes a household's utility, q_i is the consumption of goods in index i, c_i represents the "subsistence consumption" and b_i are the marginal budget shares. Following condition 1), the consumption level of each good is at least equal to c_i, which for this reason is also referred to as "committed quantities" or a household's minimum consumption of good i. The marginal budget shares have to be positive, which is one drawback of the LES as this condition consequently rules out inferior goods.

Maximizing the Stone-Geary utility function under the budget constrain, we obtain the LES demand system equation as reflected in the model in equation 3.5.

$$p_i * q_{i,h} = p_i * c_{i,h} + b_{i,h} * \left(Y_h - \sum_i p_i * c_{i,h} \right) \tag{3.5}$$

Where index h stands for the different representative household groups, p_i denotes the purchaser price of commodity i and Y_h is each household's available budget. The subsistence consumption of all goods in monetary terms is $\sum_i p_i * c_{i,h}$ and the difference between the household budget and total subsistence consumption $Y_h - \sum_i p_i * c_{i,h}$ is analogously referred to as the "supernumerary income" or discretionary income (Valin et al., 2014).

Calibration of the LES

A household's subsistence consumption of a good can be determined using the income elasticity, $\eta_{i,h}$, and the Frisch parameter, ω_h, which is also referred to as the "flexibility of money" (Sadoulet & Alain de Janvry, 1995).

$$c_{i,h} = q_{i,h} * \left(1 + \frac{\eta_{i,h}}{\omega_{i,h}} \right) \quad (3.6)$$

Data requirements for estimating a LES including the Frisch parameter are more restrictive, especially if only pseudo panel-data or cross-sectional data is available (Jussila, Tamminen, & Kinnunen Jouko, 2012). Both, Kuiper (2005) and Kleinwechter (2011) therefore use a simplified calibration procedure introduced by Keller (1980) wherein:

$$c_{i,h} = \left(1 - \eta_{i,h}\right) * q_{i,h} \quad (3.7)$$

This calibration procedure will be applied ex-post to the estimation of income elasticities, which is described further below.

The Engel equation, derived from the budget constraint, states in equation (3.8):

$$\sum_i p_i * \frac{\partial q_{i,h}}{\partial Y_h} = 1 \quad (3.8)$$

If extended by $\frac{y_h}{y_h}$ and $\frac{q_{i,h}}{q_{i,h}}$, we can substitute $\eta_{i,h}$ for $\frac{\partial q_{i,h} * Y_h}{\partial Y_h * q_{i,h}}$ and the budget share $\omega_{i,h}$ for $\frac{p_i * q_{i,h}}{y_h}$, which yields the restriction for the income elasticities in equation (3.9):

$$\sum_i w_{i,h} * \eta_{i,h} = 1 \quad (3.9)$$

From the above income elasticity restriction and the condition that all marginal budget shares have to sum to one (3), the following relationship between income elasticities, budget shares and marginal shares is derived:

If the LES is differentiated with respect to income, we can see that $\frac{\partial p_i * q_{i,h}}{\partial Y_h} = b_{i,h}$.

The marginal budget share thus determines the change in discretionary consumption as income changes (Sadoulet & Alain de Janvry, 1995). As the marginal budget share directly depends on the income elasticity, we can see that luxury goods ($\eta_{i,h} > 1$) depict increasing shares of total expenditure as income rises, while the opposite applies for necessities ($\eta_{i,h} < 1$)(Kuiper, 2005).

Beside the wide use of LES as the underlying demand system in CGE models it has important drawbacks. Despite the mentioned fact, that it does not allow to represent inferior goods, it furthermore implies that all goods are gross complements and exhibits a linear Engel curves. Particularly the latter characteristic contradicts empirical evidence, which is why LES should primarily be used for short-term analysis (Sadoulet & Alain de Janvry, 1995). More flexible demand systems have been developed such as the Almost Ideal Demand System (AIDS), for which various advancements were introduced such as the Quadratic Almost Ideal Demand System (QAIDS). The depiction of these systems within CGE models has however proved to be very challenging, causing problems with global regularity when solving the model (Bouët et al., 2014).

Estimation of the LES

Instead of estimating the LES for single commodities, we apply it to ten representative commodity groups to account for the system's previously mentioned drawbacks, particularly the inability to include inferior goods and the restriction that all goods are gross complements. We use cross-sectional household data from the Bhutan Living Standard Survey (BLSS) 2012 (NSB & ADB, 2012), which was also used to develop the 2012 SAM for Bhutan. The BLSS 2012 is a nationally representative household survey conducted between March and May 2012 and including about 8,900 households. The BLSS 2012 questionnaire includes a large section on food expenditure, in which households are asked to recall their consumption either over the last 7 or 30 days. A further section covers a comprehensive set of questions on non-food expenditure over a recall period of 12 months.

The budget shares $w_{i,h}$ for each of the previously identified representative household groups (RHGs) are presented in Table 3.13. To estimate the income elasticities $\eta_{i,h}$, the econometric model relies on a double-logarithmic specification as presented in equation (3.10).

$$\ln\left(p_i * q_{i,h}\right) = cons_h + \beta_{i,h} * \ln\left(Y_h\right) + \varepsilon_h \tag{3.10}$$

in which $cons_h$ is a constant, $\beta_{i,h}$ is the coefficient of interest and ε_h is the error term. The double logarithmic specification's advantage is that $\beta_{i,h}$ represents a constant income elasticity, which determines the percent change in expenditure given a one percent change in income. For each RHG the econometric model described in (3.10) is estimated using a system of seemingly unrelated regressions (SUR) (Zellner, 1962). The SUR estimation is constrained by the income restriction that was derived in (3.9). Finally, using the above described approach yields the income elasticities as reported in Table 3.14.

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Table 3.13. Household specific budget shares

Representative household type	Cereals	Processed Food	Vegetables	Animal Products	Fruits	Beverages and Spices	Energy	Other services	Basic Services	Other Goods
Urban skilled	6.0%	5.3%	5.7%	2.0%	5.0%	11.4%	19.0%	6.5%	22.1%	17.0%
Urban semi-skilled	7.7%	5.8%	7.0%	2.1%	6.2%	13.1%	17.4%	6.0%	18.7%	15.8%
Urban low-skilled	8.5%	5.9%	8.0%	2.2%	7.1%	14.1%	15.5%	5.7%	18.0%	14.8%
Urban unskilled	9.2%	5.5%	8.1%	2.2%	6.7%	14.3%	15.1%	5.2%	18.7%	15.0%
Capital dependent	5.4%	4.4%	4.6%	1.6%	4.6%	10.1%	21.1%	6.5%	24.2%	17.5%
Rural skilled	7.3%	6.4%	5.6%	1.0%	5.9%	11.6%	26.0%	6.3%	11.2%	18.7%
Rural semi-skilled	9.8%	6.4%	6.4%	1.2%	6.7%	12.9%	20.2%	7.3%	11.9%	17.2%
Rural low-skilled	11.0%	6.3%	7.4%	1.4%	7.6%	13.8%	18.4%	6.7%	11.8%	15.6%
Rural unskilled	11.4%	6.5%	8.6%	1.5%	8.7%	15.0%	15.9%	5.9%	11.5%	15.2%
Transfer dependent	11.0%	5.6%	7.1%	1.6%	7.4%	14.2%	15.2%	8.0%	17.2%	12.7%
Farmer AEZ 1	16.4%	5.7%	8.2%	1.3%	8.9%	14.3%	13.9%	8.8%	10.9%	11.5%
Farmer AEZ 2	16.9%	5.4%	6.8%	1.0%	9.3%	14.1%	14.3%	9.6%	10.1%	12.4%
Farmer AEZ 3	11.9%	5.1%	6.0%	1.1%	8.0%	14.1%	16.4%	11.5%	11.8%	14.1%
All households	10.9%	5.6%	7.0%	1.6%	7.3%	13.5%	16.5%	7.7%	15.4%	14.5%

Source: Author's own calculation based on BLSS 2012.

Table 3.14. Household specific estimated income elasticities

Representative household groups	Cereals	Processed Food	Vegetables	Animal Products	Fruits	Beverages and Spices	Energy	Other services	Basic Services	Other Goods
Urban skilled	0.57	0.77	0.56	0.70	0.68	0.70	0.94	1.19	1.00	1.47
Urban semi-skilled	0.63	0.79	0.55	0.77	0.74	0.67	1.14	1.10	1.21	1.37
Urban low-skilled	0.51	0.98	0.58	0.80	0.91	0.67	1.05	1.26	1.08	1.49
Urban unskilled	0.56	0.91	0.58	0.75	0.90	0.84	1.30	1.27	1.13	1.32
Capital dependent	0.44	0.74	0.51	0.58	0.50	0.64	0.72	1.16	0.92	1.66
Rural skilled	0.70	0.69	0.59	0.68	0.95	0.59	1.26	1.01	1.05	1.39
Rural semi-skilled	0.52	0.73	0.55	0.58	0.81	0.54	1.20	1.25	1.05	1.57
Rural low-skilled	0.52	0.85	0.43	0.69	0.75	0.69	1.17	1.31	0.97	1.64
Rural unskilled	0.46	0.90	0.55	0.80	0.98	0.58	1.47	1.21	1.22	1.56
Transfer dependent	0.54	1.13	0.60	0.83	0.92	0.66	0.82	1.30	1.09	1.55
Farmer AEZ 1	0.68	1.19	0.53	0.76	0.83	0.66	1.15	1.36	0.96	1.69
Farmer AEZ 2	0.67	1.09	0.50	0.71	0.84	0.69	1.17	1.32	0.93	1.75
Farmer AEZ 3	0.55	0.83	0.49	0.61	0.88	0.57	1.33	1.29	1.02	1.62

Source: Own analysis using BLSS 2012.

As we do not have any estimates of the Frisch elasticities, we use the previously introduced calibration procedure (3.7) to approximate households' subsistence consumption of good i. However, this is only possible for $\eta_{i,h} \leq 1$, as in any other case the subsistence consumption denoted by c_{ih} becomes negative. This problem can be circumvented by normalizing the estimated income elasticities by dividing it by the maximum income elasticity as first proposed by Dellink (2003) and later applied by Kleinwechter (2011) and Kuiper (2005). The transformed equation consequently reads:

$$c_{i,h} = \left(1 - \frac{\eta_{i,h}}{\max_j\left(\eta_{j,h}\right)}\right) * q_{i,h} \tag{3.11}$$

Appendix 3D Commodity Groups and Substitution Elasticities

Table 3.15. Commodity groups and substitution elasticities

Commodity Category	Description	Substitution elasticity
Cereals	Rice; Maize; Other cereals and oilseeds	1.5
Vegetables	Potato; Other vegetables	1.5
Fruits	Fruits	1.5
Animal products	Milk; Beef; Dairy; Other animal products	1.5
Beverage and Spices	Spices; Beverages; Alcohol and tobacco; Ara	1.2
Processed Food	Grain-mill products; Processed fruit; Lodging	1.2
Energy	Firewood, Fuels; Utilities	1.5
Other goods	Minerals; Clothing; General Machinery; Other manufactured goods	0.8
Basic services	Health; Housing; Education and other public services	0.8
Other services	Trade; Transportation; Construction; Other services	0.8
Leisure	Leisure generated using the households' labour endowment	0.1

3.10 References

Acs, S., Berentsen, P. B.M., & Huirne, R. B.M. (2007). Conversion to organic arable farming in The Netherlands: A dynamic linear programming analysis. *Agricultural Systems*, *94*, 405–415. Retrieved from http://www.sciencedirect.com/science/article/pii/S0308521X06001697

Ahamad, M. G., Khondker, R. K., Ahmed, Z. U., & Tanin, F. (2011). Seasonal Unemployment and Voluntary Out-Migration from Northern Bangladesh. *Modern Economy*, *02*, 174–179. https://doi.org/10.4236/me.2011.22023

Ali, F., & Parikh, A. (1992). Relationships among labor, bullock, and tractor inputs in Pakistan agriculture. *American Journal of Agricultural Economics*, *74*, 371–377. Retrieved from http://ajae.oxfordjournals.org/content/74/2/371.short

Aragie, E., Dudu, H., Ferrari, E., Mainar Causapé, A., McDonald, S., & Thierfelder, K. (2017). *STAGE_DEV: A variant of the STAGE model to analyse developing countries*. Brussels: Publications Office of the European Union. Retrieved from http://publications.jrc.ec.europa.eu/repository/bitstream/JRC104686/kj-na-28627-en-n_.pdf

Atwood, S., Nagpal, S., Mbuya, N., & Laviolette, L. (2014). *Nutrition in Bhutan: Situational Analysis and Policy Recommendations*. Washington DC, USA.

Ballard, C. (2000). How many hours are in a simulated day? The effects of time endowment on the results of tax-policy simulation models. *Unpublished Paper, Michigan State University*. Retrieved from https://pdfs.semanticscholar.org/59b3/4cbb9cc1c02f2c0735dec3e3bcb9ad632507.pdf

Bardhan, P. K. (1984). Determinants of supply and demand for labor in a poor agrarian economy: an analysis of household survey data from rural West Bengal. In H. Binswanger & M. Rosenzweig (Eds.), *Contractual Arrangements, Employment and Wages in Rural Labor Markets: A Critical Review.* New Haven, CT: Yale University Press.

Basu, A. K. (2013). Impact of rural employment guarantee schemes on seasonal labor markets: Optimum compensation and workers' welfare. *The Journal of Economic Inequality*, *11*, 1–34. https://doi.org/10.1007/s10888-011-9179-y

Binswanger, H. P., & Rosenzweig, M. R. (1981). *Contractual arrangements, employment, and wages in rural labor markets: a critical review* (Studies in Employment and Rural Development No. 67). Washington D.C., USA. Retrieved from http://documents.worldbank.org/curated/en/412971467997610342/Contractual-arrangements-employment-and-wages-in-rural-labor-markets-a-critical-review

Boeters, S., & Savard, L. (2013). The labor market in computable general equilibrium models. *Handbook of Computable General Equilibrium Modeling*, *1*, 1645–1718. Retrieved from https://ideas.repec.org/h/eee/hacchp/v1y2013icp1645-1718.html

Borjas, G. (2000). *Labor Economics* (2nd ed.). Boston, USA: Irwin/McGraw-Hill.

Boserup, E. (2005). *The Conditions of Agricultural Growth*. New York: Routledge. Retrieved from 978135148454197813514845419781351484541

Bouët, A., Femenia, F., & Laborde, D. (2014). *Taking into account the evolution of world food demand in CGE simulations of policy reforms: the role of demand systems* (Presented at the 17th Annual Conference on Global Economic Analysis, Dakar, Senegal). Retrieved from https://www.gtap.agecon.purdue.edu/resources/download/6876.pdf

Card, D. (1994). *Intertemporal Labor Supply: An Assessment* (Advances in Econometrics, Sixth World Congress). Cambridge University Press.

Centre for Bhutan Studies & GNH Research. (2015). *A compass towards a just and harmonious society: 2015 GNH Survey Report*. Thimphu, Bhutan. Retrieved from Centre for Bhutan Studies & GNH Research website: http://www.grossnationalhappiness.com/wp-content/uploads/2017/01/Final-GNH-Report-jp-21.3.17-ilovepdf-compressed.pdf

Connolly, M. (2008). Here comes the rain again: Weather and the intertemporal substitution of leisure. *Journal of Labor Economics*, *26*, 73–100.

Danzer, A. M. (2013). Benefit Generosity and the Income Effect on Labour Supply: Quasi-Experimental Evidence. *The Economic Journal*, *123*, 1059–1084. https://doi.org/10.1111/ecoj.12006

Dellink, R. B. (2003). Economic impacts of pollution and abatement: A dynamic empirical modelling assessment (PhD Dissertation). VU University Amsterdam, Amsterdam.

Devarajan, S., Lewis, J. D., & Robinson, S. (1990). Policy lessons from trade-focused, two-sector models. *Journal of Policy Modeling*, *12*, 625–657.

Devarajan, S., & Robinson, S. (2005). The Influence of Computable General Equilibrium Models on Policy. *Frontiers in Applied General Equilibrium Modeling: in Honor of Herbert Scarf*, 402.

Devereux, S. (2016). Social protection for enhanced food security in sub-Saharan Africa. *Food Policy*, *60*, 52–62. https://doi.org/10.1016/j.foodpol.2015.03.009

Dorji, N., Flinn, J. C., & Maranan, C. (1990). *Rice Production in the Wangdiphodrang-Punakha Valley of Bhutan* (IRRI Research Paper Series No. 140). Manila, Philippines.

Dukpa, C., & Feuerbacher, A. (2018). *Participatory compilation of seasonal calendars in nine Bhutanese districts* (mimeo).

Eickhout, B., van Meijl, H., Tabeau, A., & Stehfest, E. (2009). The impact of environmental and climate constraints on global food supply. *Economic Analysis of Land Use in Global Climate Change Policy*, *14*, 206.

Evers, M., Mooij, R. de, & van Vuuren, D. (2008). The Wage Elasticity of Labour Supply: A Synthesis of Empirical Estimates. *De Economist*, *156*, 25–43. https://doi.org/10.1007/s10645-007-9080-z

Fehr, E., & Goette, L. (2007). Do Workers Work More if Wages Are High? Evidence from a Randomized Field Experiment. *American Economic Review*, *97*, 298–317. https://doi.org/10.1257/aer.97.1.298

Feuerbacher, A., Dukpa, C., & Grethe, H. (2017). *A 2012 Social Accounting Matrix (SAM) for Bhutan with a detailed representation of the agricultural sector: Technical Documentation* (Working Paper No. 94). Berlin. Retrieved from Department of Agricultural Economics, Faculty of Life Sciences, Humboldt-Universität zu Berlin website: https://www.agrar.hu-berlin.de/de/institut/departments/daoe/publ/wp/wp94.pdf

Feuerbacher, A., Luckmann, J., Boysen, O., Zikeli, S., & Grethe, H. (2018). Is Bhutan destined for 100% organic? Assessing the economy-wide effects of a large-scale conversion policy. *PloS One*, *13*, e0199025. https://doi.org/10.1371/journal.pone.0199025

Filipski, M., Aboudrare, A., Lybbert, T. J., & Taylor, J. E. (2017). Spice Price Spikes: Simulating Impacts of Saffron Price Volatility in a Gendered Local Economy-Wide Model. *World Development*, *91*, 84–99. Retrieved from http://www.sciencedirect.com/science/article/pii/S0305750X16305204

Finnoff, D., & Tschirhart, J. (2008). Linking dynamic economic and ecological general equilibrium models. *Resource and Energy Economics*, *30*, 91–114. Retrieved from http://www.sciencedirect.com/science/article/pii/S0928765507000450

Fisher, D. U., & Knutson, R. D. (2013). Uniqueness of Agricultural Labor Markets. *American Journal of Agricultural Economics*, *95*, 463–469. https://doi.org/10.1093/ajae/aas088

Fontana, M., & Wood, A. (2000). Modeling the Effects of Trade on Women, at Work and at Home. *World Development*, *28*, 1173–1190. https://doi.org/10.1016/S0305-750X(00)00033-4

Ghimiray, M., Dorji, K. D., Katwal Bdr., T., Penjore, U., Dorji, S., Pem, S., . . . Pradhan, K. (2008). *Rice in Bhutan: A Source Book*. Thimphu, Bhutan.

Goldberg, J. (2016). Kwacha Gonna Do? Experimental Evidence about Labor Supply in Rural Malawi. *American Economic Journal: Applied Economics*, *8*, 129–149. https://doi.org/10.1257/app.20130369

Gurung, T. R. (2011). Analyse comparée de l'usage de la modélisation d'accompagnement pour faciliter la gestion adaptative de l'eau agricole au Bhoutan (Phd dissertation). Université de Paris Ouest Nanterre-La Défense, Paris. Retrieved from https://www.commod.org/content/download/4416/32897/version/1/file/Gurung_2011_PhD.pdf

Hazell, P. B. R., & Norton, R. D. (1986). *Mathematical programming for economic analysis in agriculture*: Macmillan New York. Retrieved from http://agrecon.mcgill.ca/courses/320/hazell/mathprogfront.pdf

Heckman, J. J., & MaCurdy, T. (1982). Corrigendum on a life cycle model of female labour supply. *The Review of Economic Studies*, *49*, 659–660.

Hertel, T. W. (1997). *Global trade analysis: modeling and applications*: Cambridge university press.

Hertel, T. W., McDougall Robert A., Narayanan G., B., & Aguiar, A. H. (2016). Chapter 14 - Behavioral parameters. In B. G. Narayanan, A. Aguiar, & and R. McDougall. (Eds.), *Global Trade, Assistance, and Production: The GTAP 9 Data Base* (p. 14). Purdue, USA.

Jarvis, L., & Vera-Toscano, E. (2004). Seasonal Adjustment in a Market for Female Agricultural Workers. *American Journal of Agricultural Economics*, *86*, 254–266. https://doi.org/10.1111/j.0092-5853.2004.00576.x

Jussila, M., Tamminen, S., & Kinnunen Jouko. (2012). *The estimation of LES demand elasticities for CGE models* (VATT Working Papers No. 39). Helsinki, Finland. Retrieved from Government Institute for Economic Research website: http://www.doria.fi/bitstream/handle/10024/148777/wp39.pdf?sequence=1&isAllowed=y

Katwal Bdr., T. (2016). *Cropping calendar for cereals across various agroecological zones*. Email. Thimphu, Bhutan.

Keller, W. J. (1980). *Tax incidence*. *(Contributions to economic analysis: 134)*. Amsterdam usw.: North-Holland Publ. Co.

Kleinwechter, U. (2011). Village level impacts of trade reform in China (PhD Dissertation). University of Hohenheim, Stuttgart. Retrieved from http://opus.uni-hohenheim.de/volltexte/2011/630/

Kleinwechter, U., & Grethe, H. (2015). National Wage Trends and Migration in a Chinese Village Economy: A Micro Level Modeling Approach Based on a Composite Utility Function. *American Journal of Agricultural Economics*, *97*, 701–726. https://doi.org/10.1093/ajae/aau070

Kuiper, M. H. (2005). Village modeling: a Chinese recipe for blending general equilibrium and household modeling (PhD Dissertation). Wageningen University, Wageningen, NL. Retrieved from http://library.wur.nl/WebQuery/wda/abstract/1744830

Lofgren, H., Harris, R. L., & Robinson, S. (2002). *A standard computable general equilibrium (CGE) model in GAMS*: Intl Food Policy Res Inst. Washington D.C., USA.

Mann, C. E., & Hobbs, P. R. (1988). *Wheat and wheat development in Bhutan*. Mexico City, Mexico.

McDonald, S., & Thierfelder, K. (2015). A Static Applied General Equilibrium Model: Technical Documentation: STAGE Version 2: January 2015. *Model Documentation*.

Mehta, M. P., Rabgyal, J., & Acharya, S. (2015a). *Commodity Chain Analysis of Ginger in Bhutan*. Thimphu, Bhutan.

Mehta, M. P., Rabgyal, J., & Acharya, S. (2015b). *Commodity Chain Analysis of Large Cardamom in Bhutan*. Thimphu, Bhutan.

Melo, J. de, & Robinson, S. (1989). Product differentiation and the treatment of foreign trade in computable general equilibrium models of small economies. *Journal of International Economics*, *27*, 47–67. https://doi.org/10.1016/0022-1996(89)90077-9

MoAF. (2006). *Smallholder Fruits and Vegetable Production Possibilities: A Baseline Study of Five Selected Dzongkhags in Bhutan*. Thimphu, Bhutan.

MoAF. (2009). *Agricultural Census 2008 - Microdata*. Thimphu, Bhutan.

MoAF. (2012). *Cost of rice production in different agro-ecological zones*. Thimphu, Bhutan.

MoAF. (2013a). *Agricultural Sample Survey 2012 - Dataset*. Thimphu, Bhutan.

MoAF. (2013b). *Production Cost for Major Vegetables in Bhutan*. Thimphu, Bhutan.

MoAF. (2014). *Agricultural Sample Survey 2013 - Dataset*. Thimphu, Bhutan.

MoAF. (2016). *Microdata on the Agricultural Sample Survey rounds conducted in 2012, 2013, 2014 and 2015 first and second year half*. Thimphu, Bhutan.

MoEA. (2012). *Diagnostic Trade Integration Study*. Thimphu, Bhutan.

NLC. (2014). *Altitude data of gewog centres in Bhutan*. Thimphu, Bhutan.

NSB. (2018). *2017 Population and Housing Census of Bhutan: National Report*. Thimphu, Bhutan. Retrieved from National Statistics Bureau (NSB) of Bhutan website: http://www.nsb.gov.bt/publication/download.php?id=1352

NSB, & ADB. (2012). *Bhutan Living Standard Survey 2012 - dataset*. Thimphu, Bhutan.

NSB, & World Bank. (2012). *Bhutan Poverty Analysis 2012*. Thimphu, Bhutan. Retrieved from National Statistics Bureau; World Bank website: http://www.nsb.gov.bt/publication/files/pub6pg3078cg.pdf

NSB, & World Bank. (2017). *Bhutan Poverty Analysis 2017*. Thimphu, Bhutan. Retrieved from National Statistics Bureau; World Bank website: http://www.nsb.gov.bt/publication/files/pub6pg3078cg.pdf

Penjore, D. (2004). Security of Bhutan: Walking Between the Giants. *Journal of Bhutan Studies*, *10*, 108–131. Retrieved from http://www.dspace.cam.ac.uk/handle/1810/227045

Perroni, C., & Rutherford, T. F. (1995). Regular flexibility of nested CES functions. *European Economic Review*, *39*, 335–343. https://doi.org/10.1016/0014-2921(94)00018-U

Phuntsho, S., Schmidt, K., Kuyakanon, R.S. and Temphel, K.J. (2011). *Community Forestry in Bhutan: Putting People at the Heart of Poverty Reduction*. Jakar and Thimphu, Bhutan.

RC Khangma. (2003). *RNR Technical Recommendations*. Khangma, Bhutan.

RC Wengkhar. (2015). *Cropping calendars for fruits and vegetables across agroecological-zones in Bhutan*. Wengkhar, Bhutan.

Reardon, T., Stamoulis, K., Cruz, M. E., Berdegué, J., & Banks, B. (1998). *Rural non-farm income in developing countries: Special Chapter* (The state of food and agriculture No. 283-356). Rome, Italy. Retrieved from FAO website: http://www.fao.org/docrep/w9500e/w9500e00.htm

Roder, W., Nidup, K., & Chettri, G. (2008). *The Potato in Bhutan*. Thimphu, Bhutan.

Röhrig, F. (2016). Adoption of Sustainable Land Management technologies among smallholder farmers in Eastern Bhutan: A microeconomic assessement using a mathematical programming model approach (Master thesis). University of Hohenheim, Hohenheim.

Ruthenberg, H. (1971). *Farming systems in the tropics* (Ed. 3). Oxford, UK: Oxford University Press.

Sadoulet, E., & Janvry, A. de. (1995). *Quantitative development policy analysis* (1st ed.). Baltimore: Johns Hopkins University Press.

Samdup, T., Udo, H. M.J., Eilers, C., Ibrahim, M. N.M., & van der Zijpp, A. J. (2010). Crossbreeding and intensification of smallholder crop–cattle farming systems in Bhutan. *Livestock Science*, *132*, 126–134. Retrieved from http://www.sciencedirect.com/science/article/pii/S1871141310001915

Sariyev, O., Gurung, T., Feuerbacher, A., & Loos, T. (2017). *Study on intra-household decision-making and food security: Primary data collected in Dagana and Tsirang, Bhutan* (mimeo).

Sears, R. R., Phuntso, S., Dorji, T., Choden, K., Norbu, N., & Baral, H. (2017). *Forest ecosystem services and the pillars of Bhutan's Gross National Happiness* (Occasional Paper No. 178). Bogor, Indonesia.

Sen, A. K. (1966). Peasants and Dualism with or without Surplus Labor. *The Journal of Political Economy*, 425–450. Retrieved from http://www.jstor.org/stable/1829592

Shrestha, S., Katwal Bdr., T., & Ghalley BB. (2006). *Adoption and Impact Assessment of Improved Maize Technologies in Bhutan*. Thimphu, Bhutan.

Skoufias, E. (1996). Intertemporal substitution in labor supply: Micro evidence from rural India. *Journal of Development Economics*, *51*, 217–237. Retrieved from http://www.sciencedirect.com/science/article/pii/S0304387896004130

Tashi, S., & Wangchuk, K. (2016). Organic vs. conventional rice production: comparative assessment under farmers' condition in Bhutan. *Organic Agriculture*, *6*, 255–265. https://doi.org/10.1007/s13165-015-0132-4

Taylor, J. E., Charlton, D., & Yúnez-Naude, A. (2012). The End of Farm Labor Abundance. *Applied Economic Perspectives and Policy*, *34*, 587–598. https://doi.org/10.1093/aepp/pps036

Troost, C., & Berger, T. (2015). Dealing with Uncertainty in Agent-Based Simulation: Farm-Level Modeling of Adaptation to Climate Change in Southwest Germany. *American Journal of Agricultural Economics*, *97*, 833–854. https://doi.org/10.1093/ajae/aau076

UN. (2009). *System of National Accounts 2008*. New York. Retrieved from https://unstats.un.org/unsd/nationalaccount/docs/sna2008.pdf

Valin, H., Sands, R. D., van der Mensbrugghe, D., Nelson, G. C., Ahammad, H., Blanc, E., . . . Willenbockel, D. (2014). The future of food demand: understanding differences in global economic models. *Agricultural Economics*, *45*, 51–67. https://doi.org/10.1111/agec.12089

Wangchuk, D., & Katwal Bdr., T. (2014). *Promoting hybrid maize as spring crop under rice-fallow systems: Success and lessons learnt*. Thimphu, Bhutan.

Wodon, Q., & Beegle, K. (2012). Labor shortages despite underemployment? Seasonality in time use in Malawi. In M. C. Blackden & Q. Wodon (Eds.), *World Bank Working Paper: Vol. 73. Gender, Time Use, and Poverty in Sub-Saharan Africa* (pp. 97–116). Washington, DC: World Bank.

World Bank. (2018). *World Development Indicators*. Dataset. Washington DC, USA. Retrieved from http://data.worldbank.org/data-catalog/world-development-indicators

Yeshey. (2012). Economics of mechanizing rice cultivation at RNRRDC Bajo. *Journal of Renewable Natural Resources Bhutan*, *8*, 42–52.

Zellner, A. (1962). An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias. *Journal of the American Statistical Association*, *57*, 348–368. https://doi.org/10.1080/01621459.1962.10480664

Zhang, X., Yang, J., & Wang, S. (2011). China has reached the Lewis turning point. *China Economic Review*, *22*, 542–554. Retrieved from http://www.sciencedirect.com/science/article/pii/S1043951X11000587

Chapter 4 Is Bhutan Destined for 100% organic?

- Assessing the Economy-wide Effects of a Large-scale Conversion Policy

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Abstract

Organic agriculture (OA) is considered a strategy to make agriculture more sustainable. Bhutan has embraced the ambitious goal of becoming the world's first 100% organic nation. By analysing recent on-farm data in Bhutan, we found organic crop yields on average to be 24% lower than conventional yields. Based on these yield gaps, we assess the effects of the 100% organic conversion policy by employing an economy-wide computable general equilibrium (CGE) model with detailed representation of Bhutan's agricultural sector incorporating agroecological zones, crop nutrients, and field operations. Despite a low dependency on agrochemicals from the onset of this initiative, we find a considerable reduction in Bhutan's GDP, substantial welfare losses, particularly for non-agricultural households, and adverse impacts on food security. The yield gap is the main driver for a strong decline in domestic agricultural production, which is largely compensated by increased food imports, resulting in a weakening of the country's cereal self-sufficiency. Current organic by default farming practices in Bhutan are still underdeveloped and do not apply the systems approach of organic farming as defined in the IFOAM organic farming standards. This is reflected in the strong decline of nitrogen (N) availability to crops in our simulation and bears potential for increased yields in OA. Improvement of soil-fertility practices, e.g., the adoption of N-fixing crops, improved animal husbandry systems with increased provision of animal manure and access to markets with price premium for organic products could help to lower the economic cost of the large-scale conversion.

Keywords: Organic agriculture; Agricultural policy; Large-scale conversion; Food security; Economy-wide modelling; Yield gap; Bhutan

4.1 Introduction

There is an uncontested need to reduce the environmental impacts of agriculture. Converting from a conventional to an organic agricultural system is viewed as one strategy to meet this need (NRC, 2010). A key challenge is, however, not to compromise the supply of food and biomass. Current studies on large-scale conversions vigorously debate the existence and size of yield gaps between conventional and organic agriculture (Ponisio et al., 2015) and the question of whether 100% organic agriculture (OA) can feed a growing world population (Connor, 2008; Muller et al., 2017; Ponti, Rijk, & van Ittersum, 2012; Seufert, Ramankutty, & Foley, 2012). So far, little research has been conducted on the economy-wide impacts of large-scale conversions to OA on a national scale. This might be due to the lack of genuinely formulated policy objectives, which aim to convert the entire agricultural sector on a large scale. Bhutan has received remarkable international attention following its announcement to become the world's first 100% organic nation by 2020 (Paul, 2015).Besides environmental conservation, which is one of the four pillars of Bhutan's Gross National Happiness philosophy, there are also other motifs for this policy, such as promoting the brand "Bhutan" (GNHC, 2013)

OA is a holistic agricultural system that strictly relies on natural inputs and promotes practices like the maintenance of soil fertility, conservation of biodiversity, and animal welfare according to the norms of the International Federation of Organic Agriculture Movements (IFOAM) (IFOAM, 2014). The usage of most chemical fertilizers (except for mineral phosphate and potassium not enriched by chemical processes), pesticides and genetically modified crops is prohibited. In animal husbandry, the use of artificial growth hormones is banned, and antibiotics are only allowed in exceptional cases. In 2012, 37% of Bhutan's farmers used agrochemicals on about 19% of arable land (MoAF, 2013b). Given its low reliance on agrochemicals, there is the notion that the country is destined for 100% OA (Tashi, 2015). However, this notion does not properly account for the difference between "organic by default" (i.e., no use of chemical inputs and mineral fertilisers) and organic by IFOAM principles, which are based on a holistic system approach (Ton, 2013). Given the limited adoption of OA's key principles, we refer to organic by default when using the term OA in the context of Bhutan.

Due to the absence of agrochemical inputs in OA, access to nutrients for plant growth is limited and the occurrence of pests and diseases is more difficult to manage, resulting in lower yields than in conventional agriculture (CA). This is well documented for developed countries (Ponisio et al., 2015), but there is very limited research on OA's relative productivity in developing countries generally, and in Bhutan specifically. Our study contributes to this research gap by estimating organic-to-conventional yield ratios of 16 annual and perennial crops using on-farm data from a nationally representative survey covering about 6,200 Bhutanese farmers.

The main contribution of this study is to assess the economy-wide impacts of Bhutan's proclaimed 100% organic policy. Given agriculture's critical role for the country's economy, employing about 50% of the labour force in 2012 (ADB & NSB, 2013), significant effects of such an unprecedented national conversion policy on household welfare and food self-sufficiency are to be expected. Furthermore, the detailed representation of the agricultural sector in our model allows to investigate how the conversion affects agricultural output, land use, and the availability of crop nutrients.

4.2 Policy Background

The general concern for the environment is deeply anchored in Bhutan's policies, for instance, by the constitutional mandate to maintain 60% forestry cover at all times (RGoB, 2008) or the pledge to stay a carbon neutral country (RGoB, 2010). Part of the 100% organic policy rationale is to promote Bhutan as an organic brand, which shall help to commercialize smallholder agriculture, alleviate poverty, and add value to the tourism sector (Duba, Ghimiray, & Gurung, 2008). In order to become 100% organic, Bhutan's government intends to "phase out [the] use of harmful chemical fertilizers and pesticides" (RGoB, 2010, p. 29) which effectively resembles a ban on agrochemicals. The use of mineral fertilizers compliant with IFOAM regulations (rock-phosphate and mineral potassium not enriched by chemical processes), do not play a role in Bhutan. Further, there is no domestic agrochemical production and the import of agrochemicals is a government controlled monopoly accounting for about 0.2% of total imports (in value terms) (FAO, 2012; MoF, 2013b). Hence, a ban on importing or producing agrochemicals is relatively easy to implement and would only affect cropping systems directly, as animal husbandry in Bhutan follows traditional practices with negligible use of non-compliant inputs, such as artificial growth hormones.

Since the first announcement of the 100% OA objective in 2008 (Tashi, 2015), the consumption of synthetic fertilizers used in Bhutan remained stable, while the use of pesticides even increased with an average annual growth rate of 11.8%, which is attributed to labour shortages (Neuhoff, Tashi, Rahmann, & Denich, 2014; Yeshey & Bajgai, 2014) (see Appendix 4A). In

2012, 13,943 hectares were cultivated under CA, i.e., 18.6% of total cultivated land (MoAF, 2013b). Of the remaining 61,194 hectares only about 545 hectares of crop land (less than 1% of total arable land) were certified organic (NOP, 2016) leaving the largest share of cultivated land to organic by default, i.e., no organic certification and no usage of agrochemicals, but also no use of improved organic practices. However, the Royal Government of Bhutan (RGoB) does not necessarily tie achieving 100% OA to governmental certification, except for exports, for which an internationally recognized certification is compulsory (Neuhoff et al., 2014).

The implementation of the 100% organic policy in Bhutan is very different from policy measures addressing organic farming, e.g., within the Common Agricultural Policy of the European Union (EU). In the EU, conversion to certified OA is based on incentives like subsidies compensating for yield reductions and increase of labour costs while rewarding environmental and societal benefits of OA. Clear regulations were developed in close relation to the IFOAM norms (IFOAM, 2014) that define organic agriculture and the practices applied (e.g., EC No 834/2007 (European Council, 2007)). A conversion to OA in such a context is usually a conscious decision made by farmers, who are motivated by reasons of economic viability and their ethical values and often these actions are embedded in grassroots-movements (Dabbert, Haring, & Zanoli, 2004; Fairweather, 1999). However, expert interviews with government representatives, researchers, and farmers conducted between 2014 and 2016 showed that Bhutan's 100% organic policy is not the result of a bottom-up process involving farmers, but rather a top-down policy. An early report even noted: "farmers lack awareness on organic farming. They are even confused: why organic now when they have just learnt to practice conventional farming" (Duba et al., 2008, p. 21).

The top-down nature of Bhutan's 100% OA policy merits special emphasis. It is largely based on the phasing out of chemical inputs, but does not properly integrate measures that lead to the adoption of improved organic farming practices (e.g., composting, improved manure management, use of nitrogen (N)-fixing plants, management of biodiversity for bio control and others) as defined in the principles of IFOAM (IFOAM, 2014). CA farmers in Bhutan would thus predominantly convert to organic by default and not by IFOAM principles. The relevant stakeholders do not seem to sufficiently discuss and account for this difference.

Bhutan, unlike many South Asian countries, has achieved a relatively high degree of food security as reflected by most nutrition indicators and in 2012, only 2.8% of the population were reported to live under the food poverty line of 2,124 kcal (NSB & World Bank, 2012). Yet, stunted growth in children younger than five years old and anaemia, which affects women and children, remain serious challenges (Atwood et al., 2014). Besides affecting food security, the OA policy could conflict with the objective of increasing self-sufficiency in cereals – a key priority of Bhutan's agricultural policy. Through investments in mechanization and irrigation schemes, domestic paddy production shall be increased by 26% to achieve a rice-self-sufficiency rate of 67% until 2018 (GNHC, 2013). Considering the geopolitical tensions surrounding Bhutan, increasing food self-sufficiency is a valid national priority and this study will assess how this policy objective is affected by a 100% organic conversion.

4.3 Materials and Methods

We simulated the 100% organic policy in Bhutan as a phase-out of agrochemical-use, according to which conventional farmers adopt the current farming practices of their organic by default counterparts without introducing any technological advancement. This simulation only concerned the cropping sector as the livestock sector does not use any inputs that are non-compliant with OA. We followed a two-step approach. In step one, we utilized data from a nationally representative farm survey to test for differences in productivity of OA and CA within each of Bhutan's three agroecological zones (AEZs). In step two, we employed a single country Computable General Equilibrium (CGE) model to simulate the economy-wide impacts of the 100% organic policy. CGE models are a common method used to assess the effects of policies and economic shocks, particularly in the field of agriculture and food policy, as they comprehensively depict the interdependencies in the entire economy. Both steps are linked by updating the model's database, a 2012 Social Accounting Matrix (SAM) of Bhutan, using the results of the yield difference estimation.

4.3.1 Data and Estimation Procedure of OA-CA Yield Differences

The analysis of yield differences is based on the nationally representative Agricultural Sample Survey (ASS) 2012 containing crop output data of about 6,200 farmers (MoAF, 2013b). This dataset is the only recent survey that includes questions on agrochemical use in crops on a farm level. The dataset was obtained from the Ministry of Agriculture and Forests (MoAF) in Bhutan and was de-identified prior to access. Crops were classified as conventionally produced if farmers used chemical fertilizers, pesticides, or both on the crop area. The dataset was combined with altitude data on the sub-district (*gewog*) level to generate variables identifying the following three main AEZs. AEZ1 is the humid, sub-tropical zone at altitudes below 1,200 meters above sea level (masl). AEZ2 is the dry-subtropical AEZ in altitudes between 1,200 and 1,800 masl. AEZ3 is the temperate zone in altitudes above 1,800 masl.

Yield data, calculated by dividing production in kilograms by area in hectares, was cleaned by excluding the 1% and 99% percentile outliers within each crop and AEZ. Yield differences were calculated as an organic-to-conventional ratio per crop and AEZ level if at least 25 observations were available per cultivation system (OA or CA), otherwise the crop was excluded from the analysis. Observations of crops cultivated without agrochemical use (i.e., organically-grown crops) by farmers who utilized agrochemicals in other crops were also excluded in order to avoid any possible effect of nutrients from synthetic fertilizers via crop rotations and to avoid any effects of pesticide application or pesticide drift. Fieller confidence-intervals were calculated for the yield ratios and significance levels were tested conducting the non-parametric Wilcoxon rank-sum test on absolute yield levels. A non-parametric procedure was applied as the Shapiro-Wilk W test revealed that the majority of crop yields neither follows a normal nor a lognormal distribution.

The results of the yield gap analysis were utilized to update the model database. In case the yield difference was found to be significant (p-value < 5%), the cultivation system specific mean yields were used to compute total quantity produced per crop based on the distribution of land in the database among cultivation systems. If yield differences were not significant, the mean of all observations per crop across both cultivation systems was used.

4.3.2 Economy-wide Model Framework

4.3.2.1 Model Database

The 2012 SAM for Bhutan determines the structure of economic institutions and agents and is documented by Arndt Feuerbacher, C. Dukpa et al. (2017). The following two modifications were implemented:

Firstly, data from the ASS 2012 and the Bhutan Living Standard Survey 2012 (ADB & NSB, 2013) were used to disaggregate farm activities, factors, and households according to the three AEZs. Crop-producing activities were further disaggregated according to cultivation systems (i.e., OA or CA), which results in cultivation system and AEZ specific input-output structures. Secondly, eight field operation activities (e.g., manual weeding with or without pesticide use) were incorporated using available crop budget data. Each produces a corresponding field operation commodity that enters the crop producing activity as a production input. The field operation "Mechanical land preparation", for instance, comprises ploughing and puddling of land using a powertiller requiring fuel, agricultural labour (*family and hired farm labour*), and agricultural capital (*powertiller*). The incorporation of field operations is a novel feature in CGE modelling. It allows simulations to explicitly model the trade-off between technological choices and directly links the labour requirement to each operation, rather than aggregating it.

Table 4.1 provides an overview of the SAM accounts. Farm activities comprise crop, livestock, post-harvest and community forestry activities and require farm production factors. Farm labour is either family labour (i.e., from the same household) or hired. We do not explicitly depict labour exchange groups, which is a common practice in Bhutanese agriculture, because the amount of labour supplied is typically close or equal to the labour received in return. There are two livestock accounts. Since other livestock than cattle (predominantly poultry, pigs, sheep, and goats) comprise only 5.2% of total livestock units in Bhutan (MoAF, 2013d), they are grouped together in the other animals account. In addition to farm labour and livestock there are also four agricultural land types, powertillers and other machinery. Income from these farm production factors accrues to either the farmer or landless households. We did not disaggregate by farm-size, which is rather homogenous in Bhutan, with more than 95% of farmers cultivating less than four hectares of land and a median landholding of about one hectare (MoAF, 2013b). Non-agricultural households were differentiated by factor ownership and residence in either rural or urban areas. Agricultural households, activities and production factors were disaggregated by AEZ and in case of crop production and land also by cultivation system. In accordance with Bhutanese law, irrigated-land is only utilized by rice cultivation. Some activities have by-products such as crop residues, fodder, manure and draught animal services, which are used as inputs by other farm activities. Just as field operations, they are assumed to be non-tradable within Bhutan and thus were segmented according to AEZs. A table listing all SAM accounts in detail is provided in the supporting information (see Appendix 4B).

Table 4.1. Disaggregation of the 2012 Bhutan SAM

Category	Item	
Activities	Agriculture:	Crops[1] (7), Livestock[2] (2), Field operations[1] (9), Community forestry[1], Commercial forestry, Post-harvest processing[1] (5)
	Industry:	Extractive industries, Food processing, Textile, Other manufacturing, Public utilities
	Services:	Construction, Trade, Transportation, Hotel and restaurants, Government services, Other services
Factors	Labour:	Skilled, Unskilled, Family farm[2], Hired farm[2]
	Land:	Rainfed land[1], Irrigated land[1], Orchards[1], Pasture land[2]
	Capital:	Private capital, Public capital, Informal capital, Powertiller[2], Other machinery, Cattle[2], Other animals[2]
Margins	Trade, Transportation	
Institutions	Agricultural households:	Farmer, Landless
	Non-agricultural households:	Urban skilled, Urban unskilled, Rural skilled, Rural unskilled, Capital dependent, Transfer dependent
	Private enterprises, Public enterprises, Government, Rest of the world (Row)	
Taxes	Import tax, Excise tax, Sales tax, Income tax, Production tax	
Capital	Investments, Stock changes	

Note: Number in parenthesis describes the quantity of items, e.g. there are seven crop sectors.
[1] Disaggregated by the three agroecological zones and cultivation system
[2] Disaggregated by the three agroecological zones

4.3.2.2 Behavioural relationships in the model

A CGE model captures the entire circular flow within an economy, as illustrated by the following example. A farmer household located in the low-altitude zone (AEZ1) allocates land and labour to an AEZ-specific cropping activity from which it receives a factor rent in return which finances its expenditure for consumption, taxes, transfers, and savings. The cropping activity receives income from the sale of its output, which is again needed to finance the use of intermediate inputs and factors. Hence, each agent or institution expenditure represents income somewhere else within the circular economy.

According to our model setup, each crop can be produced by two cultivation systems (OA vs. CA) across the three AEZs and a Constant Elasticity of Substitution (CES) demand function is utilized to aggregate total supply across all activities producing the same crop. We assumed no price premiums for OA goods. Organic and conventional output are instead perfect substitutes produced with different technology and cost structures. There has been hardly any research assessing the Bhutanese consumers' willingness to pay a price premium for OA produce. For the case of organic rice, no significant price premium was found to be paid by Bhutanese consumers (Tashi & K. Wangchuk, 2016). Due to the lack of a domestic market for officially-certified organic products, this finding can be generalized for all crops that are produced under OA.

Agricultural exports could potentially benefit from price premiums. Yet, except for a few minor export items, such as lemongrass oil, the vast majority of exports are not sold as organic products, even though cardamom and citrus fruits (two of the three most important agricultural export items) are produced without agrochemical use. Moreover, the purchasing power of the current main export markets, India and Bangladesh, which absorb 90% of total agricultural export value (MoF, 2013b), is rather low and hence we do not assume a price premium for export goods. While the domestic market for organic products is not established yet, there is a strong awareness of Bhutanese consumers to distinguish between domestic and imported produce. This becomes apparent when visiting the country's largest market, the Centenary Farmers Market in the capital city Thimphu, where Indian imports are sold at the ground floor and only Bhutanese products are allowed to be sold on the first floor. Using the Armington assumption (Armington, 1969) that makes imports imperfect substitutes for domestic products, we were able to reflect this pattern of consumer preference in our model.

The CGE model adjusted for this study is the single country, comparative-static STAGE2 model which is comprehensively described in McDonald and Thierfelder (2015). The institutions and agents in the model are production activities, commodity markets, households, incorporated enterprises, the government, and the capital market. All markets are assumed to be perfectly competitive where consumers maximize utility and producers' profits and prices adjust to clear markets. Household consumption follows the Linear Expenditure System according to which households maximize their utility from consumption of which a fixed part represents vital subsistence consumption. A large share of what Bhutanese farmers consume is their own produce. This is not explicitly reflected in the model. Instead, farmers purchase their own output through the commodity market.

Activities describe the domestic production of commodities, which combine fixed shares of intermediate inputs (i.e., inputs required for the production process) and production factors (i.e., labour, capital and land) and transform them to outputs. In contrast to intermediate inputs, factor inputs can be substituted with each other to differing degrees (implemented as multi-level CES functions). The substitution possibilities between factors is determined by a production structure, which was extended to incorporate field operations. This novel approach allows to explicitly model technological trade-offs within the agricultural sector, such as land preparation using either manual labour, draught power or powertillers. It also includes a nest governing the substitution of cultivated land and fertilizer input, for which we use a low substitution elasticity of 0.4 as proposed by (Bouët, Dimaranan, & Valin, 2010) in the context of developing countries. A detailed documentation of the model's production structure and parameters is provided in the supporting information (see Appendix 4C).

4.3.2.3 Model closures

Since Bhutan is a small country, the model assumes fixed world market prices. The external exchange rate is fixed. This reflects Bhutan's current currency regime of a one-to-one peg of the Bhutanese Ngultrum with the Indian Rupee. India is by far Bhutan's most important trade partner, accounting for more than 78% of imports and 94% of Bhutan's exports in 2012 (MoF, 2013b). The consumer price index (CPI) is set as the model's numeraire. The model is investment-driven (investment is fixed as a share of final demand) with equi-proportionately varying saving rates for households and enterprises. Government consumption and savings are fixed in quantity terms, and the government account is balanced by relative changes in the income tax rate.

Capital supply is constant and assumed to be immobile and activity specific as we consider a short-term adjustment horizon. Skilled and unskilled labour are perfectly mobile across activities. Agricultural labour, both family and hired farm labour, are segmented according to AEZs, and thus only mobile within the activities of the same AEZ. The three land-types (irrigated land, rainfed land, and orchard) are set immobile across AEZs and cultivation systems, establishing the entry point of the shock of converting to organic agriculture. Unlike the other factors, the model closure for land accounts for unemployment, as a significant share of total arable land was left fallow in the base period. The land supply regime is explained within the next section.

4.3.2.4 Modelling approach

To achieve Bhutan's 100% organic policy, a likely real-world policy instrument would be a ban on the use of agrochemicals. In a CGE model, such a policy is typically mimicked using a prohibitive tax (e.g., import or sales tax) which increases prices such that economic agents are incentivized to entirely substitute the use of the taxed good (Boulanger, Dudu, Ferrari, & Philippidis, 2016). This approach has the disadvantage that a very high distortion of input prices would be needed in order to achieve a scenario close to 100% conversion. Therefore, a novel approach is applied in this study, modelling the phase-out of CA as a conversion of conventional to organic land within each AEZ and land type.

Equation (4.1) describes the converted quantity of conventional to organic land $CVT0_{on}$, which is the base supply of conventional land $FS0_{cn}$ multiplied by the share of conversion $shrcvs$ and the diagonal matrix $mapland_{cn,on}$ to map organic *(on)* and conventional *(cn)* land-types according to AEZ and land type. Due to technical reasons, $shrcvs$ is limited to 99.99% to simulate Bhutan's 100% organic policy.

$$CVT0_{on} = FS0_{cn} * shrcvs * mapland_{cn,on} \tag{4.1}$$

Organic activities may not absorb all converted land and the portion of unutilized converted land is captured by the variable CVI_{on}. Equation (4.2) formally describes the binary mechanism that determines the factor price WF_{on} for organic land types *(on)*.

$$\frac{WF_n}{CPI} = \begin{cases} \dfrac{WF0_n}{CPI}, \text{ if } FW_n \geq FW0_n \text{ or } CVI_n > 0 \\ \left(\dfrac{FS0_n + \left(FW0_n - FW_{on}\right)}{shfs_n} \right)^{\frac{1}{elafs_n}}, \text{ if } FW_n \leq FW0_n \text{ and } CVI_n = 0 \end{cases} \tag{4.2}$$

where $FS0_{on}$ is the organic land supply in the base period, $FW0_{on}$ is the base quantity of fallow land, FW_{on} is a variable for fallow land, $shfs_{on}$ is a calibrated shift parameter, and $elafs_{on}$ is the supply elasticity of land which is set to 0.1. There are no specific land supply estimates for Bhutan, but the selected elasticity fits well within the range of land supply elasticities applied throughout the literature (van Meijl, van Rheenen, Tabeau, & Eickhout, 2006). The land price, deflated by the CPI, is assumed constant ($WF0_{on}$) if the total supply of land within each AEZ and land-type is equal to or smaller than base supply (i.e., supply at perfect elasticity). However, land prices increase according to an upward sloping land supply curve once fallow land from the base period is put under cultivation, which then represents a land expansion within a specific AEZ and land-type.

4.4 Results

As previously mentioned, we applied a two-stage approach. In this section, firstly the results of the yield estimation are provided, which establish the entry point for the model analysis. Secondly, we present the results of the economy-wide model in detail.

4.4.1 Yield Differences between OA and CA

The yield difference estimation shows that conventional yields are mostly higher than organic yields (i.e., yield ratios below one). Differences are statistically significant for 15 out of 25 yield comparisons all at the 0.1% significance level (Figure 4.1). The prevalence of CA is highest in AEZ3, with 46.5% of cultivated area under CA. These shares are much lower in AEZ2 (12.1%) and AEZ1 (1.4%), which explains the lower number of yield comparisons in these AEZs.

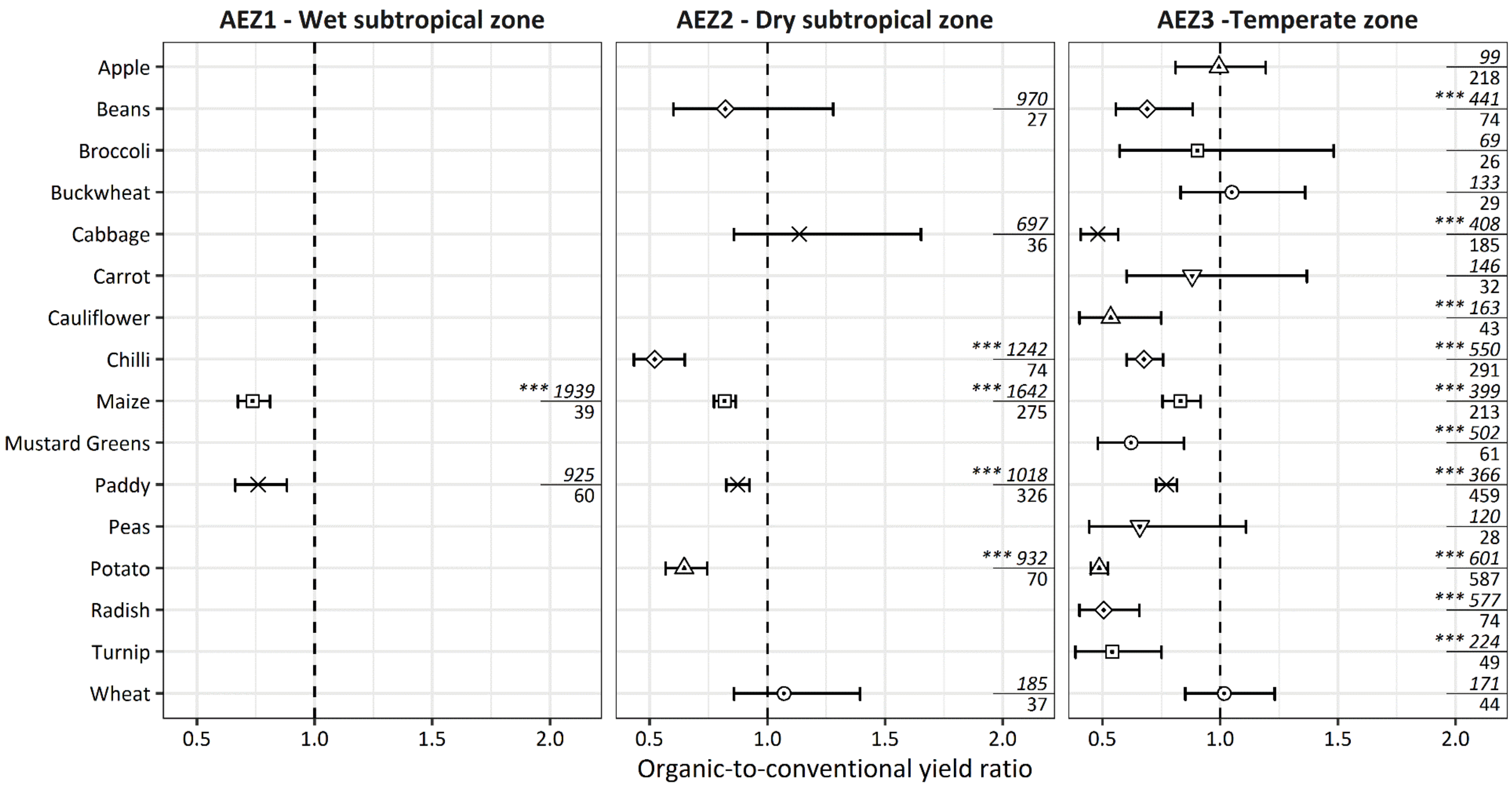


Figure 4.1. Organic-to-conventional yield ratios for 16 crops across AEZs in Bhutan

Note: Based on data from (MoAF, 2013b); The panel on the right-hand side shows the significance level of the Wilcoxon rank-sum test (*** P < 0.001) and the fraction shows the number of organic (numerator) and conventional (denominator) observations.

The estimated ratios for paddy, which are of particular importance given Bhutan's focus on rice self-sufficiency, are only statistically significant within AEZ2 and AEZ3, where 70.2% of paddy is produced. For paddy in AEZ1, the Wilcoxon rank-sum test does not yield a significant difference although the confidence interval is below the unitary ratio. Table 4.2 provides an overview of shares of conventional production across crops and regions after adjusting for significance in yield differences. Except for the major crops (i.e., paddy, maize, and potato), crops are aggregated in the SAM, which is why yield differences of minor crops (e.g., cabbage) are not directly traceable in the model.

Table 4.2. Percentage shares of crop output value in model database.

Crop / Region	Share of conventional agriculture in production per crop and within region				Share of crop in total crop production value
	AEZ1	AEZ2	AEZ3	National	
	(%)	(%)	(%)	(%)	(%)
Paddy	3.3	29.2	61.1	30.4	22.0
Maize	1.3	12.3	63.8	22.0	12.8
Other Cereals*	0.0	3.3	8.3	4.3	7.2
Vegetables	0.0	8.9	29.6	18.6	15.1
Potato	0.0	16.5	88.5	77.1	12.9
Spices	0.0	0.0	0.0	0.0	9.1
Fruits	2.6	1.9	63.1	15.0	20.9
Total crops	**1.7**	**13.0**	**57.1**	**25.7**	**100.0**

Columns 2-5 refer to the share of conventional crop production per crop type and region. Column 6 refers to each crops' share in total crop output value on the national level independent of production system (CA and OA). AEZ1-3 are the three main agroecological zones in the low-, mid-, and high-altitude ranges.
*Includes legumes and oilseeds

The relevance of crop yield differences for the economy-wide simulations in step two depends on the share produced by CA and a crop's relative weight within the agricultural sector. Table 4.2 shows that according to both criteria, paddy, maize, and potato have the highest shares produced by CA and are also among the most important crops accounting for 48% of total crop output. In AEZ2 and AEZ3, these crops also have large and significant yield gaps (Figure 4.1). In contrast, the conventional production of other crops (e.g., vegetables) is of very small magnitude and for spices it does not even exist.

4.4.2 Model results: Economy-wide changes of the 100% OA policy

4.4.2.1 Macro-level Changes

The large-scale exogenous conversion of conventional land constitutes a negative factor endowment shock due to generally lower yields within OA. In the base, all conventional land (13,943 hectares) accounted for 18.6% of total cultivated land, but comprised a disproportionately higher share of total land returns (24.3%).

Consequently, the 100% organic policy results in decreasing overall economic activity (Figure 4.2). Households experience a loss in purchasing power as factor income declines, food prices surge and household consumption shrinks accordingly (-5.5%). Investments as a fixed share of aggregate demand decrease (-2.3%). Fixing the government demand in quantity terms results in constant government expenditure in real terms. In line with falling household demand total imports also decrease, however, to a lower extent (-2.6%). Exports increase (3.2%) as decreasing non-agricultural factor prices raise the competitiveness of export industries. Net savings abroad increase (10.8%) as a result of a lower current account deficit. Overall, the model results suggest that Bhutan's economy would experience a drop in real GDP of -1.1% and a drop in total domestic absorption by -3.1%.

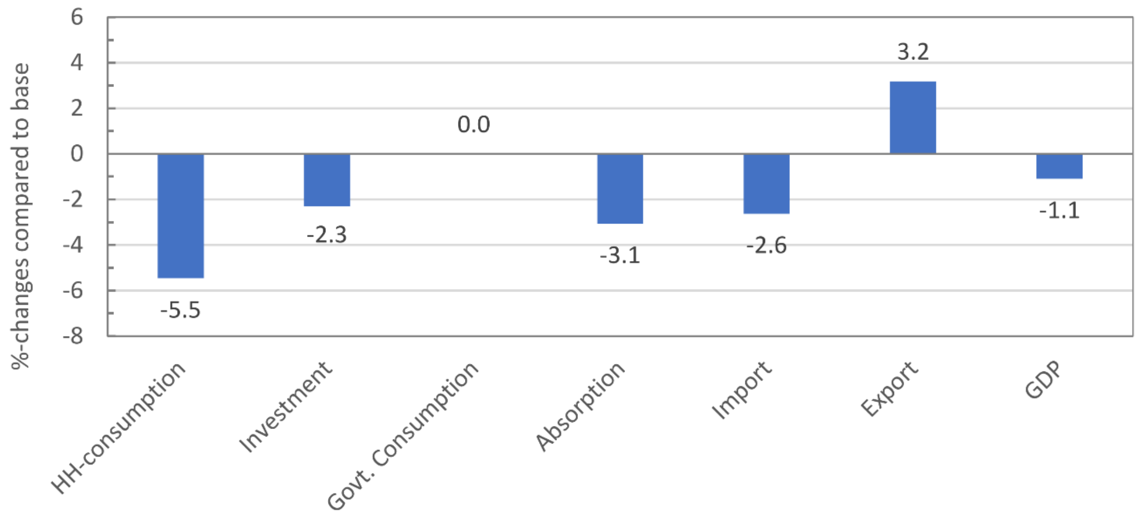


Figure 4.2. Percentage changes of macro indicators in real terms after simulating a 100% organic policy.

4.4.2.2 Changes in Factor Markets

After the conversion, total cultivated land increases slightly by 0.8%. The OA policy affects land-types very differently. Total irrigated land and orchards decline (-6.7% and -2.7%), while the cultivation of total rainfed land increases (4.0%). An overview of the converted land per land type and AEZ is provided in Table 4.3. The largest share of conversion occurs in the AEZ3, while the shock affects only a small share of cultivated land in AEZ2 and particularly AEZ1, where most agriculture is already organic by default. Previous fallow land is cultivated in addition to reallocated conventional land in those cases where changes in cultivated organic land after the conversion (reported in column five of Table 4.3) are larger than the convertible conventional land (column four). This holds, for example, for irrigated land in AEZ1, for orchard land in AEZ1 and AEZ2, and for rainfed land across all AEZs. Cultivated organic irrigated land only increases in AEZ1 and not all previous conventional irrigated-land is cultivated in AEZ2 and AEZ3.

Table 4.3. Reallocation of conventional land and change in cultivated organic land

AEZ	Land type	Organic land in base (ha)	Converted conventional land (ha)	Chg. in cultivated organic land (ha)	Chg. in total cultivated land (%)
AEZ1	Irrigated land	5,446	186	260	1.3
	Rainfed land	14,779	92	831	5.0
	Orchard	5,314	86	118	0.6
	Sub-Total	*25,539*	*364*	*1,210*	*3.3*
AEZ2	Irrigated land	5,045	1,831	1,435	-5.8
	Rainfed land	16,599	1,408	2,335	5.1
	Orchard	2,181	36	48	0.5
	Sub-Total	*23,824*	*3,275*	*3,818*	*2.0*
AEZ3	Irrigated land	1,869	2,301	1,506	-19.1
	Rainfed land	9,141	7,512	7,835	1.9
	Orchard	820	533	247	-21.1
	Sub-Total	*11,830*	*10,347*	*9,588*	*-3.4*
National	Irrigated land	12,360	4,318	3,202	-6.7
	Rainfed land	40,519	9,013	11,001	4.0
	Orchard	8,315	655	413	-2.7
	Total	**61,194**	**13,986**	**14,616**	**0.8**

AEZ1-3 are the three main agroecological zones in the low-, mid-, and high-altitude ranges. Column three reports cultivated organic land in the base and column four the total conventional land available for conversion. Column five describes the net absolute change in organic land after converting all or a share of conventional land. If all conventional land is converted, then previous fallow land can be cultivated. In this case, a positive change in total cultivated land is reported in column six.

Note: Based on the reference year 2012.

The lower yields of OA paddy reduce the use of irrigated land, since this land can only be used for the cultivation of paddy, but not for other crops as defined by the current legal setting in Bhutan. This is particularly relevant in AEZ2 and AEZ3, where organic yields are significantly lower than yields in CA. In contrast to irrigated land, farmers can cultivate a wide range of crops on rainfed land and in orchards, which allows them to specialize in those crops which have the highest productivity under the given conditions. Thus, the demand for rainfed land increases in all AEZ. The reduction in the cultivation of total orchard land should be interpreted as a drop in utilization (i.e., less orchards are managed and harvested) and is driven by the strong drop in AEZ3, where apple cultivation depends on agrochemical use.

Table 4.4 shows the changes in factor prices. Due to the inelastic land supply curve, land prices increase strongly once all fallow land is cultivated. This is particularly the case for rainfed land across all AEZs. Despite higher labour intensity within cropping activities, overall agricultural wages decrease due to the lower productivity of OA. Aggregate labour absorbed by cropping activities in AEZ1 and AEZ2 increases by 4.8% and 5.8%, respectively, while in AEZ3 it drops by -4.7%, which results in an aggregate increase of 2.3%. The additional agricultural labour demanded by cropping activities is released by post-harvest and off-farm activities. These either require less labour because of falling output prices reflecting lower demand for their final outputs (e.g., forestry and weaving of textiles) or because of decreased availability of necessary inputs (e.g., milling of cereals). The overall reduction in household demand results in a decrease of non-agricultural output, which has negative consequences for non-agricultural labour and capital.

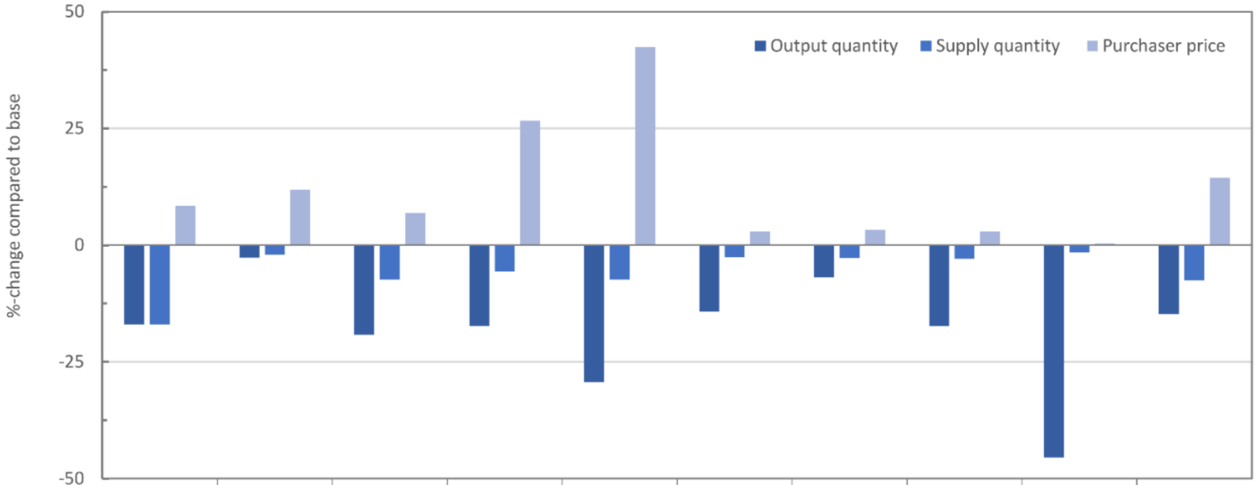
Table 4.4. Percentage changes in factor prices after simulating a 100% organic policy.

	Production factors	AEZ1 (%)	AEZ2 (%)	AEZ3 (%)	National (%)
Agricultural production factors	Irrigated land	13.4	0.0	0.0	4.9
	Rainfed land	61.0	70.3	39.7	57.4
	Orchard	5.1	4.6	0.0	4.4
	Pasture land	4.6	4.9	2.8	4.0
	Family farm labour	0.6	0.6	-2.9	-0.6
	Hired farm labour	-0.2	-1.0	-2.8	-1.4
	Powertiller	9.7	8.0	-9.9	-0.1
	Cattle	4.6	4.9	2.8	4.0
	Other animals	-1.5	-1.5	-0.3	-1.3
	Other machinery	-	-	-	-8.1
Non-agricultural production factors	Skilled labour	-	-	-	-8.1
	Unskilled labour	-	-	-	-5.4
	Private capital (factor income)	-	-	-	-4.6
	Public capital (factor income)	-	-	-	-0.3

AEZ1-3 are the three main agroecological zones in the low-, mid-, and high-altitude ranges.

4.4.2.3 Changes in Agricultural Output

Aggregate crop output declines by -14.7% in quantity terms resulting in a strong increase of crop prices (Figure 4.3). The reduced output in paddy and potato explains the largest part (52.4%) of the decline in crop output. Strong reductions in output are also observable for other cereals, spices, and fruits, however; these crops have lower shares in total production. Only 3.1% of domestic maize demand is imported and household demand for maize was estimated to be extremely inelastic reflected by an income elasticity just above zero (Minten & C. Dukpa, 2010a). Due to these specific trade linkages and consumer preferences maize production drops only modestly (-2.6%).



	Paddy	Maize	Other cereals	Vegetables	Potatoes	Spices	Fruits	Rice,milled	Flour	All crop products
Output quantity	-16.9	-2.6	-19.2	-17.3	-29.4	-14.3	-6.9	-17.3	-45.5	-14.7
Supply quantity	-16.9	-2.0	-7.4	-5.7	-7.4	-2.5	-2.8	-2.9	-1.6	-7.6
Purchaser price	8.4	11.9	7.0	26.7	42.4	3.0	3.3	3.0	0.4	14.5

Figure 4.3. Percentage changes in crop output, supply, and purchaser prices after simulating a 100% organic policy

In many other cases, reductions in output are absorbed by trade. The mechanism by which output reduction is absorbed by either or both increased imports or decreased exports is dependent on the initial trade linkage measured as a percentage of base supply. In quantity terms, crop imports increase by 20.7% largely caused by higher imports of potatoes and vegetables. Considering all food imports, the strong increase of milled rice imports (16.1%) represents in absolute terms the largest increase of any food item. Total crop exports experience a significant drop (-29.8%), of which 56.8% is due to the reduction in potato exports. As a result of both declining exports and increased imports of traded crops, supply decreases at much lower rates than production (Figure 4.3).

Purchaser prices and output of edible livestock products decrease because of lower household demand (See Appendix 4D for more details), and, in case of output because of higher demand for complementary non-edible livestock output (i.e., manure and draught power). Since the stock of animals is fixed exogenously, the supply of manure is inelastic. Consequently, following the conversion, manure prices increase strongly across AEZ (13.9%, 19.0% and 21.4% in AEZ1, AEZ2, and AEZ3, respectively). An increase in manure supply depends on changes in livestock management systems that result in an increasing recovery rate of manure droppings (e.g., by changes in animal husbandry from extensive pasture systems to indoor stable systems). This is reflected in the model, by allowing a low substitution elasticity between cattle and labour in the production structure and by using a CET specification to govern the output composition, which allows for higher output shares of manure and draught power while the output of edible livestock products decreases. Livestock product imports decrease as purchaser prices drop and total domestic production including edible and non-edible products slightly increases.

The lower drop in livestock production dampens the reduction of crop output, resulting in a decline of aggregate agricultural production of -10.6%. On the aggregate level, total food production (which includes processed food and excludes non-edible output) falls by -9.3%. Food supply is only reduced by -3.6% thanks to the increase in food imports.

4.4.2.4 Changes in Agricultural Inputs

The phase-out of agrochemicals results in a strongly increased demand for organic plant protection and organic fertilization (Table 4.5). The effects are most pronounced for AEZ3 where the share of converted conventional land is highest. Due to a slight increase of total land use in AEZ1 and AEZ2, total demand for field operations increases. In AEZ3, where total cultivated land decreases, demand declines for mechanical land preparation, manual land preparation, and other operations.

Table 4.5. Percentage changes of field operation supply

Field operations / Agroecological zones	**AEZ1** (%)	**AEZ2** (%)	**AEZ3** (%)
Mechanical land preparation	0.2	0.2	-0.2
Draught animal land preparation	5.5	4.3	3.1
Manual land preparation	48.9	66.9	-1.2
Organic fertilization	6.1	5.7	8.8
Chemical fertilization	-100.0	-100.0	-100.0
Other operations	4.3	6.1	-7.3
Organic plant protection	9.9	24.8	95.3
Chemical plant protection	-100.0	-100.0	-100.0

AEZ1-3 are the three main agroecological zones in the low-, mid-, and high-altitude ranges.

The intensity of fertilizer use decreases. While there is a slight land expansion, the aggregate supply of the nutrients N, phosphorus (P), and potassium (K) declines by -6.4% from 105.6 to 98.8 kg ha^{-1}, due to the abolishment of most synthetic and mineral fertilizers. In the base situation, synthetic and mineral fertilizers contribute with 26.9%, 6.7%, and 2.6% to the total supply of N, P, and K, respectively. This can only be partially replaced by an increased use of manure, which has a nutrient content of 1.6% N, 0.8% P, and 2.9% K (on dry matter basis) on average in Bhutan (Chettri, Ghimiray, & Floyd, 2003). Given that N comprises 81.4% of the NPK content in previously used synthetic fertilizers, availability of N drops significantly (-22.4%) and the average N application rate falls from 38.4 to 29.8 kg ha^{-1}. The absolute amount of P applied remains almost stable at 15.0 kg ha^{-1} (-0.1%) and the use of K increases slightly by 3.4% to 54.0 kg ha $^{-1}$. The NPK composition in the base of 36.3% N, 14.2% P, and 49.4% K changes to 30.2% N, 15.2% P, and 54.6% K.

4.4.2.5 Changes in Food Consumption and Welfare

Following a 100% organic conversion policy, national food self-sufficiency declines by -5.1% from previously 84.1% to 79.0%. Self-sufficiency is computed by dividing the value of domestic production by the sum of the values of domestic production and imports minus exports using constant prices of the base period. Cereal self-sufficiency is reduced by an even higher rate (-6.3%) from 61.5% to 55.2%. The decline in cereal self-sufficiency is largely driven by the substantial drop in paddy output and the increase in rice imports. Agricultural households experience a decrease in food consumption by -2.3% on average with considerable regional differences. Farmers' consumption in the low-altitude zone (AEZ1) remains constant, while farmers in the temperate zone (AEZ3) decrease consumption by -5.6% (Table 4.6). Non-agricultural households face higher reductions in income and thus on average reduce food consumption at a higher rate (-5.2%).

Table 4.6. Percentage changes of household income and food consumption for different income types and agroecological zones

Household types	Household income (%)	Food consumption (%)
Non-agricultural households	*-5,3*	*-5.2*
Urban skilled	-5.2	-5.0
Urban unskilled	-5.9	-5.3
Rural skilled	-5.1	-5.5
Rural unskilled	-5.7	-5.6
Other income	-4.6	-4.5
Agricultural households	*-1.9*	*-2.3*
AEZ1 farmer	2.5	0.0
AEZ2 farmer	1.0	-0.8
AEZ3 farmer	-7.3	-5.6
AEZ1 landless	-3.0	-3.9
AEZ2 landless	-2.9	-3.0
AEZ3 landless	-4.8	-4.4
National	**-4.3**	**-3.9**

AEZ1-3 are the three main agroecological zones in the low-, mid-, and high-altitude ranges.

Welfare, measured either in USD per capita or the share of equivalent variation in base household expenditure, decreases for all households, except for agricultural households in AEZ1 (Figure 4.4). The average Bhutanese bears a welfare loss of -51.95 USD or -5.51% in terms of base household expenditure. Agricultural households both experience lower welfare losses in relative and absolute terms compared to non-agricultural households. The strongest relative welfare-decline; however, is incurred by farmers in AEZ3, where most of the agricultural output is reduced causing lower factor income from labour and land (particularly irrigated land). In AEZ1 and AEZ2, landless households suffer from higher welfare losses than farmer households, because land rents increase while wages remain stagnant or even decline. Farmer households in AEZ1 even show a slight benefit, as they receive higher factor income from labour and land. In addition to these welfare changes at the household level, positive welfare effects result from the reduced current account deficit, which implies lower foreign debt and reduced interest payments in future periods. Using an alternative closure with a fixed current account balance, but flexible exchange rate, welfare of households on average drops by -2.1% of base income, while real GDP drops at a similar rate (-0.9%).

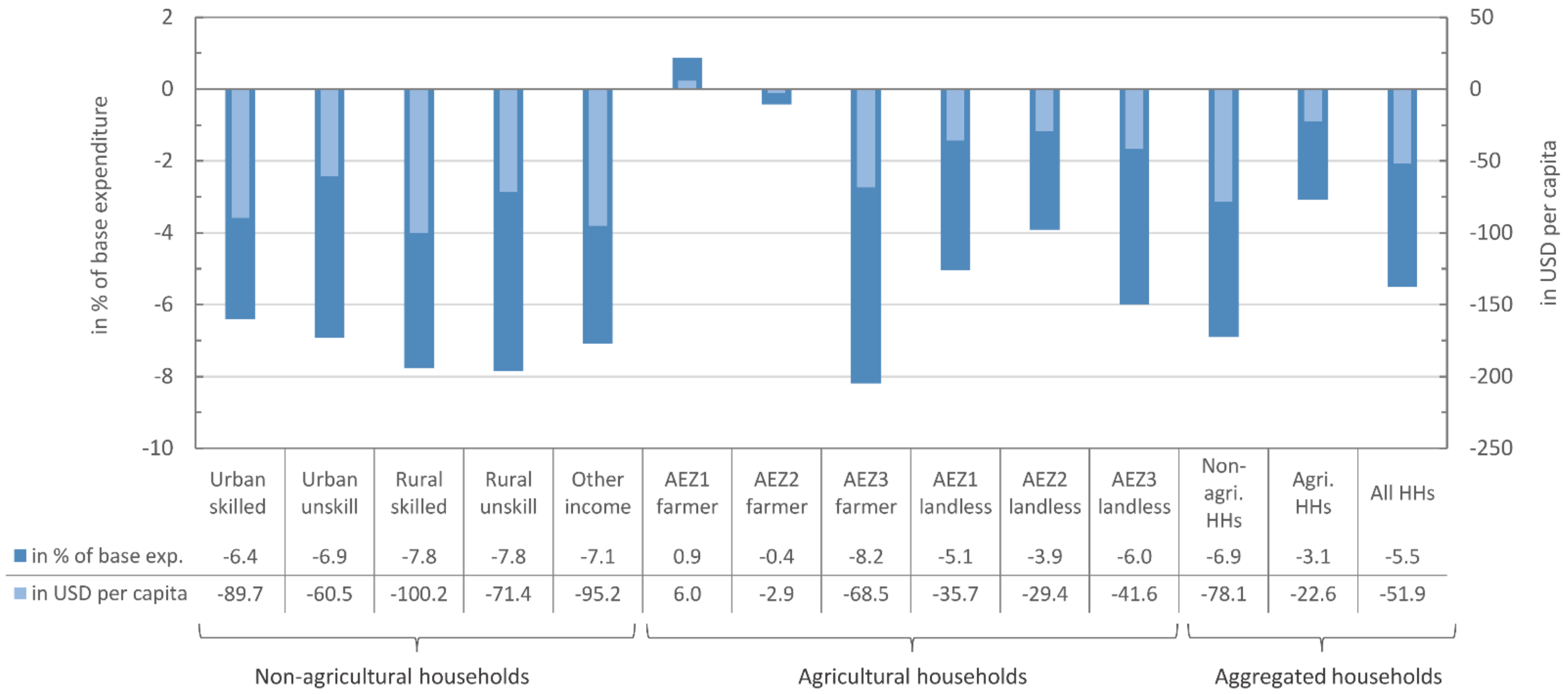


Figure 4.4. Welfare effects of Bhutan's 100% organic conversion policy

Note: Changes in welfare are measured as equivalent variation (EV) as share of base household expenditure on the left-hand side and in USD per capita on the right-hand side.

4.5 Discussion

4.5.1 Discussion of Estimated Yield Ratios

Based on our data the estimated yield gap between OA and CA is the key input determining the model results. Our estimated simple average organic-to-conventional-ratio of 0.76 compares well with recently estimated global mean ratios that range between 0.75 and 0.81 (Ponisio et al., 2015; Ponti et al., 2012; Seufert et al., 2012). Yield ratios in developing countries are particularly controversial due to data scarcity. Ponisio et al. (2015) and Ponti et al. (2012) do not find any statistically significant differences of yield ratios between developing and developed countries. In contrast, Seufert et al. (2012) find a significantly lower ratio of 0.57 for developing countries compared to 0.80 for developed countries.

Our yield ratio estimates for paddy and most other major crops seem to be plausible when compared to literature. The paddy OA-CA yield ratios for AEZ2 (0.87) and AEZ3 (0.77) are at the lower end or respectively below the range of ratios (0.86 to 1.05) reported by Ponti et al. (2012). But for the main three field crops in Bhutan (paddy, maize and potato), our yield ratios estimates fall well within the range of ratios provided in the supplementary materials of Ponisio et al. (Ponisio et al., 2014, 2015). Arguably, yield ratios derived from literature can only serve as a limited point of reference to validate our results due to limited comparability. Yet, our results are also corroborated by field trial evidence showing that yields in the current low-input farming system in Bhutan would increase through (higher) application of agrochemicals (Chettri et al., 2003; Dema, Dorji, Pem, & Tenzin, 2012; Ghaley & Christiansen, 2010).

Due to the lack of data, critics often highlight that yield ratios in developing countries are potentially biased, because in some cases low-input conventional systems are compared with optimized OA systems (Connor, 2008), while very low ratios are partially explained by atypically high conventional yields (Reganold, 2012). To date, there have been no field trials of experimental stations or controlled on-farm trials in Bhutan that studied the yield difference between OA and CA generally or specifically for different farming intensities. Field trials in Kenya (Adamtey et al., 2016; Musyoka, Adamtey, Muriuki, & Cadisch, 2017) analysing organic and conventional farming systems of different intensities (mainly N input and rotation design) find yield differences in OA and CA with OA < CA or OA=CA or OA>CA depending on fertiliser inputs, management practices, crop species, and location. We therefore assume that under Bhutanese conditions similar context dependent results are to be expected. The only study assessing organic and conventional yields in Bhutan analysed rice grain yield data from 120 farms evenly sampled across all three AEZs in 2012 and 2013 (Tashi & K. Wangchuk, 2016). Using ANOVA models the authors could not find any statistically significant differences between organic and conventional yields. This finding clearly differs from our results, as we find organic paddy yields in AEZ2 and AEZ3 to be 13% and 23% lower. Applying the same procedure (ANOVA) on our 2012 dataset, we find the yield difference of paddy even in AEZ1 to be statistically significant at the 1% level.

The dataset used to estimate the yield gaps is the only representative farm survey conducted in Bhutan with crop specific questions on agrochemical use. However, it lacks further relevant information on variables that might influence yields, such as farmer's education, asset ownership, intensity of input use as well as the slope of fields and the type of soils, which could have been used for regression analyses. To assess the robustness of our results with respect to any potential upward or downward biases of the yield estimates, we conducted a sensitivity analysis of the yield parameters.

4.5.2 Discussion of Model Results

Only a few studies have previously assessed the impacts of a large-scale conversion. Most of these are rather motivated by stylized thought-experiments using model approaches without accounting for economy-wide effects (Halberg, Sulser, Høgh-Jensen, Rosegrant, & Knudsen, 2006; Pretty, Ball, Lang, & Morison, 2005). The only comparable study simulates a 100% conversion for the Danish agricultural sector employing a comparative-static, single-country CGE model (Jacobsen & Frandsen, 1999). Under similar conditions, i.e., assuming no improvement in organic yields after conversion and allowing imports of animal feed, the authors find agricultural production to decline by -20.4% compared to the simulated decline of -10.6% for Bhutan. While organic farming practices might be more advanced in developed countries, there is also a greater dependency on agrochemicals, which could explain the comparatively lower drop in agricultural production for the case of Bhutan. Moreover, unlike developed countries, Bhutan's livestock sector is predominantly ruminant based (MoAF, 2013d) and relies only to a small degree on conventional inputs and concentrate feed (J. Gurung et al., 2015) and thus is only indirectly impacted by a 100% conversion.

Looking at the economy-wide implications of a 100% OA conversion, the contraction in crop output leads to negative economic growth (-1.1% decline in real GDP or about 18.8 million

USD). More than half of the reduction in crop output is due to the strong reduction in domestic production of paddy and potato, both of which are crops with large initial shares of conventional production and high yield gaps. Additionally, consumer preferences and trade linkages matter, as the example of the moderate decline in maize production shows. Trade also appears to buffer the drop in domestic production as reflected by the strong decline of the food self-sufficiency rate. In this context, the decline in paddy output appears to be most sensitive, which highlights the need to devote more resources to increase efficiency in organic paddy production, if the current degree of self-sufficiency is to be maintained. It is important to emphasize, that a 100% organic conversion on a country-level with the opportunity to import more conventionally produced food creates leakage of environmental externalities in the countries, which produce the additional imports.

The reduction in GDP and household welfare is considerable given that the agricultural sector comprises only about 10% of GDP in 2012. From a distributional point of view, the cost of the 100% conversion would largely be borne by non-agricultural households. Among agricultural households particularly farmers in the temperate zone (AEZ3) would suffer from declining welfare. The welfare effects depend on the degree to which households are willing to substitute domestic food with imported food, since the price level of the latter is not impacted. The chosen model setup aggregates imports and domestic goods according to a national substitution elasticity, without considering household specific preferences.

Referring to the four pillars of food security (FAO, 2009) our results show adverse impacts for food availability, access, and stability. Our model does not capture changes within the fourth pillar, food utilization (i.e., the metabolism of food by individuals) (Tweeten, 1999). Food availability corresponds to the supply of food, which declines at the aggregate level by 3.6% and in case of crops by even 7.6%. Also, food access drops markedly as shown by the decrease in food consumption by households. Hence, the 100% OA policy is likely to partially reverse Bhutan's past achievements in terms of food security and to jeopardize households close to or under the food poverty line of 2,124 Kcal. Our results show an increased dependency on food imports from India, which can have ambiguous effects on food stability. Stronger dependency on food imports might make the country less vulnerable against harvest failures within Bhutan, yet also increases the exposure to possible changes in India's trade and foreign policy.

From an agronomic perspective the model results are in line with ex-ante expectations regarding the impacts on land use and nutrient availability. Overall, the land area under cultivation increases, but only due to increased cultivation of rainfed land, while cultivation of orchards and irrigated land declines. In case of irrigated land, this is not only due to declining competitiveness of paddy cultivation, but also due to the Bhutanese law prohibiting other crops to be grown on irrigated land, which is a policy to foster rice-self-sufficiency. If other crops were allowed to be cultivated on irrigated-land, then paddy cultivation would likely decline further as irrigated-land would increase in price. Yet, in reality, many farmers cultivate other crops besides paddy on irrigated-land. Therefore, we probably underestimate the effects of the 100% organic policy on rice self-sufficiency.

A key challenge of OA is the supply and availability of crop nutrients, particularly N. As the organic fertilizers (e.g., compost, animal manure) permitted in OA provide a lower nutrient density and a slower nutrient release compared to synthetic fertilizers, nutrient availability in OA often does not match plant needs (Tilman, Cassman, Matson, Naylor, & Polasky, 2002). Animal manure, predominantly from cattle, mixed with crop residues (i.e., farmyard manure) is the most important organic fertilizer in Bhutanese agriculture. Forests and grasslands account for about 22% and 53% of cattle's feed requirement, respectively, allowing for a nutrient transfer to cropland (J. Gurung et al., 2015; Walter Roder, Gratzer, & Wangdi, 2002). Yet, as cattle husbandry is often not stable based, animals either graze freely or are tethered on site. Thus, there is the potential for increased targeted nutrient transfer to crop land through improved animal husbandry systems, which has to comply with OA standards for animal welfare. After the simulated conversion, the availability of P and K remain stable or even increase. Animal manure cannot replace the previous share of N from synthetic fertilizers (27%), resulting in a decline in N availability (-22.4%).

Our analysis assumes the initial headcount of livestock to be fixed, which limits the potential of additional manure production. In organic farming systems, the only source of N inputs that can replace synthetic N fertilizers is biological N fixation by cultivation of legumes (pulses, perennial legume based leys, or green manure in crop rotations) (C. Watson, Atkinson, Gosling, Jackson, & Rayns, 2002). In the context of Bhutan, experiments have shown that green manuring is an option to achieve recommended nutrient levels in the soil for the cultivation of rice (but not for wheat) (Chettri et al., 2003) . This potential, however, appears to be underutilized in Bhutan. Green manuring is rarely practiced (Tashi, 2015, p. 105) and pulses represent only about 3% of total cultivated area. Moreover, leguminous fodder crops are not yet used in Bhutan since most cattle husbandry systems are based on extensive grazing on pastures and in forests. In addition to legumes, further organic fertilizers such as leaf litter from forests and recycled materials from crop and household waste also play a rather minor role. Given the limited adoption of improved soil fertility management practices at the current stage and due to the lack of data, our model does not explicitly incorporate crop rotations and only includes manure as an organic fertilizer. Since multiple cropping and crop rotations are inherent features in the cropping system of both organic and conventional farmers in Bhutan (Katwal, 2013), there is substantial potential to improve the adoption of N-fixing crops in order to lower the yield gap (Barbieri, Pellerin, & Nesme). However, modelling their potential without sufficient data and recognizable efforts or initiatives undertaken to improve their adoption remains speculative.

OA is generally known to be more labour intensive than CA, but this factor receives little attention in the literature. The labour intensity of organic rice production in Bhutan, for instance, is 11% higher for organic farmers due to higher labour requirement for weeding and applying farmyard manure (Tashi & K. Wangchuk, 2016). Using the novel approach to model field operations, we explicitly depict the technological trade-off between both systems and show that aggregate labour absorbed by crop activities increases by 2.3%. Unlike claims in literature (Badgley et al., 2007; Reganold & Wachter, 2016), our results do not show that the higher labour intensity of OA results in positive welfare effects for agricultural households, because of higher income from agricultural labour. Following the 100% OA policy, wages only increase slightly in those regions with low conventional production. In AEZ3, where the OA conversion is most challenging, agricultural output drops significantly and cultivated land declines by -3.4%, resulting in a lower demand for labour by cropping activities. Furthermore, in AEZ2 the benefit of slightly higher agricultural wages is offset by the loss in purchasing power, due to higher food prices.

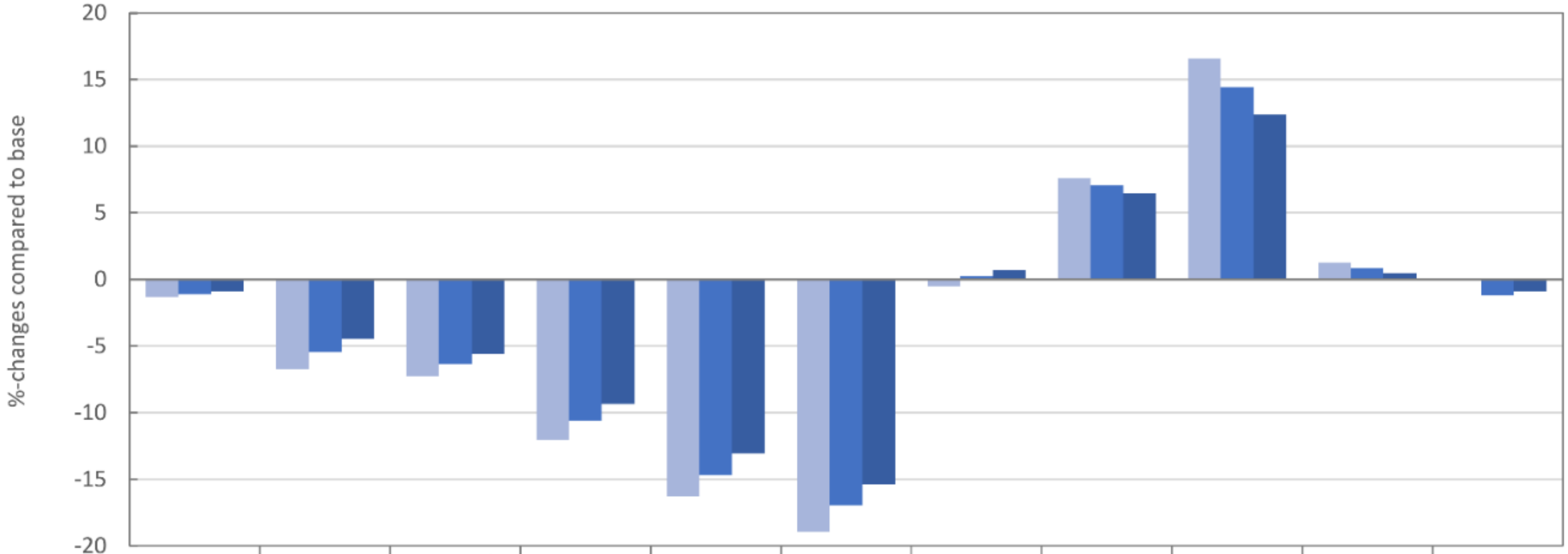
Since the OA conversion leads to higher labour requirement within specific periods, e.g., the periods of weeding and manuring, the depiction of seasonal labour would be intriguing and could influence changes in wages and land allocation. Yet, research on how to depict seasonality of labour markets in economy-wide models only started recently (Arndt Feuerbacher & Grethe, 2017). A further model limitation is the lack of labour mobility between agricultural and non-agricultural sectors. Non-agricultural wages are reduced at higher rates than agricultural wages, which implies that allowing migration between agriculture and non-agriculture sectors would result in an even higher decline of agricultural wages.

Our model framework does not incorporate the environmental benefits from OA, due to a lack of data and research, which would help to derive their potential magnitude. The mentioned leakage-effect would also require to also considerations with regard to the adverse effects on countries from which additional conventionally produced food is imported. Moreover, our model does not account for any possible spillover effects that might improve Bhutan's brand as a high-value tourist destination. However, according to the model results, tourist arrivals would need to more than double, if the societal cost of converting to organic farming should be born from an increase in tourist royalties.

4.5.3 Sensitivity Analysis

In order to check the robustness of our model and results for variations in the yield gap, we simulated two further scenarios by varying the yield gap of all crops by +20% and -20%. Like in the reference scenario, this variation only affected those yield ratios that were found to be statistically significant.

Following the described variation in yield gaps, real GDP varied only moderately, between -1.3% and 0.9% (Figure 4.5). The 20% increase in the yield gap triggered higher relative reductions in household consumption, food self-sufficiency, and agricultural production compared to a 20% decrease in the yield gap. This is due to the limited adaptive capacity of the agricultural sector to absorb a large reduction in its productivity. Manure production, for instance, cannot be increased infinitely and increases at a diminishing rate vis-à-vis the change in yield gap. In contrast, land cultivation increases (decreases) with a higher (lower) yield gap. Indeed, running an additional scenario without a yield gap, we even observe a drop in total land cultivation of -1.0%. Since agricultural labour and land are demanded in fixed shares, agricultural wages increase as more land is brought under cultivation.



	GDP (real)	HH cons. (real)	Food Self-Sufficiency	Agricultural Production	Crop Production	Paddy Production	Livestock Production	Manure Production	Crop Purch. Price	Land expansion	Agricultural wage change
+20% yield gap	-1.3	-6.7	-7.3	-12.0	-16.3	-19.0	-0.5	7.6	16.6	1.3	0.0
Reference	-1.1	-5.5	-6.3	-10.6	-14.7	-16.9	0.2	7.1	14.5	0.8	-1.2
-20% yield gap	-0.9	-4.5	-5.6	-9.4	-13.1	-15.4	0.7	6.5	12.4	0.5	-0.9

Figure 4.5. Sensitivity analysis to check robustness of main indicators for variation in the yield gap.

4.5.4 Policy Implications

There is an obvious and serious conflict between the 100% OA policy with increased food self-sufficiency. In this paper, we assess this conflict in case of the current governmental approach of defining OA as “free of agrochemicals” while other aspects of OA being a holistic system are neglected (Seufert, Ramankutty, & Mayerhofer, 2017). Our study does not impose any adoption of improved organic farming practices, which have been proven to potentially close the yield gap in comparable situations (Adamtey et al., 2016), since there are no interventions or trends recognizable in Bhutanese agriculture that would make such an assumption reasonable. In case of an optimised organic farming system, the conflict between food self-sufficiency and OA may be reduced and it is an obvious policy implication, that this would require an adequate political strategy for the improvement of productivity of OA in Bhutan.

In order to increase yield levels of today’s organic by default farming system, government investments in research and extension are necessary. Yet, up to now research on organic farming is concentrated at one of the five national Renewable Natural Resources (RNR) research centres (Duba et al., 2008) and the research policy formulated in 2011 only refers to organic farming once in 24 pages by stating to “give primacy to organically clean agriculture and minimize the role of external inputs” (RGoB, 2011, p. 7). Given the challenge of converting to 100% organic, the current research capacity is still too limited and would need to be expanded significantly (Neuhoff et al., 2014). Specifically, technology development (e.g., optimised fertilization strategies based on biological N fixation, development of plant-based pesticides, adaptation of crop rotations, technological solutions for labour intensive practices such as weeding in rice, breeding of adapted crop varieties, improvement of mixed farming systems with animal husbandry) for an intensification of the traditional agricultural systems is needed to improve yields in OA.

Besides research efforts and short-term dissemination of best-practice examples (peer-to-peer extension), demonstration farms and intensive training of extension workers could reduce the societal conversion costs. Access to export markets for high-value niche products might be another way to capitalize on the advantages of OA. Such opportunities could also arise in India in the long-run, where the awareness for quality and other added values of food products is growing among the middle class. However, the most important factor in the context of food self-sufficiency is the emergence of a market for organic produce inside Bhutan, which requires increased efforts to create consumer awareness.

Other political strategies of dealing with the conflict of food self-sufficiency and OA are less powerful. For example, excluding the paddy sector to achieve higher rice self-sufficiency would largely diminish the benefits of an organic conversion and entail the risk of agrochemicals leaking into other cropping activities. Alternative to banning agrochemicals, taxing agrochemical inputs would reduce their usage where they are least efficient, while still allowing them where they provide a high benefit-cost ratio. In Bhutan, levels of agrochemical use are low, which can imply high marginal-benefits while causing low marginal-damage to the environment. Finally, such alternatives that aim at less than 100% OA will lower the potential of branding Bhutan as a genuine “organic and green country”, which may be considered the most important benefit of OA in Bhutan.

Our results show the importance of increased conventional food imports to buffer the negative productivity shock on Bhutan’s cropping sector. This effect can hardly be avoided as any trade policy has to comply with Bhutan’s free trade agreement with India. A non-discriminatory measure would be to tax all agricultural goods that were not produced under organic standards, hence resulting in an effective import tax on most food items. However, this would further increase agricultural prices. A similar option would be to introduce sales taxes on agricultural produce, which could be rebated as production subsidies. This would lower the relative price difference between imported and local produce, but simultaneously provoke the risk of consumer protests in urban areas. As 100% organic is likely to benefit the tourism sector, policymakers could alternatively increase the tourism royalty in order to compensate farmers for lower productivity. This would benefit both farmers and consumers, yet the tourist’s willingness to accept such an increase in royalty is uncertain.

4.6 Conclusions

We studied Bhutan’s policy to convert 100% to OA analysing the economy-wide effects of such an unprecedented large-scale conversion policy. From a method development perspective, we conclude that shifting land between organic and non-organic farming activities in a CGE with a detailed depiction of the agricultural production structure, including the specification of complementary and substitutable field operations, is an adequate method to analyse the economy-wide effects of a conversion from conventional to organic agriculture.

Regarding the implications of OA in Bhutan, we found a substantial yield gap between OA and CA for most crops despite the country’s low reliance on agrochemical inputs. We were able to show that lower yields and higher labour requirements in OA to substitute the previous use of pesticides and fertilizers in CA resulted in a strong contraction of agricultural output, substantial losses in welfare and negative implications for food security. Based on our data, converting Bhutan's CA to the current organic by default farming system seems to be insufficient at fulfilling the promise of a 100% OA as a sustainable and environmentally friendly farming system that maintains current levels of food production. To reach this aim, further adaptations of cropping systems (fertilisation management, crop protection, integration of livestock) are necessary to narrow the current yield gaps and to develop truly holistic organic farming systems. We acknowledge that our database is far from sufficient to come up with conclusions regarding the potential of an optimized OA system, as little or no data for improved organic farming practices from field trials or farm pair comparisons exist for Bhutan. As for our model analysis, further research is needed to adequately address challenges that go beyond the scope of this study, such as potential environmental benefits and positive spillover effects, e.g., a boost in tourist arrivals.

Against the background of substantial efforts by the Bhutanese government to make agriculture more productive and commercial, our results showed that the 100% organic policy affects the cropping sector like a production tax without the opportunity of redistributing any tax income. Bhutan's policymakers should recognize these trade-offs, prioritize accordingly, and develop strategies to mitigate the conflict of objectives between OA and high food self-sufficiency. Increased efforts in the area of agricultural research, extension outreach and market development are necessary in order to ensure that a 100% OA policy can be reconciled with an improvement of rural livelihoods. If these efforts result in the adoption of advanced organic farming practices and access to price premiums then Bhutan's 100% conversion to OA may result in lower economic cost than assessed in this study and farmers may even benefit from conversion to improved OA.

4.7 Appendix

Appendix 4A Agrochemical Use in Bhutan

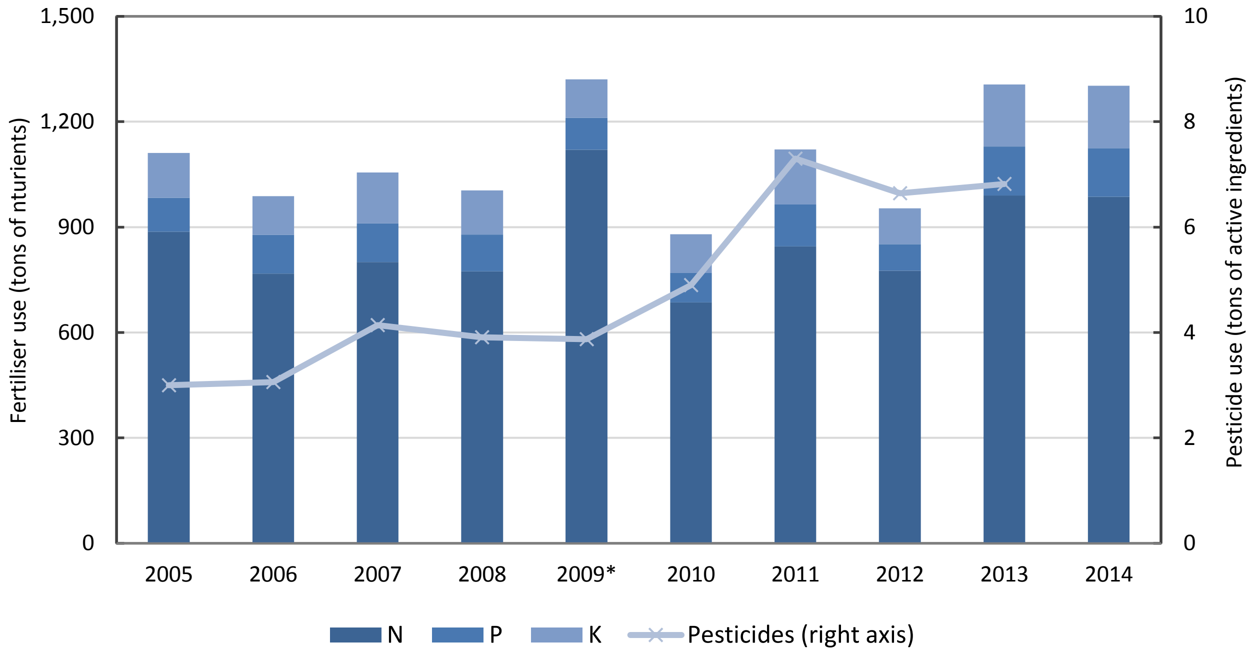


Figure 4.6. Use of agrochemicals in Bhutan 2005-2014

Data sources: Own calculation based on FAO (2017). *Fertilizer use data for 2009 was adjusted to the imported quantity of fertilisers as reported by official trade statistics (MoF, 2010a).

Appendix 4B 2012 Social Accounting Matrix Accounts

Commodities

Commodity Name	Description and comment
Crops	
Paddy	Cultivation of paddy rice on irrigated-land
Maize	
Other cereals	
Crop residues	By-product of paddy, maize and other cereals activities; disaggregated according to AEZ
Crop fodder	By-product of all crop producing activities; disaggregated according to AEZ
Vegetables	
Potato	
Spices	
Fruits	
Livestock	
Milk	
Beef	
Manure	Disaggregated according to AEZ
Live animals	
Draught power	Disaggregated according to AEZ
Other animal products	
Field operations	
Mechanical land preparation	Disaggregated according to AEZ
Draught-power land preparation	
Manual land preparation	
Organic fertilization	
Chemical fertilization	
Organic plant protection	
Chemical plant protection	
Other operations	
Compound feeding	
Food products	
Milled Rice	Milled paddy
Flour	Milled other cereals
Dairy	
Animal feed	
Tabaco and alcoholic beverages	
Ara	Home-brewed alcohol
Beverages	
Forest products	
Firewood	
Logs	
Non-wood forest products	
Industrial products	
Other minerals	
Other food	
Clothes	
Other manufacturing	
Fuels	
Chemical fertilizer	
Pesticides	
Electricity	
Services	
Construction services	
Transportation services	
Trade	
Lodging	
Other services	
Public services	

Activities

Activity Name	Description
Crops	
Paddy*	Disaggregated by AEZ and cultivation system (conventional versus organic)
Maize*	
Other cereals*	
Vegetables*	
Potato*	
Spices*	
Fruits*	
Livestock	
Cattle husbandry*	Disaggregated according to AEZ
Other animal husbandry*	
Field operations	
Mechanical land preparation*	Disaggregated according to AEZ
Draught-power land preparation*	
Manual land preparation*	
Organic fertilization*	
Chemical fertilization*	
Organic plant protection*	
Chemical plant protection*	
Other operations*	
Compound feeding*	
Food products	
Rice milling*	Disaggregated according to AEZ
Cereal milling*	
Dairy*	
Cereal processing*	
Ara production*	
Other food production	Producing the commodities: other food, animal feed, tobacco and alcoholic beverages, beverages
Forest products	
Community forestry*	Disaggregated according to AEZ
Forestry	
Industrial products	
Mining	
Textiles	
Other manufacturing	
Electricity generation	
Services	
Construction	
Transportation	
Wholesale and Trade	
Hotels and restaurants	
Other services	
Public services	

* denotes farm activities which require family-farm and hired-farm labour

Factors

Factor name	Description
Labour	
Skilled labour	
Unskilled labour	
Family-farm labour	Labour supplied by the farm household; Disaggregated according to AEZs
Hired-farm labour	
Agricultural land	
Pasture land	Disaggregated according to AEZs
Irrigated land	Disaggregated according to AEZs and cultivation system
Rainfed land	
Orchards	
Capital	
Other machinery	Non-incorporated capital mostly used by farm-households
Powertiller	Disaggregated according to AEZs
Cattle	
Other animals	
Private capital	Incorporated capital of private enterprises
Public capital	Incorporated capital of public enterprises

Institutions

Institutions	Description
Enterprises	
Private enterprises	
Public enterprises	
Households	
Urban skilled households	Households in urban areas with primarily income from skilled labour
Urban unskilled households	Households in urban areas with primarily income from unskilled labour
Rural skilled households	Households in rural areas with primarily income from skilled labour
Rural unskilled households	Households in rural areas with primarily income from unskilled labour
Capital dependent households	Households dependent on income from private capital
Transfer dependent households	Households dependent on transfers from domestic and foreign households
Farm household	Households in rural areas living from family farm labour and land; Disaggregated according to AEZs
Landless household	Households in rural areas with primarily income from hired-farm labour; Disaggregated according to AEZs
Government and taxes	
Government	
Import taxes	
Excise taxes	
Sales taxes	
Direct taxes	
Indirect taxes	
Other institutions	
Investment / savings	
Stock changes	
Rest of the world	All trade partners of Bhutan

Appendix 4C Model Extensions and Parameters

The original model structure of STAGE2 (Scott McDonald & Thierfelder, 2015) was extended to fit the purpose of this study. The following three extensions were made:

Firstly, in addition to trade and transport margins for domestic consumption, the extended model also incorporates margins for exports, as due to the mountainous terrain in Bhutan considerable transport costs apply to export-goods as well.

Secondly, more flexibility regarding the output of selected multi-product activities (i.e. the livestock and forest activities) is allowed for by introducing a constant elasticities of transformation (CET) function as described by Punt (2013). This is particularly relevant for the production of animal products. For example, the cattle herding activity's outputs (milk, beef, manure, draught power and live animals) are not determined by fixed shares (Leontief) as in the standard model, but are made flexible to the degree of the CET parameter.

The third and most substantial extension was the adjustment of the production structure. The standard production structure of STAGE2 consists of a three-level nest aggregating intermediate inputs and production factors, which is adopted for the model's non-agricultural activities. The light shaded nests in Figure 4.7 represent this standard structure, with the exception that the land aggregate is shifted from level L3.1 to L5.2. Generally, we assume that intermediate inputs and value added components are aggregated according to fixed shares at L1. Intermediate inputs are also demanded in fixed shares (L2.1). Value added at L2.2 and factor aggregates below (L3.2 and 3.3) are aggregated using CES technology.

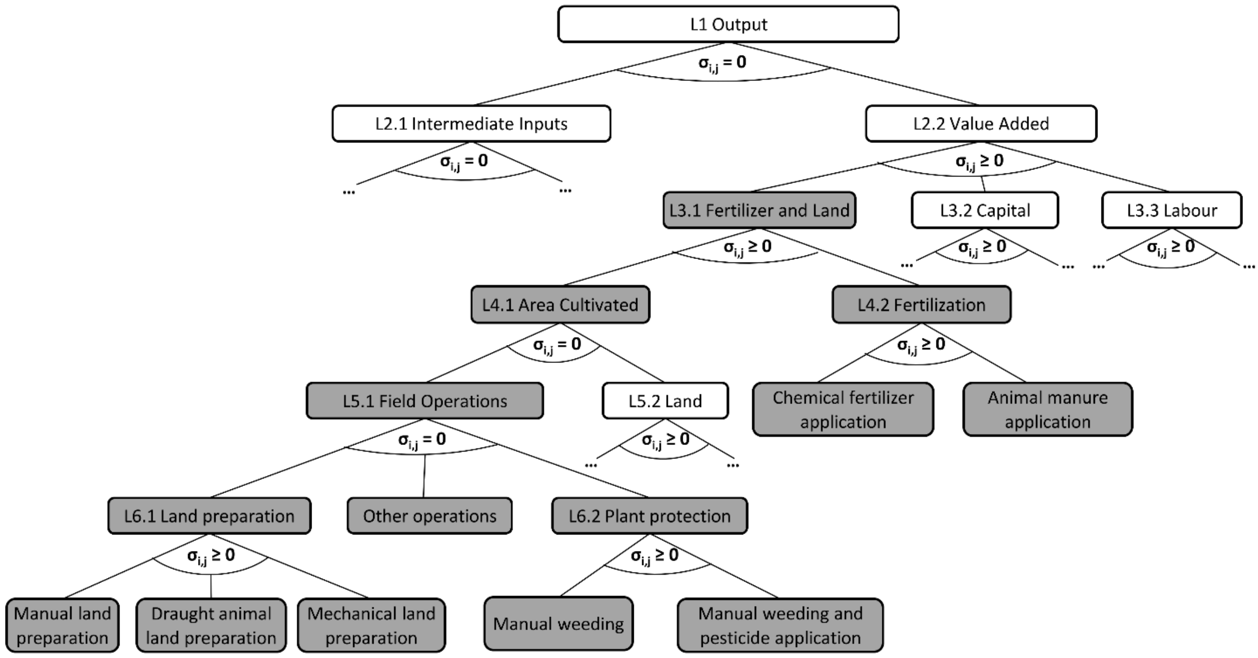


Figure 4.7. Extended production structure of economic activities.

Note: Sigmas denote substitution elasticities. Light shaded nests represent the standard three level structure and dark shaded nests represent the extended structure including field operations.

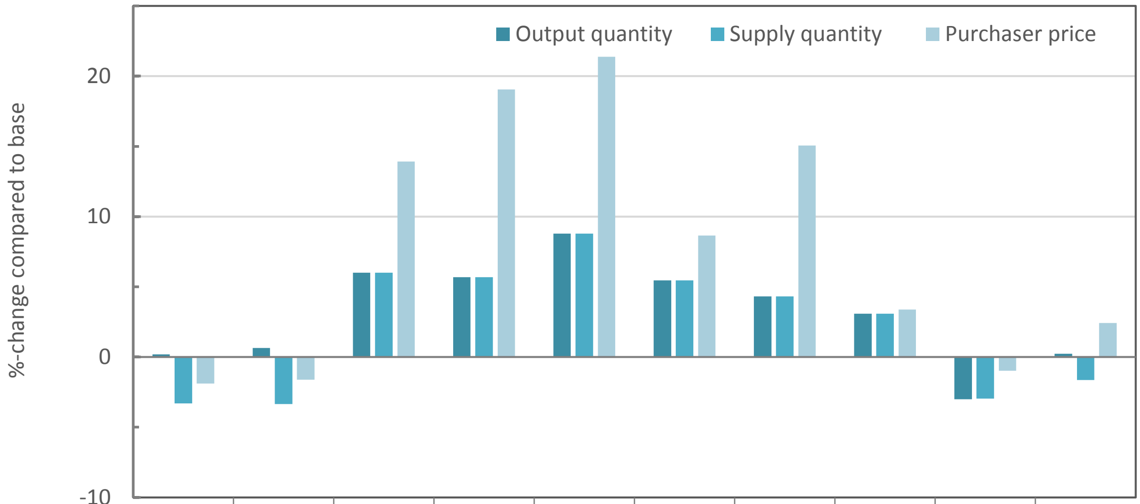
In case of agricultural activities, the production structure incorporates field operations, which are represented by the dark shaded nests in Figure 4.7. Since only cropping activities use field operations and land, this part remains empty for the remaining activities. Level L3.1 governs the activities' degree of intensification by aggregating area cultivated and fertilization. At this nest, we use a low substitution elasticity of 0.4 as proposed by (Bouët et al., 2010) in the context of developing countries. An important relationship is captured at the Area Cultivated nest L4.1, which aggregates field operations and land in fixed shares. Assuming a fixed share at L4.1 makes land only substitutable with fertilizer at level L3.1, which is reasonable, as increasing the cultivated area also increases the requirement for labour for land preparation, harvesting, etc. At L4.2 the operations chemical fertilizer and animal manure application are aggregated, which includes the respective labour requirement. This is one exemplary technological trade-off represented in the structure, further trade-offs are the nests L6.1 (land preparation) and L6.2 (plant protection). These latter two are aggregated at fixed shares together with other operations at L5.1. Other operations includes all field operations, which do not include any technological trade-off such as sowing, irrigation, and harvesting.[27]

For the value added nest L2.2 within this structure we apply elasticities from the GTAP database (T. Hertel, McDougall, Narayanan, & Aguiar, 2008). The elasticity taken for the aggregation of capital (L3.2) and labour (L3.3) equals 1.5 and is based on Hertel (1997a). For the elasticity of the land-fertilizer aggregate (L.31) we follow (Bouët et al., 2010), which use an elasticity of 0.4 in the context of developing countries. No elasticities are needed at nest level 4.1 and 5.1, where the nest is aggregated using fixed shares assuming Leontief technology. This entails the logic that every unit of land requires the same bundle of field operations. The elasticity governing the aggregation of different land types is assumed to be 1.2, however, the choice of elasticity does not affect model results as at the current aggregation level all activities only use one type of land. The elasticity of aggregating chemical fertilizer and organic fertilizer at nest L4.2 is set as 1.2, which is within the range of estimates of 0.523 and 1.327 that Ali und Parikh (1992) found for non-tractorized and tractorized plots in Pakistan. The substitution of different land preparation technologies (mechanically, animal traction or manual) is assumed to be perfectly elastic, which is why we assume a very high elasticity of 6 at nest L6.1. At nest L6.2 the elasticity to aggregate plant protection operations is assumed to be 0.5, reflecting imperfect elasticity.

The Armington elasticities for the aggregation of imports and domestically produced goods are also taken from the GTAP database (T. Hertel et al., 2008). Income elasticities for households are based on estimates provided by Minten and Dukpa (2010a), which estimated an Almost Ideal Demand System (AIDS) for Bhutan using 2007 household data.

[27] In case of livestock activities, labour enters at L5.1 and pasture land at L5.2. At L4.2, instead of fertilizers the different types of feed (Compound feed,crop residues and crop fodder) are aggregated.

Appendix 4D Impacts on the Livestock Sector



	Milk	Beef	Manure AEZ1	Manure AEZ2	Manure AEZ3	Draught power AEZ1	Draught power AEZ2	Draught power AEZ3	Other animal products	All lvst. products
Output quantity	0.2	0.6	6.0	5.7	8.8	5.5	4.3	3.1	-3.0	0.2
Supply quantity	-3.3	-3.3	6.0	5.7	8.8	5.5	4.3	3.1	-3.0	-1.6
Purchaser price	-1.9	-1.6	13.9	19.0	21.4	8.7	15.1	3.4	-1.0	2.4

Figure 4.8. Percentage changes in livestock output, supply, and purchaser prices after simulating a 100% organic policy

4.8 References

Adamtey, N., Musyoka, M.W., Zundel, C., Cobo, J.G., Karanja, E., Fiaboe, K.K.M., Muriuki, A., Mucheru-Muna, M., Vanlauwe, B., Berset, E., Messmer, M.M., Gattinger, A., Bhullar, G.S., Cadisch, G., Fliessbach, A., Mäder, P., Niggli, U. and Foster, D. (2016), "Productivity, profitability and partial nutrient balance in maize-based conventional and organic farming systems in Kenya", *Agriculture, ecosystems & environment*, Vol. 235, pp. 61–79.

Ali, F. and Parikh, A. (1992), "Relationships among labor, bullock, and tractor inputs in Pakistan agriculture", *American Journal of Agricultural Economics*, Vol. 74 No. 2, pp. 371–377.

Armington, P.S. (1969), "A Theory of Demand for Products Distinguished by Place of Production", *IMF Staff Papers*, Vol. 16 No. 1, pp. 159–178.

Atwood, S., Nagpal, S., Mbuya, N. and Laviolette, L. (2014), *Nutrition in Bhutan: Situational Analysis and Policy Recommendations*, Washington DC, USA.

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M.J., Aviles-Vazquez, K., Samulon, A. and Perfecto, I. (2007), "Organic agriculture and the global food supply", *Renewable Agriculture and Food Systems*, Vol. 22 No. 2, pp. 86–108.

Barbieri, P., Pellerin, S. and Nesme, T., "Comparing crop rotations between organic and conventional farming", *Scientific Reports*, Vol. 7 No. 1, p. 13761.

Bouët, A., Dimaranan, B.V. and Valin, H. (2010), *Modeling the global trade and environmental impacts of biofuel policies, IFPRI Discussion Paper*, Washington DC.

Boulanger, P., Dudu, H., Ferrari, E. and Philippidis, G. (2016), "Russian Roulette at the Trade Table: A Specific Factors CGE Analysis of an Agri-food Import Ban", *Journal of Agricultural Economics*, Vol. 67 No. 2, pp. 272–291.

Chettri, G.B., Ghimiray, M. and Floyd, C.N. (2003), "Effects of farmyard manure, fertilizers and green manuring in rice-wheat systems in Bhutan: results from a long-term experiment", *Experimental Agriculture*, Vol. 39 No. 02, pp. 129–144.

Connor, D.J. (2008), "Organic agriculture cannot feed the world", *Field Crops Research*, Vol. 106 No. 2, pp. 187–190.

Dabbert, S., Haring, A.M. and Zanoli, R. (2004), *Organic farming: Policies and prospects*, Zed Books.

Dema, Y., Dorji, K.D., Pem, T. and Tenzin, N. (2012), "Long term study on potato-maize based farming system as managed by the farmers of Eastern Bhutan", *Journal of RNR Bhutan*, Vol. 8 No. 1, pp. 53–62.

Duba, S., Ghimiray, M. and Gurung, T.R. (2008), *Promoting organic farming in Bhutan*, Thimphu, Bhutan.

European Council (2007), "Council regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing regulation (EEC) No 2092/91", *Off. J. Eur. Union*, Vol. 189, pp. 1–23.

Fairweather, J.R. (1999), "Understanding how farmers choose between organic and conventional production. Results from New Zealand and policy implications", *Agriculture and Human Values*, Vol. 16 No. 1, pp. 51–63.

FAO (2009), *Declaration of the world summit on food security*, Rome, Italy.

FAO (2012), *Bhutan - Agricultural Sector review Vol. 1*, Rome, Italy.

FAO (2017), "FAOSTAT database", available at: http://www.fao.org/faostat/en/ (accessed 10 March 2017).

Feuerbacher, A., Dukpa, C. and Grethe, H. (2017), *A 2012 Social Accounting Matrix (SAM) for Bhutan with a detailed representation of the agricultural sector: Technical Documentation, Working Paper*, Berlin.

Feuerbacher, A. and Grethe, H. (2017), *Incorporating seasonality of labour markets in a general equilibrium framework*, Paper presented at the 20th Annual Conference on Global Economic Analysis, Purdue, USA.

Ghaley, B.B. and Christiansen, J.L. (2010), "On-farm assessment of mineral nitrogen and cultivar effects on rice productivity in Bhutan highlands", *Acta Agriculturae Scandinavica, Section B - Plant Soil Science*, Vol. 60 No. 5, pp. 460–471.

GNHC. (2013). Eleventh Five Year Plan 2013-2018: Volume 1: Main Document. Thimphu.

Gurung, J.B., Tamang, N.B., Dorji, T., Gyeltshen, J., Wangdi, J. and Maya Rizal, G. (2015), *Optimizing Feed and Fodder Production and Utilization*, Jakar, Bhutan.

Halberg, N., Sulser, T.B., Høgh-Jensen, H., Rosegrant, M.W. and Knudsen, M.T. (2006), "The impact of organic farming on food security in a regional and global perspective", in Halberg, N., Alroe, H.F. and Knudsen, M.T. (Eds.), *Global development of organic agriculture: challenges and prospects*, CABI, pp. 277–322.

Hertel, T., McDougall, R., Narayanan, B. and Aguiar, A. (2008), *Chapter 14: Behavioral Parameters, GTAP 7 Data Base Documentation*, West Lafayette, USA.

Hertel, T.W. (1997), *Global Trade Analysis: Modeling and Applications*, Cambridge university press.

IFOAM (2014), *The IFOAM norms for organic production and processing: Version 2014.*, Bonn, Germany.

Jacobsen, L. and Frandsen, S. (1999), *Analysis of the economic consequences of restructuring Danish agriculture for organic production*, Copenhagen, Denmark.

Katwal, T.B. (2013), *Multiple cropping in Bhutanese agriculture: Present status and opportunities*, Thimphu.

McDonald, S. and Thierfelder, K. (2015), "A Static Applied General Equilibrium Model: Technical Documentation. STAGE Version 2: January 2015", *Model Documentation*.

Minten, B. and Dukpa, C. (2010), *An analysis of household food demand in Bhutan*, Ministry of Agriculture and Forests of Bhutan, Thimphu.

MoAF (2013a), *Agricultural Sample Survey 2012*, Thimphu, Bhutan.

MoAF (2013b), *Livestock Census 2012 micro-data*, Thimphu, Bhutan.

MoF (2010), *Bhutan Trade Statistics 2009*, Thimphu, Bhutan.

MoF (2013), *Bhutan Trade Statistics 2012*, Thimphu, Bhutan.

Muller, A., Schader, C., Scialabba, N.E.-H., Brüggemann, J., Isensee, A., Erb, K.-H., Smith, P., Klocke, P., Leiber, F., Stolze, M., Niggli, U. and El-Hage Scialabba, N. (2017), "Strategies for feeding the world more sustainably with organic agriculture", *Nature Communications*, Vol. 8 No. 1, p. 1290.

Musyoka, M.W., Adamtey, N., Muriuki, A.W. and Cadisch, G. (2017), "Effect of organic and conventional farming systems on nitrogen use efficiency of potato, maize and vegetables in the Central highlands of Kenya", *European Journal of Agronomy*, Vol. 86, pp. 24–36.

Neuhoff, D., Tashi, S., Rahmann, G. and Denich, M. (2014), "Organic agriculture in Bhutan: potential and challenges. Organic Agriculture", *Org. Agr.*, Vol. 4 No. 3, pp. 209–221.

NOP (2016), "About Us", available at: http://www.nop.gov.bt/about-us/ (accessed 30 November 2016).

NRC (2010), *Toward sustainable agricultural systems in the 21st. century*, The National Academies Press, Washington DC, USA.

NSB and ADB (2012), *Bhutan Living Standard Survey 2012 - dataset*, Thimphu, Bhutan.

NSB and World Bank (2012), *Bhutan Poverty Analysis 2012*, Thimphu, Bhutan.

Paul, S. (2015), "To build a greener economy, Bhutan wants to go organic by 2020", *Reuters,* 28 September, available at: http://www.reuters.com/article/us-bhutan-emissions-farming-idUSKCN0RS0DO20150928 (accessed 4 January 2017).

Ponisio, L.C., M'Gonigle, L.K., Mace, K.C., Palomino, J., Valpine, P.d. and Kremen, C. (2014), *Data from: Diversification practices reduce organic to conventional yield gap: Diversification practices reduce organic to conventional yield gap*, Vol. 282, The Royal Society; Dryad Digital Repository.

Ponisio, L.C., M'Gonigle, L.K., Mace, K.C., Palomino, J., Valpine, P.d. and Kremen, C. (2015), "Diversification practices reduce organic to conventional yield gap", *Proc. R. Soc. B*, Vol. 282 No. 1799, p. 20141396.

Ponti, T. de, Rijk, B. and van Ittersum, M.K. (2012), "The crop yield gap between organic and conventional agriculture", *Agricultural Systems*, Vol. 108, pp. 1–9.

Pretty, J.N., Ball, A.S., Lang, T. and Morison, J.I.L. (2005), "Farm costs and food miles: An assessment of the full cost of the UK weekly food basket", *Food Policy*, Vol. 30 No. 1, pp. 1–19.

Punt, C. (2013), “Modelling multi-product industries in computable general equilibrium (CGE) models”, Stellenbosch: Stellenbosch University, 2013.

Reganold, J.P. (2012), “The fruits of organic farming”, *Nature*, Vol. 485 No. 7397, pp. 176–177.

Reganold, J.P. and Wachter, J.M. (2016), “Organic agriculture in the twenty-first century”, *Nature Plants*, Vol. 2, p. 15221.

RGoB (2008), *The Constitution of the Kingdom of Bhutan*, Thimphu, Bhutan.

RGoB (2010), *Economic Development Policy of the Kingdom of Bhutan, 2010*, Thimphu, Bhutan.

RGoB (2011), *Renewable natural resources (RNR) research policy of Bhutan*, Thimphu, Bhutan.

Roder, W., Gratzer, G. and Wangdi, K. (2002), “Cattle grazing in the conifer forests of Bhutan”, *Mountain Research and Development*, Vol. 22 No. 4, pp. 368–374.

Seufert, V., Ramankutty, N. and Foley, J.A. (2012), “Comparing the yields of organic and conventional agriculture”, *Nature*, Vol. 485 No. 7397, pp. 229–232.

Seufert, V., Ramankutty, N. and Mayerhofer, T. (2017), “What is this thing called organic? – How organic farming is codified in regulations”, *Food Policy*, Vol. 68, pp. 10–20.

Tashi, S. (2015), “The Prospects of Organic Farming in Bhutan”, Dissertation, University of Bonn, Bonn, Germany, 11 February.

Tashi, S. and Wangchuk, K. (2016), “Organic vs. conventional rice production: comparative assessment under farmers’ condition in Bhutan”, *Organic Agriculture*, Vol. 6 No. 4, pp. 255–265.

Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R. and Polasky, S. (2002), “Agricultural sustainability and intensive production practices”, *Nature*, Vol. 418 No. 6898, pp. 671–677.

Ton, P. (2013), *Productivity and Profitability of Organic Farming Systems in East Africa*, Bonn, Germany.

Tweeten, L. (1999), “The Economics of Global Food Security”, *Applied Economic Perspectives and Policy*, Vol. 21 No. 2, pp. 473–488.

van Meijl, H., van Rheenen, T., Tabeau, A. and Eickhout, B. (2006), “The impact of different policy environments on agricultural land use in Europe”, *Scenario-Based Studies of Future Land Use in Europe*, Vol. 114 No. 1, pp. 21–38.

Watson, C.A., Atkinson, D., Gosling, P., Jackson, L.R. and Rayns, F.W. (2002), “Managing soil fertility in organic farming systems”, *Soil Use and Management*, Vol. 18.

Yeshey and Bajgai, Y. (2014), “An assessment of glyphosate use and its cost effectiveness as a substitute for farm labor on paddy terrace bunds”, *Journal of RNR Bhutan*, Vol. 10 No. 1, pp. 27–34.

Chapter 5 Increasing Forest Utilization within Bhutan's Forest Conservation Framework

- The Economic Benefits of Charcoal Production

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Abstract

Bhutan is known for its rich natural resource endowments and strict conservation policy. With 70% forest cover, only 5% of the forest area is designated to commercial management. Recent analyses advocate for increasing forest utilization to decrease the country's dependence on imports of forest-based products, particularly charcoal, as a mean to diversify the national economy. This study examines how increasing the forest area under commercial management might allow for sustainable charcoal production in Bhutan. Using an optimization model, cost efficient locations of charcoal production sites were identified at subnational level. Simulation results show that at a discount rate of 12% charcoal production is profitable in eleven of the nineteen districts. Domestic charcoal production has the potential to offset up to 61% of charcoal imports, requiring an increase in utilized forest area from 5% to 15% of total forest area. Charcoal production would represent a high value-added activity, with an average value-added share of 50.8%. Transportation and labour costs have only minor effects on profitability, comprising 11.7% and 2.5% of output value, respectively. Monte Carlo simulations and sensitivity analyses confirm the results that using a decentralized approach, Bhutan can increase commercial forest management without jeopardizing its highly acclaimed forest conservation agenda. Policy implications and areas of future research are briefly highlighted.

Keywords: Forest utilization; Forest conservation; Bhutan; Charcoal production; Optimization; Economic assessment

5.1 Introduction

Bhutan is endowed with tremendous natural resources: about 70% of the country is forested with a constitutionally manifested minimum forest cover of 60% (RGoB, 2008). With a high degree of endemic flora and fauna Bhutan ranks among the top ten countries as regards species per unit land area. Using a benefit transfer method, Kubiszewski, Costanza, Dorji, Thoennes, and Tshering (2012) approximate the total value of ecosystem services in Bhutan at about $15.5 billion/year.

Recent studies have emphasized the untapped potential of Bhutan's forestry sector (Jadin et al., 2015; Siebert & Belsky, 2015; Uddin, Taplin, & Yu, 2007) for wood production and how it can contribute to Bhutan's economic strategy of diversifying the "economic base with minimal ecological footprint" and sustainably adding "value to natural resources" (RGoB, 2010, p. 5). The Royal Government of Bhutan (RGoB) has set the target to more than double current level of forest under commercial management from about 5% to 12% of total forest area until 2018 (GNHC, 2013). This increase in forest area utilization might mitigate Bhutan's recent macroeconomic turbulences, caused by its high current account deficit, which induced restrictions on imports, credit issuance and currency exchanges (BBS, 2012; RMA, 2012).[28] Charcoal - one of Bhutan's largest single import items with a share of almost 2% in total imports in 2013 - seems to be a forest commodity of particular relevance and potential (MoF, 2013b).

In Bhutan, charcoal is in high demand by metallurgical industries, where it is used as a chemical reducing agent for the production of ferro-alloys and calcium carbide. Charcoal can be substituted by coke, which is another source of carbon. However, due to its lower greenhouse gas emission profile charcoal represents a more environmentally friendly alternative. (Emmerich & Luengo, 1996; Hu et al., 2011; Suopajärvi & Fabritius, 2013). As they are primarily used as chemical reducing agents, neither coke nor charcoal can be replaced by hydropower, which is abundantly available in Bhutan at very low cost, or any other sources of electricity. Charcoal imports from India experienced an almost tenfold increase between 2005 to 2014, growing from approximately 9,400 to 90,000 tons during that period (see Figure 5.1) MoF, 2013b, 2014, 2015; UN, 2015a. Within the same time span, real import unit prices increased at an average rate of 4.1%.

[28] In the remainder of this paper, we refer to increased forest utilization as an increase of utilized forest area (i.e. extensification of forest area). This study does not consider higher degrees of intensification of existing forest area as a mean of increased forest utilization.

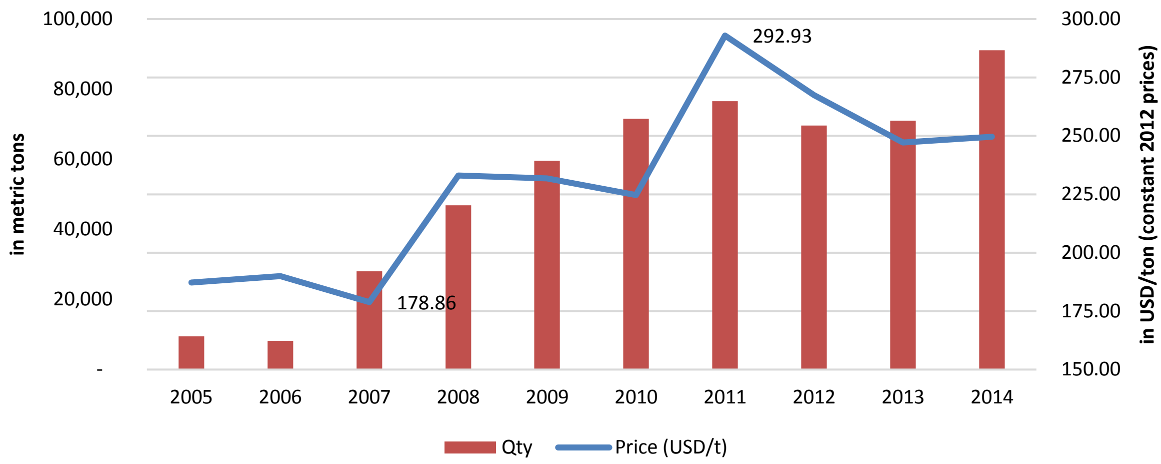

Figure 5.1. Quantity and unit prices of charcoal imports from 2007-2014

Source: MoF, 2013, 2014, 2015; UN, 2015.

In the 1990s, the objective of increasing charcoal production in Bhutan was already an integrated part of a World Bank project (World Bank, 1985). These plans were eventually abandoned for two principal reasons. First, it was argued that labour supply constraints and logistical barriers associated with transporting wood to the charcoal retorts would make production economically infeasible. Second, it was claimed that charcoal production would have been possible if the necessary forest land (8,500 ha) had been made available. However, the Forest Department "appear[ed] to be reluctant to place such a large area of forest land outside its control" (World Bank, 1992). The same arguments still represent significant barriers for associated investments today.

Strict conservation approaches to forest management continue to be of highest priority for many policymakers and civil society in general. During group discussions and expert interviews with government officials in 2013, it was noted that charcoal production and an increased level of forest utilization by extending the area under commercial forest management is commonly associated with deforestation and environmental degradation. Further, supply of labour continues to be perceived as a major constraint, with labour shortages being primarily experienced in agriculture (Neuhoff et al., 2014). Last but not least, transportation costs per ton and km continue to be high and are approximately 60% higher than in neighboring India (RSTA, 2012). Given their alleged importance, the subsequent analysis will focus on these factors. The contribution of this paper to the policy dialogue and literature is as follows: First, we summarize recent literature on forestry issues and economic development in Bhutan to enhance the understanding how a scenario of increased forest utilization and charcoal production links to the broader economic development discussion in Bhutan. Second, we employ a transport and investment optimization model to assess the economic feasibility of forest utilization for charcoal production. The model represents a novel approach to analyzing the potential of forest utilization in Bhutan as it disaggregates results at sub-national levels. This allows initial conclusions regarding the comparative advantage of different regions in Bhutan for commercial forest management. Third, the robustness of this quantitative analysis is tested using Monte-Carlo simulation techniques and sensitivity analyses. The paper concludes with a brief discussion of policy implications.

5.2 Study Context

5.2.1 Forest Conservation and Utilization in Bhutan

Bhutan's forest cover is estimated at about 70% of total land area (Gilani et al., 2015).[29] Although there have been regional reports of forest degradation (Moktan, 2014), Bruggeman, Meyfroidt, and Lambin (2016) reported that the Bhutanese forest area remained constant during the 1990s and even increased slightly in the first decade of the 21st century. Even though its large forest area, only about 5% of Bhutan's forests are under commercial management while about a third (32.8%) is within protected areas (MoAF, 2012b). Consequently, and despite making up 3% of Bhutan's GDP, the forestry sector employed only 0.5% of Bhutan's labour force in 2012, i.e. approximately 1,500 workers (ADB & NSB, 2013; NSB, 2014).

In 2013, a forest resources potential assessment (FRPA) estimated that additional 333,040 to 514,730 hectares of forest area could be sustainably utilized, corresponding between 12.3% and 19.0% of total forest area, respectively (MoAF, 2013c). Bhutan's current low level of commercial forest utilization can be attributed to rigorous forest conservation policies and the overarching constitutional mandate of maintaining 60% of forestry cover at all times to come (RGoB, 2008). The country's extreme mountainous terrain and the associated risk of natural-based hazards is one of the primary reasons for assigning such high priority to forest conservation. In 1979, logging by private operators was banned and has ever since been exclusively performed by the government (MoAF, 2011). Devastating consequences from deforestation in neighbouring countries such as Nepal have made a lasting impression on

[29] If shrub forests are included in the land cover calculation, the forest area increases to approximately 80%.

Bhutanese society. Given both its mountainous terrain and dependency on hydropower, ecosystem service functions from forests, such as watershed conservation and soil erosion prevention, are particularly vital for the sustainable usage of natural resources in Bhutan (Nkonya, Srinivasan, Anderson, & Kato, 2014). Hence, increasing sustainable forest utilization must be accompanied by appropriate safeguards to prevent loss of forest ecosystem services.

Productive forest management in Bhutan is differentiated by forest area under commercial management, divided into forest management units (FMUs) for the extraction of wood and timber for sale, and forests exclusively utilized by the rural population, i.e. forests to satisfy local demand for wood and timber for subsistence use. In case of community forests, after local, subsistence use is satisfied below the approved harvest levels, local communities can also trade and sell remaining quantities up to the approved level. The regulatory framework for local forest use grants rural households subsidized royalty rates and entitle them to an annual firewood supply of either 8 or 16 m^3 of stacked volume, depending on whether they live in an area serviced with electricity (RGoB, 2006). The Natural Resources Development Corporation Limited (NRDCL) has the exclusive mandate for commercial wood extraction (NRDCL, 2009). The NRDCL manages FMUs with a net operable forested area of 138,521 hectares, representing approximately 5% of the total forest area in 2012 (MoAF, 2012b).

Several measures are applied by the government to FMUs to avoid "weakening the ecological productivity of the forest area" and comply with the country's conservation objectives (MoAF, 2011). First, extraction is limited by the annual allowable cut (AAC), which is determined by the Department of Forests and Park Services. Second, the predominant silvicultural practice applied by the NRDCL is group selection cutting accompanied by artificial and/or natural regeneration (Moktan, Gratzer, Richards, Rai, Dukpa et al., 2009; Thinley U, 2002). Single-tree harvesting is the most common extraction method for local use, particularly in broadleaved forests. Third, given the extreme terrain, there are substantial efforts to ensure reduced impact logging in Bhutan (Thinley U, 2002). Various studies have assessed the sustainability of silvicultural systems in Bhutan with particular focus on the preferences of group selection versus single-tree harvesting in the context of natural regeneration and herbivore browsing (Buffum, Gratzer, & Tenzin, 2008; Covey et al., 2015; Moktan, Gratzer, Richards, Rai, & Dukpa, 2009; Moktan, Gratzer, Richards, Rai, Dukpa et al., 2009). The cable cranes used in Bhutan are generally gravity machines with logging reaches of up to 1,500 meters. Prime timber is exclusively extracted by the NRDCL, while for the extraction of forest residues (lops and tops) also contractors are engaged (NRDCL, 2009). Lops and tops represent the resource base for charcoal production and in the remainder of this paper we refer to these products as fuelwood.[30]

5.2.2 Wood Energy Potential and the Need for Forest Sector Reforms

Various studies have analyzed Bhutan's potential for increasing forest utilization. Uddin *et al.* (2007) concluded more generally that increasing the use of forest products could help to reduce the country's vulnerability towards its "one-commodity-one-country dependence", i.e. hydropower exports to India. Siebert and Belsky (2015) particularly highlight the country's wood-based biomass energy potential and that political objectives such as energy independence, increasing rural income and employment, and even biodiversity conservation could be met by increasing managed extraction of wood for energy. Given that Bhutan currently imports massive amounts of wood-based commodities, especially charcoal, Jadin *et al*. (2015) analyzed the net effects of Bhutan's forest conservation policies on the displacement of land use abroad, focusing on the trade of wood products with India. The authors argue that low added-value activities such as charcoal production are externalized to neighboring countries, especially India while Bhutan specialized in high value-added activities (production of metallurgical products).[31] Their first and most explicit assumption is that charcoal production is a low value-added activity compared to upstream industrial activities such as steel production. The second and rather implicit assumption is that through functional upgrading, i.e. importing charcoal, negative externalities were "exported" to countries with a less stringent regulatory framework for forest utilization than Bhutan. If produced domestically, the high standard of environmental stewardship in Bhutan can also be applied to charcoal production. These aspects are discussed in the concluding sections of this paper.

5.3 Methodology and Data

5.3.1 General Approach

Despite Bhutan's relatively small geographic size, a spatially disaggregated approach at the district level was chosen to account for high transportation costs associated with Bhutan's extreme mountainous terrain and highly variable fuelwood supply and pricing across districts.

[30] For the purpose of this paper we have adopted the definition of fuelwood as used by FAO (1983); World Bank (2011) for their analysis of charcoal production, i.e. fuelwood is the wood used for the production of charcoal and the wood used for final energy consumption by households for cooking and heating, for commercial or for industrial uses.

[31] Jadin et al. (2015) considered the country's position of being a net importer of charcoal as a "functional upgrading in the value chain".

There are twenty districts (Figure 5.2) or Dzongkhags in Bhutan. Excluding Gasa, a sparsely populated and alpine Dzongkhag in Northern Bhutan, sustainable forest resource utilization data are available for the other 19 districts. The present analysis applies the parameters of the carbon twin retort modular system described by Reumermann and Frederiks (2002) as it is regarded as a good technical fit for charcoal production in Bhutan. A more detailed description on charcoal technology can be found in Appendix 5A. District level fuelwood pricing, fuelwood quality (i.e., the basic density and moisture content of wood) and transportation distance data were collected from various sources. The ten-year average charcoal import price (reported in CIF terms) is used as a proxy for output prices. We assume that domestic charcoal producers would receive the difference between these prices and the respective transportation cost to charcoal consumers. Given the small size of Bhutan's economic compared to its neighboring countries, domestic charcoal output is assumed to not impact the import price of charcoal.

The analytical framework relies on two models. First, a mathematical programming-based transport model was developed to identify locations for charcoal production sites by optimizing forest resource allocation and transportation costs under production constraints. The outputs of this model include (i) a fuelwood supply and use matrix associated with charcoal production sites and (ii) a charcoal supply matrix for the industrial centers. These matrices are used as inputs to the second model, which is a multi-period investment model, programmed using R software to assess the profitability of each production site. The second model is also used to perform a Monte Carlo risk analysis, which conducts 1000 simulations of model outcomes based on the stochastic variance of the major model parameters, such as the prices of charcoal and fuelwood. In addition to the Monte Carlo risk analysis, *ceteris-paribus* scenarios were simulated to further test the robustness of the model results.

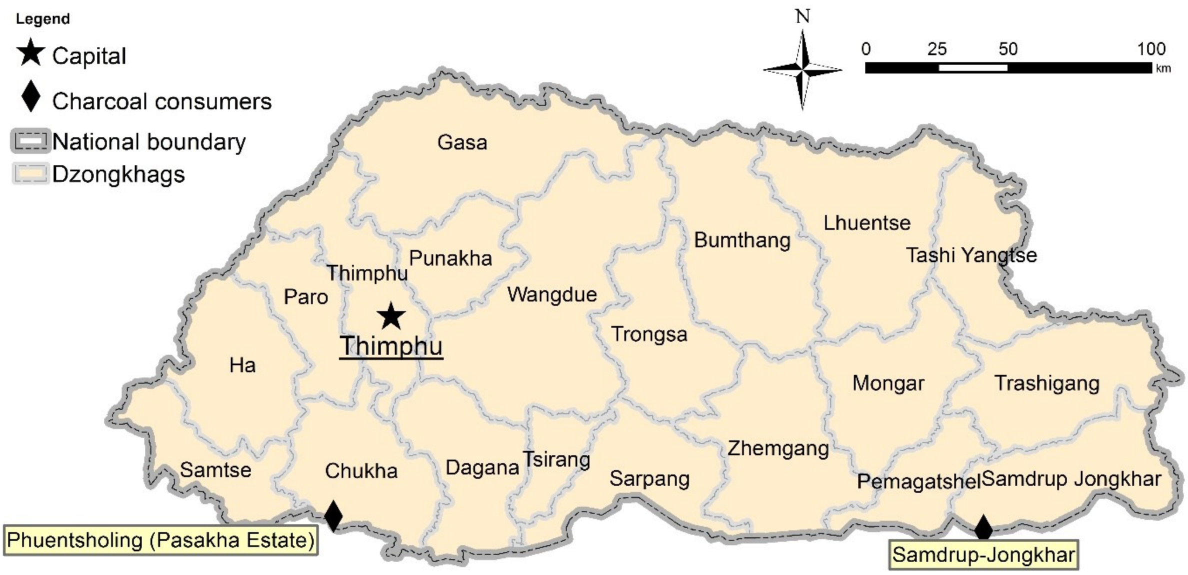

Figure 5.2. Map of Bhutan showing Dzongkhags and locations of charcoal consumers

Source: Author's illustration.

5.3.2 Estimation of Forest Resource Availability

The current levels of forest utilization in Bhutan does not supply sufficient amounts of fuelwood for domestic charcoal production, which results in the current levels of import volumes discussed earlier. Consequently, charcoal producers would either be forced to compete with existing fuelwood consumers (i.e., fuelwood used by households for cooking and heating) or an extension of the area under forest utilization would be necessary to increase the supply. Given the strict regulations within the forestry sector and the separation of rural and urban timber markets, modelling the market equilibrium of fuelwood within the present framework extends beyond the scope of this study. Instead, this analysis is based on the estimated sustainable supply of forest resources associated with the increased utilization of forest area.

This additional supply of fuelwood is estimated at the district scale using various factors:

(1) additional potential of commercially manageable FMU area of forest type[32] *k* in district *i* (in hectares) - $For_{i,k}$;

(2) actual net operable forest area (expressed as a share of commercially manageable forest area) – $NetOp$;

(3) Annual Allowable Cut in m^3 per hectare and forest type - AAC_k;

and

(4) the percentage of AAC that is harvested as fuelwood - $\%FW_k$. Data tables for each of the parameters are presented in Appendix 5B.

The sum of $For_{i,k}$ is assumed to represent the lower estimate from the recent FRPA study (MoAF, 2013c), which is equal to 333,040 hectares. The FRPA is a spatial-multi criteria analysis (details in Appendix 5C) assessing the additional forest areas that might be brought under commercial management via FMUs. The estimates of additional potential forest production area range between 333,040 to 514,730 hectares (12.3% and 19.0% of total forest area). The upper estimate is based on a maximum slope of 45° and includes watershed areas. The lower estimate excludes watershed areas and includes only slopes below 35° to account for reducing erosion probability. Both estimates exclude protected areas, which comprise 28.6% of Bhutan's forest area (Gilani et al., 2015). This shows that even when applying conservative and conservation-based selection criteria, a significant forest area is available for increasing forest utilization.

The constant $NetOp$ share is equal to 46.6% (MoAF, 2012b). This share is based on national data and is not differentiated by forest type due to data limitations. AAC_k and $\%FW_k$ have been determined by Schindele (Schindele, 2004). AACs per hectare of managed forest are quite low in Bhutan, ranging from 1.3 to 3.1 m^3/hectare. This is partially due to climatic conditions, harvest technology limitations and challenging mountainous terrain. However, AACs may also be lower than necessary due to conservative forest management practices. The percentage of the harvest that is fuelwood is used to compute how much of the annual harvest could be used for charcoal production. Large portions of currently unused FMU areas are characterized as broadleaved forests. Broadleaved forests have both a higher AAC and a higher percentage of AAC that is harvested as fuelwood compared to other forest types. However, hardwoods

[32] Blue pine (*Pinus wallichiana*), chir pine (*Pinus roxburghii*), fir, mixed conifer, broadleaf & conifer and broadleaf.

generally grow less straight than softwoods, making them harder to utilize for construction or furniture manufacturing. Additionally, hardwood forests have been previously utilized to a lesser extent. According to forestry officers from the MoAF, hardwood timber is more difficult to process using the current technologies available in Bhutanese sawmills.

Based on the data presented above, the supply of additional fuelwood $Q_i^{Fwd\_S}$ can be estimated for each district according to equation (5.1):

$$Q_i^{Fwd\_S} = NetOp * \sum_{k=1}^{6} \left(For_{i,k} * AAC_k * \%FW_k \right) \quad (5.1)$$

5.3.3 Transport Model

A two-stage, cost-minimizing mathematical programing model was implemented to determine the most profitable locations for the charcoal production units among the 19 Bhutanese districts studied. These locations were determined based on fuelwood quality, availability, and costs. Transport costs include fuelwood transport costs and, at the second level, charcoal transport costs to the metallurgical industry centers (referred to as *consumers*) in Phuentsholing (P/ling) and Samdrup Jongkhar (S/Jongkhar). Wolfsmayr and Rauch (2014) present in their literature review a large number of studies that applied similar optimization models to decision-making problems. For example, Nørstebø and Johansen (2013) used a comparable modelling approach to determine the optimal locations of quay facilities and log transportation routes in Norwegian coastal regions.

In 2012, the largest share of charcoal imports (83.4%) was consumed in P/ling, (SW Bhutan; see Figure 5.2). The remaining 16.6% was supplied to S/Jongkhar (SE Bhutan) (MoF, 2015). Decentralized domestic charcoal production sites are faced with inherent transportation costs to either SW or SE Bhutan. These costs substantially vary at the district level. Assuming that the charcoal imports from 2012 (69,567 tons) reflect the maximum domestic demand, the total charcoal demands of P/ling and S/Jongkhar are equal to 58,019 and 11,548 tons, respectively.

The transportation costs between districts and consumers were calculated using the Bhutanese Road Safety and Transport Authority (RSTA) road map and transportation cost data (RSTA, 2012, 2014). According to the RSTA, transporting one ton via hilly routes amounts to US-$ 0.17 per kilometer and ton. The cost via flat routes is considerably cheaper at only US-$ 0.10

per kilometer and ton.[33] Hence, some shorter routes in Bhutan may result in higher transportation costs compared to longer routes that travel via India over flat terrain and back into Bhutan. Only transportation distances resulting in minimum costs were considered when determining the distances between districts and from districts to consumers. The transportation costs between districts are only relevant for the transport model, as this value is based on the cost of transporting fuelwood between districts as input for charcoal production. A portion of the district-to-district fuelwood transportation cost matrix (transportation cost from district j to district i; $TC_{i,j}^{Fwd}$) is shown in Appendix 5D, which displays the transportation costs of one m^3 of fuelwood between Dzongkhag centers. The charcoal transportation costs between the districts i and consumers l ($TC_{l,i}^{Char}$) are calculated per ton and km using the same data and road map as the fuelwood district-to-district matrix.

Annual fuelwood prices per district were provided by the NRDCL for a period from 2008 to 2014. These prices were converted to constant 2012 prices denoted in USD (NRDCL, 2014). Table 5.1 lists these values, parameter abbreviations and the underlying data sources for an example district (Bumthang).

[33] Transportation cost data are published for 4-5 and 8-10 metric ton trucks, of which an average is used. Hiring charges excluding halt charges are 0.14 and 0.08 USD/km and ton, respectively. Halt charges are added as a 25% mark-up to the total hiring charges.

Table 5.1. District-specific parameters and data used in the transport and investment model of Bumthang

District-specific parameters		i = Bumthang	Dimensions	Data Sources
Avg. green wood density ρ_i^{green}		0.803	tons/m^3	Sukla *et al*., 1992; Sukla and Negi, 1994
Avg. green wood moisture content mc_i^{green}		48.7%	% wet basis	
District-specific charcoal conversion ratio $conv_i^{Char}$		6.84	m^3 fuelwood (wet basis) per ton of charcoal (dry basis)	Appendices C and E
Fuelwood price in Bumthang P_i^{Fwd}		12.32	USD/m^3	Mean based on NRDCL (2014)
Distance to P/ling (via Bhutan and India)	Over hilly roads	312	km	RSTA (2014)
	Over flat roads	195	km	
Cost of charcoal transportation to P/ling $TC_{P/ling,i}^{Char}$		70.19	USD/ton	
Distance to S/Jongkhar (via Bhutan and hilly roads only)		464	km	
Cost of charcoal transportation to S/Jongkhar $TC_{S/Jongkhar,i}^{Char}$		74.35	USD/ton	

5.3.4 Objective Function and Model Constraints

The minimized objective function (5.2) includes all of the inherent production costs, such as costs associated with fuelwood purchases, fuelwood transport, capitalized production costs per unit charcoal and charcoal transport to metallurgical industries. The model can be used to assess charcoal production in any district if the technology related minimum annual fuelwood supply of 17,828 m^3 is satisfied via an internal supply or purchase from other districts. This constraint was implemented in the transport model using binary variables.

$$\begin{aligned} Min\ Z = & \sum_{i}^{19}\sum_{j}^{19}\left[\left(P_j^{Fwd} + TC_{i,j}^{Fwd}\right) * Q_{i,j}^{Fwd_e}\right] \\ & + \sum_{l}^{2}\sum_{i}^{19}\left[Q_{l,i}^{Char_{Output}} * PC_i^{Char_{Process}} + Q_{l,i}^{Char_{Output}} * TC_{l,i}^{Char}\right] \\ & + \sum_{l}^{2} Imp_l^{Char} * P^{Char\_imp} \end{aligned} \quad (5.2)$$

where P_j^{Fwd} is the district and quality specific fuelwood price[34], $TC_{i,j}^{Fwd}$ is the district and product specific transport cost of one m^3 of fuelwood from supplying district *j* to receiving district *i*, $Q_{i,j}^{Fwd_e}$ is the extracted amount of fuelwood in district *j* supplied to district *i*. $Q_{l,i}^{Char_{Output}}$ is the amount of charcoal produced by district *i* for consumer *l* (l = P/ling or S/Jongkhar), $PC_i^{Char_{Process}}$ is the capitalized processing cost per unit of charcoal based on the district-specific fuelwood properties, $TC_{l,i}^{Char}$ is the district-specific transport cost of charcoal to consumer *l*, $\mathrm{Im}\,p_l^{Char}$ is the amount of foreign charcoal imported by the consumers and P^{Char_imp} is the corresponding charcoal import price. The computation of $PC_i^{Char_{Process}}$ is based on the financial project parameters described within the investment model section (see below section 5.3.4). In addition, constant economies of scale were assumed.

The minimization is subject to the following inequalities:

$$\sum_{j}^{19} Q_{i,j}^{Fwd_e} \leq Q_i^{Fwd\_S} \tag{5.3}$$

Equation (5.3) ensures that the actual extracted amount of fuelwood in each district is less than or equal to the total additional fuelwood availability under sustainable forest management.

$$\sum_{l=1}^{2}\left[Imp_l^{Char} + Q_{i,l}^{Cha\_Output} \right] \geq \sum_{l=1}^{2} Q_l^{Cha\_Demand} \tag{5.4}$$

Equation (5.4) enforces the constraint that the total domestic charcoal production and imports must be equal to or greater than the total domestic demand of charcoal consumers *l*, $Q_l^{Cha\_Demand}$, which was 69,567 tons in 2012.

$$Q_i^{Char_{Output}} = \begin{cases} \sum_{j}^{19} \dfrac{Q_{i,j}^{Fwd_e}}{conv_i^{Char}}, \text{ if } \sum_{j}^{19} Q_{i,j}^{FWD_e} \leq 17{,}828 \text{ t} \\ 0, \text{ if } \sum_{j}^{19} Q_{i,j}^{FWD_e} \leq 17{,}828 \text{ t} \end{cases} \tag{5.5}$$

[34] Unfortunately, price data per fuelwood type were not available. The overall fuelwood prices were used instead.

The binary variables in equation (5.5) ensure that charcoal is only produced if the available amount of fuelwood exceeds the technical lower bound of 17,828 t, where $\sum_{j}^{19} Q_{i,j}^{FWD_e}$ is the sum of regionally "domestic" and "imported" fuelwood.

Forest types and the associated fuelwood characteristics vary substantially across Bhutan. These variations are accounted for by calculating a district-specific fuelwood to charcoal conversion ratio $conv_i^{Char}$. This ratio indicates the wet basis volume of fuelwood that equates to one ton of dry basis charcoal. The ratio was calculated using the district-specific fuelwood (Table 5.1) and charcoal production technology parameters (Table 5.2). The equation is presented in 0. Average wood characteristics per district are estimated based on the percentages of forest types within a respective district. These values also account for the physical properties (see data in Appendix 5B) of representative tree species commonly found within each district (MoAF, 2013c; Sukla, Guru, & Negi, 1992; Sukla & Negi, 1994).

Finally, the transportation model optimizes the charcoal supply to consumers in P/ling and S/Jongkhar at a minimum cost to the Bhutanese national economy. The model is solved using the LibreOffice built-in *Calc* spreadsheet solver. Note that the model is solved on a national level. We assume that the government, which controls the forestry sector through the NRDCL, can design conditions to minimize production costs at the national level. Thus, the model provides the most efficient method for satisfying the charcoal demand associated with the Bhutanese metallurgical industry, whether via imports or domestic production. In the latter case, the model provides the most cost efficient locations for charcoal production as well as the necessary material flows, which are constrained by the sustainable forest exploitation restrictions specified in equation (5.1). The results from the transportation model are used as input for the investment model, namely the fuelwood district-to-district supply matrix $Q_{i,j}^{FWD_e}$ and the charcoal supply matrix $Q_{l,i}^{Char_{Output}}$.

5.3.5 Investment Model

Table 5.2 summarizes the technical and financial parameters of a two module twin-retort charcoal production unit with a minimum processing capacity of 17,828 m^3. The reference year for the analysis is 2012. All values are expressed in real USD. Data originally reported in other currencies and years were adjusted accordingly. Capital expenditure data for the charcoal production technology are based on previous installations and expert opinion, as provided by Siemons (2014). In the investment model, production technology related costs, such as capital expenditures, maintenance costs and labour inputs, are adjusted based on the installed capacity determined by the transport model's baseline run. We assume that the capacities of charcoal production units can be tailored custom-specific at linear cost relationship. Hence, if a charcoal production site has a processing capacity of 35,656 m^3 of fuelwood, all production technology related costs would double. This constant economy of scale assumption was validated by expert opinions. However, due to economies of scale, it could be assumed that certain costs, such as staff supervision and machinery (e.g., forklifts) costs, are likely to increase at a lower than proportionate rate.

Transportation data for production equipment was obtained through personal communications with transport companies and local experts in Bhutan (A. Chetri, personal communication, November 20, 2014; Hapag-Lloyd, personal communication, November 4, 2014). The labour cost is estimated based on values 20% over the national median wages per skill level (ADB & NSB, 2013).

Table 5.2. Investment and model parameters

Parameters	Value	Dimension
a) Technical parameters		
# of modules $Q^{Modules}$	2	Modules
Retort cycle duration $rc^{Duration}$	4.5	Hours
Nominal retort capacity rc	4.77	m^3/retort
Capacity factor $CapFac$	96%	Full load equivalent hours/annual hours
Moisture content of carbonized wood mc^{WCarb}	30%	Wet basis (water content/total wood weight)
Charcoal yield $char^{yield}$	34%	Dry charcoal/dry wood
Moisture content of charcoal mc^{Char}	4%	Wet basis
Fuelwood (annual minimum input capacity; $plantcap^{Min}$	17,828	m^3 fuelwood/year at a 96% capacity factor
Electricity consumption q^{Elec}	43.8	MWh/year at a 96% capacity factor
b) *Initial investment*		
Building and Infrastructure	131,940	USD
Carbonization modules	494,775	USD/module
Auxiliary equipment	105,552	USD
Shipping cost NL – Bhutan	32,968	USD
Total upfront capital expenditure $capex$	1,260,011	USD
Expected contingency $Cont_o^{CAPEX}$	10%	% of total initial investment
c) *Project financials*		
Project duration T	15	Years
Real discount rate r	12%	
Maintenance cost $Main_t$	31,500	USD/year; 2.5% of initial investment
Insurance cost	4,780	USD/year; 0.3% of initial investment
Electricity rate p^{Elec}	34,6	USD/MWh
Charcoal import price $P_t^{Char\_imp}$	257.1	USD/ton (mean price from 2005-2014)
Labour cost $labour$	1,518	USD/month
Land lease $land$	2,500	USD/year

Sources: a) Reumerman & Frederiks, 2002; Siemons & Baaijens, 2012; R. V. Siemons, personal communication, November 3, 2014; b) Hapag-Lloyd, personal communication, November 4, 2014; R. V. Siemons, personal communication, November 3, 2014; c) ADB & NSB, 2013; BEA, 2013; Belli, Anderson, Barnum, Dixon, & Tan, 1998; R. V. Siemons, personal communication, November 3, 2014; UN, 2015a.

The carbon twin retort technology is a fairly novel charcoal production technology and availability of performance data is limited. Accordingly, the project duration is limited to 15 years, while the plant is designed to operate for approximately 20 years. The model does not consider a terminal value at the end of the project. Maintenance costs are determined as a share of the initial investment, which is equal to 2.5% based on expert opinion (Siemons, 2014). Based on the average basic density and green wood moisture content of Bhutanese firewood, the carbonization cost of the carbon twin retort technology is estimated at 99 USD/ton (i.e. the cost to convert fuelwood to charcoal). Literature reviewing entire charcoal production cost (Meyer, Glaser, & Quicker, 2011) also include the cost of fuelwood and transportation, which can widely vary between countries. Comparing carbonization costs across countries is thus more appropriate as it is not subject to differences in fuelwood and transportation cost. Norgate and Langberg (2009) report carbonization cost of 113 USD/ton for the Lambiotte continuous retort. Suopajärvi and Fabritius (2013) cite a study in Brazil with 60 USD/ton carbonization cost. For a pilot plant in southern India using coconut shells for the carbonization associated costs were about 76 USD/ton (Dhamodaran & Babu, 2011). This shows that average carbonization cost of 99 USD/ton for Bhutan are at the higher end of the range of carbonization cost. As carbonization costs depend on a range of parameters, such as upfront capital expenditure, maintenance cost, capacity factor, and other production inputs (labour, electricity, etc.) the associated uncertainty is addressed by varying some of these parameters within the Monte Carlo Simulations (see Table 5.3). To further test the robustness of model results towards variation in carbonization cost a *ceteris-paribus* sensitivity analysis is conducted.

The discount rate reflects the cost of capital incorporating the risk free return and risk premium. This analysis disregards inflation; therefore, a real discount rate is applied, and all cash flows are expressed in real terms.[35] Furthermore, because the objective of this analysis is to assess the economic benefits of charcoal production, we ignore debt leverage and tax implications. These assumptions do not alter the actual results, as both the capital return and taxes contribute to the overall economic welfare. The discount rate was set to 12%, which lies within the upper boundary of the range of discount rates (10-12%) that has been traditionally applied by the World Bank in the context of developing countries (Belli et al., 1998).

The economic efficiency of charcoal production is analyzed using a multi-period cash flow modelling framework, which is commonly utilized in investment appraisals. The model is programmed in R with loops for the indices *i* (districts) and *t* (periods). The equations used in the model, variable abbreviations and parameters are presented and explained in Appendix 5F if they were not introduced in Table 5.1 or Table 5.2.

5.3.6 Monte Carlo Simulations

The model is extended by incorporating Monte Carlo simulations (MCS), which reflect uncertainties in model parameters. MCS are used to perform a risk analysis. Simulations are performed using the statistical software package R. Each simulation includes 1000 iterations,

[35] Between 2010 and 2014, inflation and lending rates in Bhutan ranged between 5.5% and 13.5%, and 10.0 to 16.0% between 2010 and 2014 RMA (2015). The applied real discount rate of 12.0% would thus correspond to a nominal discount rate of approximately 17.5% – 25.5%, which is well above the country's interest rate environment.

in which the prices (charcoal and fuelwood), capital expenditure contingency and technological parameters vary annually according to the (assumed) statistical distributions presented in Table 5.3.

Table 5.3. Upper- and lower bounds of general model variables

Log-normal distributed variables	Mean	Standard Deviation	5% percentile	95% percentile
Charcoal import price (2006-2014) (USD/ton)	230.28	36.71	175.25	295.10
Fuelwood price (2008-2014) (USD/m^3) (example given for Bumthang)	12.00	4.2	6.45	19.81
Triangular distributed variables	**Mean**		**Lower boundary**	**Upper boundary**
Capex contingency	10%		5%	15%
Maintenance cost (%)	2.5%		1.5%	3.5%
Capacity factor (%)	90%		84%	96%

Charcoal and district fuelwood price data were limited (ranging from six to ten years); therefore, it was not feasible to conduct a statistical time-series analysis. Additionally, it was not possible to estimate the distribution functions or account for potential trends. Instead, we assume that prices are distributed according to a log-normal distribution. The distribution parameters, the mean and standard deviation were computed using the available time series data. It is reasonable to assume that each district's fuelwood market is separated from other districts due to high transportation costs. Because of this market separation and the lack of sufficient time series price data, we also do not assume that charcoal import prices and fuelwood prices are correlated. The ParameterSolver software package (Cook, 2010) was used to obtain the log-scaled means and standard deviations of the fuelwood and charcoal log-normal distributions. MCS are implemented over the 15-year project horizon.

5.4 Results and Discussion

5.4.1 Results from the Cost Minimization Model

Under the baseline scenario, 42,688 tons of charcoal are produced in eleven of the nineteen districts. This would require an additional annual fuelwood supply of 281,346 m^3, which corresponds to 88.8% of the total estimated fuelwood potential achievable through increasing the forest utilization area. In terms of forest area, 271,488 hectares or 81.65% of the total additional potential forest area would be put under commercial management, increasing the commercially managed forest area from 5% to 15% of total forest area. Fuelwood for charcoal production is supplied by twelve districts.

As shown in the fuelwood supply and use matrix (Table 5.4), the majority of districts exclusively use fuelwood from within the district. The only exceptions are Pemagatshel and Sarpang, both of which purchase fuelwood from neighbouring districts to meet the minimum production capacity constraint. There is only one instance of fuelwood exchange between non-producing districts and producing districts, with Tsirang exporting to Sarpang. This can be explained by the high transportation cost of fuelwood, which is largely due to Bhutan's unfavourable topography.

Table 5.4. Fuelwood district-to-district supply matrix in m³ according to the transport model results

District	Chukha	Dagana	Ha	Mongar	Pema-gatshel	S/Jong-khar	Samtse	Sar-pang	Trashi-gang	Tsirang	Wang-due	Zhem-gang
Chukha	38,847	0	0	0	0	0	0	0	0	0	0	0
Dagana	0	44,892	0	0	0	0	0	0	0	0	0	0
Ha	0	0	25,478	0	0	0	0	0	0	0	0	0
Mongar	0	0	0	21,333	0	0	0	0	0	0	0	0
P/gatshel	0	0	0	0	16,540	1,280	0	0	0	0	0	0
S/Jongkhar	0	0	0	0	0	26,382	0	0	0	0	0	0
Samtse	0	0	0	0	0	0	25,117	0	0	0	0	0
Sarpang	0	0	0	0	0	0	0	9,937	0	7,901	0	0
Trashigang	0	0	0	0	0	0	0	0	20,190	0	0	0
Tsirang	0	0	0	0	0	0	0	0	0	0	0	0
Wangdue	0	0	0	0	0	0	0	0	0	0	23,283	0
Zhemgang	0	0	0	0	0	0	0	0	0	0	0	20,166

Note: Baseline run; the columns represent supply (districts *j*) and the rows represent use (districts *i*).

Comparing the above model results with the charcoal demand (reference year 2012), the current southeastern demand (S/Jongkhar) could be fully met by domestic charcoal production, with the eastern districts of Mongar, Pemagatshel, S/Jongkhar and Trashigang supplying 11,568 tons of charcoal (Table 5.5). An estimated 31,120 tons of domestic charcoal could be supplied to industrial consumers in southwest Bhutan. In total, 61.4% of the reference year's imports could be offset by domestic production. An additional 26,880 tons of charcoal would still need to be imported from India to meet domestic demand.

Table 5.5. Charcoal supply matrix in metric tons according to the transport model results

District	Chukha	Dagana	Ha	Mongar	Pema-gatshel	Samdrup-Jongkhar	Samtse	Sar-pang	Trashi-gang	Wang-due	Zhem-gang	Total
P/ling	5,900	6,817	3,851	1,418	-	-	3,826	2,711	-	3,521	3,076	31,120
S/Jongkhar	-	-	-	1,807	2,700	4,021	-	-	3,040	-	-	11,568
Total	5,900	6,817	3,851	3,225	2,700	4,021	3,826	2,711	3,040	3,521	3,076	42,688

Note: Baseline run; the columns represent the supply (districts i) and the rows represent use (consumers l)

5.4.2 Results of the Stochastic Risk Analysis

The baseline run results from the transport model were used as input for the investment model to evaluate the profitability of each charcoal producing district. Median internal rate of returns (IRRs) are highest for the districts closest to the industrial consumers, including Chukha (20.8%), Samdrup Jongkhar (20.8%) and Samtse (21.2%), as reported in Table 5.6. Median IRRs for other districts range between 12.4% (Dagana) and 16.3% (Trashigang). The results for the median IRRs also show the sensitivity towards a higher discount rate, as the IRR is the highest possible discount rate at which the net present value (NPV) would still not be negative. A one percentage point increase in the discount rate would render charcoal production in Dagana inefficient. Similarly, a three percentage point increase would make charcoal production unviable in Haa, Mongar, Sarpang and Wangdue.

Table 5.6. Investment model results with 1000 iterations: Median IRR and probability of an IRR < 12%

District	Chukha	Dag-ana	Haa	Mongar	Pema-gatshel	S/Jong-khar	Samtse	Sarpang	Trashi-gang	Wang-due	Zhem-gang
Median NPV (million USD)	1,659,475	76,804	249,530	196,061	303,373	1,132,304	1,133,984	199,038	403,875	261,144	370,891
Median IRR	20.8%	12.4%	14.1%	14.0%	15.6%	20.8%	21.2%	14.4%	16.3%	14.4%	15.9%
Probability of IRR < 12%	0.2%	43.8%	18.4%	18.7%	4.1%	0.0%	0.0%	14.9%	2.4%	14.4%	3.6%

Upfront capital expenditure and output prices are identical for all the districts; therefore, the determinants of competitiveness are the cost of fuelwood and transportation. In the district with lowest profitability, Dagana, these two cost items make up 48.0% of the output value, which is unmatched by any other district (Table 5.7).

Table 5.7.Output values in the producing charcoal districts according to the baseline model run

	Chukha	Dagana	Haa	Mongar	Pema-gatshel	S/Jong-khar	Samtse	Sarpang	Trashi-gang	Wang-due	Zhem-gang	Weighted Mean
Fuelwood	25.5%	28.0%	29.7%	21.5%	34.3%	30.6%	25.3%	34.3%	28.2%	28.1%	25.6%	28.0%
Transportation	5.4%	20.0%	14.5%	23.4%	6.5%	0.0%	4.8%	9.3%	11.7%	15.7%	15.8%	11.7%
Maintenance	6.2%	6.2%	6.2%	6.3%	6.3%	6.2%	6.2%	6.2%	6.2%	6.3%	6.2%	6.2%
Other costs	3.1%	3.1%	3.2%	3.2%	3.1%	3.1%	3.1%	3.1%	3.2%	3.1%	3.1%	3.1%
Depreciation	15.4%	15.4%	15.5%	15.5%	15.5%	15.4%	15.4%	15.5%	15.5%	15.5%	15.4%	15.5%
Wages	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.6%	2.5%	2.5%	2.5%
Capital return	41.9%	24.7%	28.3%	27.6%	31.8%	42.2%	42.7%	29.1%	32.6%	28.7%	31.4%	33.0%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Fuelwood and transportation are the inputs that account for the highest share of the total output value, comprising 39.7% on average. Shares vary substantially across districts. Sarpang has the highest fuelwood share (34.3%), while Samtse has the lowest share (25.3%). This difference in fuelwood cost is not only due to differences in fuelwood prices but also to fuelwood transportation among districts. Transportation cost is included in the fuelwood cost. Sarpang imports a large share of fuelwood from neighbouring Tsirang (Table 5.4). The transportation cost of charcoal is naturally highest for districts located the farthest distance from consumers. However, districts transporting charcoal on the less mountainous routes via India, such as Sarpang (228 km to P/ling mainly via flat roads), have lower shares than districts transporting charcoal via shorter, hilly roads, such as Trashigang (180 km to S/Jongkhar via hilly roads).

The (gross) value added to the total output can be measured as the proportion of capital return, depreciation and wages. This share averages 51%, ranging from 42.6% in Dagana to 60.6% in Samtse. Value-added data from other manufacturing sectors in Bhutan are available from the 2007 supply-use-Table (SUT) (ADB & NSB, personal communication, November 2013).[36] The average value-added share of Bhutan's manufacturing sectors is 32.3%. Only the textile manufacturing sector (53.4%) has a higher value-added share. Comparing charcoal production to other manufacturing sectors illustrates the low labour intensity (6.1% of value added) compared to the average overall value from other manufacturing sector's (37.4%). Thus, producing charcoal with modern technologies would contradict the argument suggested by

[36] Value added in the 2007 SUT is computed as the sum of compensation of employees, other taxes less subsidies on production and gross operating surplus, which includes depreciation.

Jadin *et al*. (2015), who stated that Bhutan could avoid establishing a low value-added sector by relying on Indian imports.

Table 5.6 also reports the probability that charcoal production does not exceed an IRR of 12%. This risk is highest for Dagana at 43.8% followed by Mongar, Haa, Sarpang, and Wangdue. The risk of an IRR below 12% is less than 5% for all of the remaining districts, underlining the general robustness of our results.

Charcoal production would result in an overall NPV of almost six million USD (sum of the individual NPVs presented in Table 5.6). Figure 5.3 shows the variability of the NPV estimates. The lower and upper hinges of the boxes represent the first and third NPV quartiles (i.e., 50% of the simulated NPVs fall within the respective box). This figure shows that possible NPVs are more largely dispersed for Chukha, Dagana, S/Jongkhar and Samtse. Accordingly, these districts have the highest charcoal outputs.

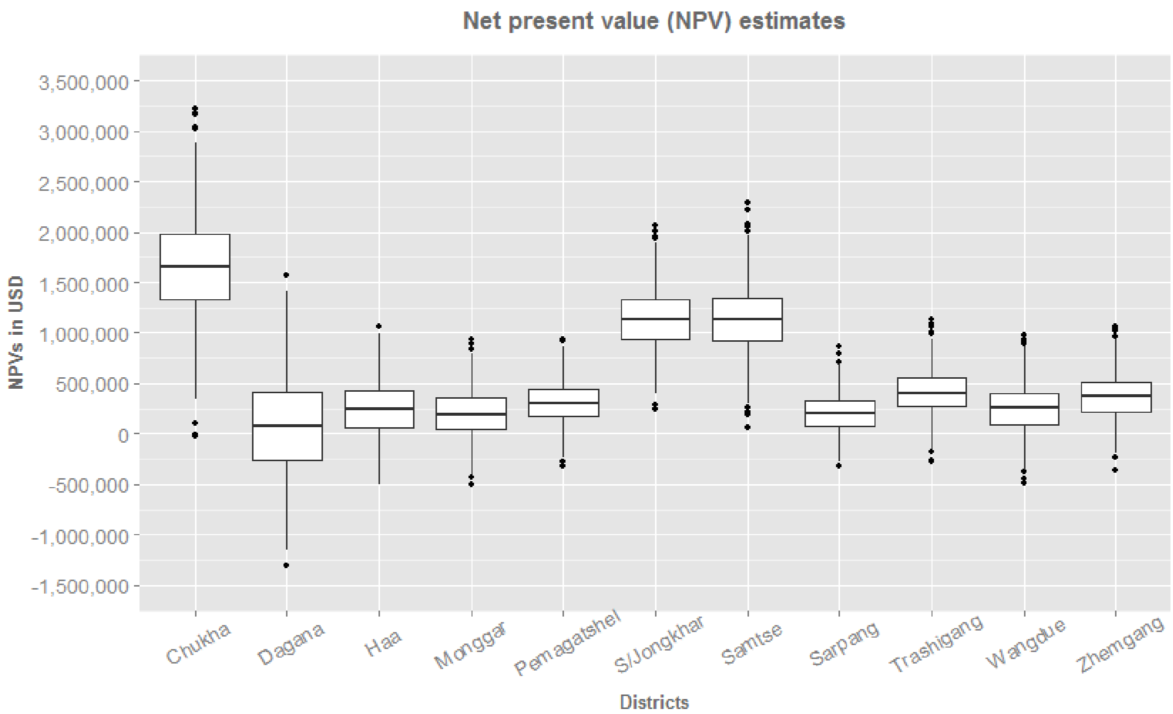

Figure 5.3. Net present value per charcoal producing district according to the baseline model run

5.4.3 Sensitivity Analysis

In addition to running Monte Carlo simulations, a *ceteris paribus* sensitivity analysis was conducted based on the transport model results. The effects of various scenarios on total charcoal output, imports and import substitution ratios are reported in Table 5.8. While the Monte Carlo simulations can be used to assess the risks associated with parameter variations, the sensitivity analysis scenarios allow us to identify structural changes in key model parameters.

Table 5.8. Sensitivity analysis scenarios

Variable	Percentage Change	Charcoal production	% change to baseline	Imports	Import substitution %
Baseline	**0%**	**42,688**	**0.0%**	**26,880**	**61.6%**
Fuelwood Price	-20%	44,315	3.8%	25,253	63.9%
	-10%	43,807	2.6%	25,761	63.2%
	+10%	41,803	-2.1%	27,765	60.3%
	+20%	33,367	-21.8%	35,115	49.8%
Fuelwood Supply	-20%	35,224	-17.5%	33,574	52.0%
	-10%	38,691	-9.4%	30,877	55.9%
	+10%	46,686	9.4%	22,882	67.3%
	+20%	50,684	18.7%	18,884	73.0%
Transport Cost	-20%	44,315	3.8%	25,253	63.7%
	-10%	43,807	2.6%	25,761	63.0%
	+10%	41,803	-2.1%	27,766	60.3%
	+20%	41,803	-2.1%	27,766	60.3%
Carbonization cost	-20%	44,569	4.4%	24,999	64.1%
	-10%	43,807	2.6%	25,761	63.0%
	+10%	41,803	-2.1%	27,765	60.1%
	+20%	33,367	-21.8%	36,201	48.0%
Charcoal Price	-20%	13,942	-67.3%	48,274	31.0%
	-10%	29,516	-30.9%	38,965	44.3%
	+10%	44,569	4.4%	24,999	64.3%
	+20%	45,687	7.0%	23,881	65.9%

Fuelwood price scenarios are used to analyze extraction cost sensitivities, which have been approximated based on historically observed fuelwood prices. Fuelwood price variations only have a significant impact if they increase by 20%, leading to a 21.8% reduction in output. As Jenkins and Sutherland (2014) reported in their analysis of optimal forest-based biofuel plant size in the US, the most influential parameters were the fuel supply and transportation cost. We investigated the degree to which variations in these parameters influenced our results. Fuelwood supply scenarios show that charcoal production would vary almost proportionally.

The model results are also relatively robust in terms of variations in transportation cost. An increase of 10% or 20% has no impact on the results. In both cases, the output of Trashigang would decrease to the minimum supply (2,684 tons), while all of the supply from Mongar shifts to S/Jongkhar. In these cases, S/Jongkhar is the only eastern district supplying P/ling. Charcoal production is only altered by a transport cost increase of > 27%, in which case production ceases in Dagana. Given the large investments in Bhutan's road network, an increase in transportation cost is relatively unlikely. A decline in transportation costs is more likely, which would induce a small increase in charcoal production according to our model results.

Variations in carbonization cost reflect potential variations in capital expenditure and technological performance (e.g. changes in yield, maintenance or capacity factor). The sensitivity analysis demonstrates that model results are largely robust to carbonization cost changes. A 10% or 20% decline as well as an increase of 10% in cost leads only to modest changes in charcoal production. However, an increase of 20% in carbonization cost triggers a significant decline in production (-21.8%) as charcoal production would become unprofitable in Dagana and Pemagatshel.

The charcoal price scenarios display the largest sensitivities. Price increases have a limited effect on charcoal production, because a large share of the production potential is already exploited. In contrast, decreasing charcoal prices would cause production to drop drastically. A 10% price decrease would cause a 30.9% reduction in output. Additionally, a 20% decrease triggers a 67.3% reduction. This is mainly because production in marginal districts (Dagana, Haa and Pemagatshel) would become unprofitable, and they would produce no charcoal at all.

5.4.4 Discussion of the Model Results

Charcoal production in our baseline scenario would place 271,488 hectares of forested area under commercial management. However, only a fraction of this forested area is operable due to the limited reach of harvesting technologies. Hence, 126,437 hectares of forest are actually harvested (taking into account the net operable share of 46.6%) resulting into the production of 281,346 m3 of fuelwood. Considering only the gross value added from charcoal production (5.0 Million USD), 39.61 USD of value is added per net operable hectare under the baseline scenario. This value does not yet consider the financial benefit realized by the sale of timber as the co-product of fuelwood harvesting for charcoal production.

The literature review of Wolfsmayr and Rauch (2014) presented criticisms concerning model applicability in primary forest fuel supply chain analyses; however, these criticisms can be overcome by combining optimization and simulation models that factor in fuelwood quality, upstream and downstream in-country transport costs, imports, and stochastic variations in prices and costs. Nevertheless, some limitations can significantly alter results. The chosen approach uses past observations of fuelwood prices as proxies for future fuelwood prices based on increased forest utilization and increased fuelwood demand from charcoal producers. In essence, the implicit assumption is that a shift in the fuelwood demand due to demands from charcoal producers is off-set by a government administered expansion of the fuelwood supply. Given the high degree of state intervention within Bhutan's timber market and prices dictated by the NRDCL, the extraction cost would provide a lower bound of the fuelwood price. We assume that extraction costs do not increase with increased forest utilization, because new FMUs are developed instead of increasing supply from existing FMUs. The uncertainty of extraction costs was considered within the sensitivity analysis, which only revealed a moderate sensitivity of results in case fuelwood price increases exceed 20%.

Using conservative values for two key parameters of this optimization analysis supports the robustness of our results. First, using a ten year average charcoal price results in a value about 10% lower than the mean charcoal price for the period 2010 to 2014. If the last five years indicate a trend of increasing charcoal prices, then our model results are rather a lower bound estimate. Second, values reflecting transportation costs are relatively high, as they are estimated based on five to ten ton trucks (RSTA, 2012). However, trucks with larger carrying capacity could significantly lower overall transportation costs.

Our analysis could be further enhanced through the application of a general-equilibrium approach. This would allow to estimate the economy-wide effects, particularly from backward linkages to the forestry sector and transportation sector, which are only reflected as the intermediate input of fuelwood and transportation services. Output increases in these sectors do not only result in generation of value added and employment, but also to additional output of logs, which is a joint-product of fuelwood production. Using the average share of logs from the annual allowable cut, the increase in forest utilization would result in additional output of 104,585 m3 of logs. In total – and including the fuelwood harvest quantities – 385,931 m3 of timber would be extracted. Based on average construction timber prices from 2012 (NRDCL, 2012), the value of logs can be valued at 9.4 million USD and is almost as high as the resulting output value of charcoal (9.8 million USD). Further, via forward linkages, the resulting increase in log production would also increase output in downstream sectors such as wood manufacturing and construction.

Additionally to FMUs, fuelwood could be supplied by community forests, allowing rural households to either consume their firewood quota or to sell it to charcoal industries. Rahut, Ali, and Behera (2015) conclude that community forests have improved Bhutanese rural household incomes and reduced poverty levels. While households are already switching to cleaner fuels (Rahut, Behera, & Ali, 2016), allowing them to sell their firewood quota to charcoal producers would further strengthen this trend. This could potentially lead to a more efficient allocation of fuelwood and significant health benefits for households due to reduced indoor air pollution (Dherani et al., 2008; Ezzati & Kammen, 2001). From a livelihood point of view, increasing charcoal production could also provide additional income opportunities for rural populations. Analyses of wood energy value chains already concluded their favorable impact for creating domestic – particularly rural – jobs (Openshaw, 2010; Remedio & Domac, 2003).

One important concern of increasing commercial forest utilization in Bhutan is whether such action would adversely impact the provision of other ecosystem services, especially regulating services. This refers to the trade-offs in multiple-use management of forests. Forests are assets that continuously generate multiple ecosystem services: provisioning services that yield firewood, timber, food, purified fresh water, non-timber forest products, medicinal resources etc., regulating services upon which local climate, carbon storage, erosion prevention, moderation of extreme weather events etc. rely, habitat services that provide living space for flora and fauna, and cultural services as basis of recreation for the local population, touristic activities, aesthetic inspiration and sometimes also spiritual experience (TEEB, 2010).

Depending on the type of forest and the management objective, these ecosystem service can be produced simultaneously at varying degrees, either in a complementary (through synergies) or competing relationship (as trade-offs) (cf. Gregory, 1972, p.393ff.; for an early overview on use compatibilities and conflicts cf. Clawson, 1974). This leads to the problem of optimizing multiple use management of forest lands which has been extensively analysed in the forest economics literature. The objective is to achieve a relative optimization of all relevant forest products and services when making temporal and spatial harvest decisions (Gregory, 1972; Bowes and Krutilla, 1985; Swallow and Wear, 1993; Swallow et al., 1997).

In our case, two complementary provisioning services result from the simultaneous harvest of timber and of wood for charcoal production because lops and tops from trees are natural by-products of timber supply. An example for a complementary relationship of a provisioning service and a regulating service are charcoal production and CO2 emission savings when the charcoal is used to replace fossil coal as an input in steel production. Further complementary relationships may exist between provision of timber through increased forest utilization and habitat services. Siebert and Belsky (2015) cite studies from India and Nepal which found that more open and disturbed environments correlate positively with availability of prey (wild pigs and ungulates) and tigers. Increased forest utilization could thus benefit the conservation of tigers and other endangered flora and fauna that prefer less dense forests.

In contrast, firewood use by local population and charcoal production might compete, even though we believe that this should not happen as we suggest to extend utilized forest area and not to collect wood from forest areas already used (see Appendix 5C and our remarks below). Also, a possible trade-off between the increased provision of charcoal and regulating services could emerge, for example when additional forest utilization would trigger soil erosion or affect the buffer capacity of forests moderating extreme weather events and natural hazards (e.g. landslides). The magnitude of a trade-off between forest ecosystem services provision does not only depend on the physical intensity of resource use (resulting in conflicts for "technical" reasons) but also on the (locally) experienced relative scarcity of the different ecosystem services, which translates into marginal values of a respective service (cf. TEEB, 2010, p.61).

It is beyond the scope of this article to develop an optimized management plan for multiple use forestry in Bhutan. However, given the country's huge forest area and as there is scope for extending forest use outside watersheds or other sensitive areas (MoAF, 2013) we do not expect strong competition with forest related regulating or cultural ecosystem services when moderately increasing forest area under commercial management for charcoal production. With the strict environmental regulatory framework for forest harvest operations existing in Bhutan, it is assumed that this would be equally applied if forest utilization area was extended. While technological improvement in harvesting techniques could further reduce ecosystem impacts, we assumed that no such advances would be made.

Recent research findings also confirm that sustainable charcoal production does not necessarily contradict the RGoB's high priority for forest conservation and sustainable economic development. A global review of studies (Mwampamba, Ghilardi, Sander, & Chaix, 2013) showed that sustainable charcoal production can be achieved with effective resource governance and policies in place. Ensuring sustainable charcoal production in Bhutan would be facilitated by the RGoB's ownership and control of all forests. Further, criteria for sustainable charcoal production have to be introduced along the entire value chain: wood production, carbonization, transport and value added, and consumption (Zulu, 2010). Of particular importance is the carbonization process as it is known to exhibit great efficiency potential (Adam, 2009; Bailis et al., 2013; Reumerman & Frederiks, 2002).

5.5 Conclusions and Policy Implications

This study provides evidence that extending the area under forest utilization for fuelwood harvesting as an input for charcoal production is economically viable in Bhutan without jeopardizing its forest conservation agenda. Six districts show high robustness against stochastic variation in model parameters. Our results demonstrate that increasing the total FMU area to 15% of the national forest area would offset almost two-thirds of the charcoal imports in 2012, worth approximately 9.8 million USD. Fuelwood and transportation cost comprise a large share of production cost in most districts, but they have no significant impact on the robustness of the results as indicated by the Monte Carlo simulations and sensitivity analysis. The input of labour for charcoal production is very low and negligible as a cost component. However, to assess the alleged barrier of limited labour supply, an assessment of total employment effects in an economy wide framework is necessary.

The results also show that meeting charcoal demand does not trigger a huge increase in area under commercial forest management. The area increases lie well within the RGoB's formulated objective to increase the FMU area to more than 12% of the total forest area by 2018 (GNHC, 2013). The constitutional mandate of maintaining a 60% forest cover would also not be violated, as the additional forest area under commercial management would still account as forest area. Compared to other manufacturing sectors in Bhutan, the average value-added share of 50.8% from charcoal production is considerably. Defying the economic potential of domestic charcoal production is thus not consistent with the claim of a functional upgrade in the value chain as stated by previous analyses (Jadin et al., 2015). Given Bhutan's macroeconomic challenges and the urgent need to reduce the current account deficit, domestic charcoal production could prove to be a valid and promising avenue to reduce the dependency on imports, while contributing to economic growth and diversification.

An important achievement of our optimization analysis is that the results are disaggregated at district level. This allows policy makers to identify districts with optimal prerequisites for charcoal production, determined by a relatively short distance to charcoal consumers as well as an optimal potential associated with additional forest resources. Mindful, that charcoal is predominantly used as a chemical reducing agent in Bhutan, charcoal production in Bhutan would not bridge a current energy demand that could later be substituted by cleaner energy sources. Charcoal – as it is used in Bhutan – can contribute to decarbonize industries in Bhutan as part of a broader bioeconomy policy.

To address the limitations of this analysis further research is needed, especially with regards to estimating timber extraction cost from new FMU area and potential cost of externalities stemming from developing and managing new FMUs. The policy implications of this analysis are not meant to overhaul forestry policies from a conservative stance to an exploitation stance. Instead, Bhutan's forest utilization should be increased while maintaining an appropriate environmental safeguards framework based on thorough analyses and a precautionary principle.

5.6 Appendix

Appendix 5A Charcoal Production Technology

There are a wide range of charcoal production technologies employed today, ranging from artisanal methods using mound or pit kilns to small and medium-scale industrial applications (e.g., standard beehive kiln, Missouri kiln, etc.). Kammen and Lew (2005) have reviewed various production technologies in detail, while Antal and Grønli (2003) provide a detailed overview of charcoal production technologies. The underlying technology used in our analysis is the carbon twin retort system. This system is a fairly novel and modular charcoal production technology based on two separate batch-wise carbonization cycles (Reumerman & Frederiks, 2002). Its modular design allows for relatively easy transportation, installation and linear up-scaling. Furthermore, it is a semi-continuous system, which requires no external heat source if operated under optimum production conditions. This is possible because emitted pyrolysis gases can be separated from the raw material during the carbonization of the first batch (exothermic phase). These gases are then directly combusted to provide additional process heat, which is then used to heat the second batch during the endothermic phase.

The efficiency of this technology is superior to traditional technologies, achieving charcoal yields (measured in tons of charcoal per ton of dry wood) of up to 34%. The holistic process layout also significantly reduces emissions, particularly CH_4, CO and particulate matter emissions (Siemons & Baaijens, 2012). In return, CO_2 emissions are higher, as the gas is an inevitable byproduct of the complete combustion of carbon compounds. The chosen technology has a proven track record in numerous countries, including developing countries (Ghana and China). The system also requires minimal labour input. The required worker skill levels are low due to the advantages of the batch process, which is relatively straight-forward. The technological and financial parameters of the carbon twin retort system were updated to reflect recent technology and cost developments (R. V. Siemons, personal communication, November 3, 2014), as presented in Table 5.2.

Appendix 5B District Forest Indicators

Table 5.9. Commercially manageable FMU area, annual allowable cut (AAC) and percentage harvested as fuelwood

Commercially manageable FMU area of forest type k in district i ($For_{i,k}$)	**Blue pine**	**Chir pine**	**Fir**	**Mixed Conifer**	**Broadleaf and Conifer**	**Broadleaf**	**Total**
Bumthang	2,478	-	1,943	8,554	-	-	12,975
Chukha	-	-	-	6,518	185	31,562	38,265
Dagana	-	-	-	6,126	-	37,038	43,164
Ha	-	-	898	4,317	-	20,628	25,843
Lhuentse	-	-	-	-	245	1,284	1,530
Mongar	-	815	198	2,605	-	17,493	21,111
Paro	603	-	60	4,602	-	-	5,265
Pemagatshel	-	781	-	-	-	14,160	14,941
Punakha	-	117	-	533	-	6,199	6,849
Samdrup Jongkhar	110	-	-	-	305	23,727	24,141
Samtse	-	-	-	330	197	21,515	22,042
Sarpang	-	-	-	380	-	8,490	8,870
Tashi Yangtse	-	-	-	2,795	-	5,556	8,352
Thimpu	700	-	2,232	12,100	-	-	15,032
Trashigang	-	-	998	8,910	-	14,662	24,570
Trongsa	-	-	161	4,082	166	3,482	7,891
Tsirang	-	34	-	1,119	-	9,395	10,548
Wangdue	-	999	-	3,542	-	18,895	23,436
Zhemgang	-	50	-	127	325	17,192	17,695
Total	**3,891**	**2,795**	**6,490**	**66,641**	**1,424**	**251,278**	**332,518**
% shares	1.2%	0.8%	2.0%	20.0%	0.4%	75.6%	
Annual allowable cut (AAC_k; m³/ha)	**1.30**	**1.70**	**1.30**	**2.47**	**2.79**	**3.10**	**2.90**
% Logs	70%	70%	70%	70%	40%	20%	29.5%
% Firewood and waste ($\%FW_k$)	30%	30%	30%	30%	60%	80%	70.5%
Green density (ρ_i^{green}; $kg/m3$)	858	842	734	804	843	823	
Moisture Content (wet basis; mc_k^{green})	53%	54%	48%	47%	42%	48%	

Sources: MoAF, 2013c; Schindele, 2004; Sukla et al., 1992; Sukla & Negi, 1994.

Appendix 5C Spatial Criteria

Table 5.10. Spatial criteria applied by the Forest Resources Potential Assessment (FRPA)

Base Criteria	Spatial Buffer/ Exclusion area
Roads (highways, feeder roads, farm roads, etc.)	200 m
Major drainages	30 m
Rural settlements	1,000 m
Towns	1,500 m
RAMSAR wetland sites	Excluded
Existing botanical, recreational parks and heritage forests	Excluded
Forest Management Units and Working Schemes	Excluded
Community Forests	Excluded
Protected area	Excluded

Note: The criteria presented above were either spatially buffered by applying a radius, as reported in the second column, or were entirely excluded from the resource assessment
Source: MoAF, 2013c.

Appendix 5D District-to-District Matrix

Table 5.11. District-to-district transportation costs of fuelwood

District	Bumthang	Chukha	Dagana	Ha	Lhuentse	Mongar	Paro	..
Bumthang	-	45.86	47.02	48.82	34.52	24.86	41.35	54.36
Chukha	46.78	-	42.97	18.53	82.00	72.14	10.91	50.13
Dagana	47.99	42.99	-	46.02	83.22	73.36	38.39	67.69
Ha	49.61	18.46	45.82	-	84.69	74.88	13.88	68.39
Lhuentse	35.12	81.76	82.94	84.77	-	9.83	77.17	39.83
Mongar	25.38	72.20	73.39	75.23	9.86	-	67.60	30.12
Paro	42.06	10.88	38.26	13.89	77.17	67.35	-	60.86
..	55.73	50.38	67.99	69.00	40.15	30.24	61.34	-

Note: in USD/ ton and trip
Please note that the matrix is not symmetrical, as the basic density (ton/m^3) of fuelwood varies between districts. The transportation cost of fuelwood that is both harvested and processed as charcoal within the same district is assumed to equal zero, as the fuelwood prices reported per district already include delivery within the district (NRDCL, 2014).
Sources: RSTA, 2012, 2014.

Appendix 5E Carbonization Conversion Ratio

$$conv_i^{Char} = \frac{\left(1 - mc^{Char}\right)}{\rho_i^{green} * \left(1 - mc_i^{green}\right) * char^{yield}} \tag{5.6}$$

Note: Equation shows the conversion ratio from m³ of fuelwood (wet basis) to tons of charcoal (dry basis). mc^{Char} and mc_i^{green} are weighted averages per district based on the data presented in Appendix 5C. $conv_i^{Char}$ and ρ_i^{green} are presented in Table 5.2.

Appendix 5F Investment Model Equations

For each district, a plant's necessary fuelwood processing capacity $plantcap_i$ must first be determined by dividing the respective column sum of the fuelwood supply matrix by the base capacity factor, $CapFac$, presented in Table 5.2.

$$plantcap_i = \sum_{l}^{2} Q_{i,l}^{Cha\_Output} * \frac{1}{CapFac} \tag{5.7}$$

Dividing the district-specific plant capacity by the minimum plant capacity, $plantcap^{Min}$, yields the scaling factor $scale_i$, which is used to adjust the production technology related costs, such as capital expenditures, maintenance costs and labour inputs. Cash flow in the investment year (*t = 0*) is computed as shown below. The first term within the bracket represents the upfront capital expenditures, including contingency expenditures. The second term represents the land lease cost, while the last terms represent the capitalized costs of advanced payments for fuelwood inputs and salaries (working capital).

$$\begin{aligned} CF_{0,i} = {} & scale_i * (capex * \left(1 + Cont_0^{CAPEX}\right) + land \\ & + \frac{5}{12} * \left(FwdCost_i + labour\right) * \left(1 - \frac{1}{\left(1 + r\right)^T}\right) \end{aligned} \tag{5.8}$$

Cash flows during operation years:

$$CF_{t,i} = GrossRevenue_{t,i} - TraOut_i - FwdCost_{t,i} - MiscCost_{t,i} \tag{5.9}$$

where

$$GrossRevenue_{t,i} = plantcap_i * CapFac_t * P_t^{Char\_imp} \quad (5.10)$$

The transportation cost of output to the final consumer:

$$TraOut_i = Q_{l,i}^{Char\_Output} * TC_{l,i}^{Char} \quad (5.11)$$

The fuelwood input cost including transportation:

$$FwdCost_{t,i} = \sum_{j}^{19} \left(P_{t,j}^{Fwd} + TC_{i,j}^{Fwd} \right) * Q_{i,j}^{Fwd_e} \quad (5.12)$$

Miscellaneous costs:

$$MiscCost_{t,i} = scale_i + \left(land + Main_t + CapFac_t * \left(labour * 12 + p^{Elec} * q^{Elec} \right) \right)$$

5.7 References

Adam, J. C. (2009). Improved and more environmentally friendly charcoal production system using a low-cost retort–kiln (Eco-charcoal). *Renewable Energy*, *34*(8), 1923–1925. doi:10.1016/j.renene.2008.12.009

ADB, & NSB (November 2013). 2007 32-sector and 51-commodity Supply-Use-Table for Bhutan as excel-sheet (Email).

Antal, M. J., & Grønli, M. (2003). The art, science, and technology of charcoal production. *Industrial & Engineering Chemistry Research*, *42*(8), 1619–1640.

Bailis, R., Rujanavech, C., Dwivedi, P., Oliveira Vilela, A. de, Chang, H., & Miranda, R. C. de. (2013). Innovation in charcoal production: A comparative life-cycle assessment of two kiln technologies in Brazil. *Energy for Sustainable Development*, *17*(2), 189–200. doi:10.1016/j.esd.2012.10.008

BBS (2012, March 18). Businesses affected by Rupee crunch. *BBS Online News*. Retrieved from http://www.bbs.bt/news/?p=10449

BEA. (2013). *Bhutan Power Corporation Limited Tariff Review Report*. Thimphu.

Belli, P., Anderson, J., Barnum, H., Dixon, J., & Tan, J.-P. (1998). *Handbook on economic analysis of investment operations*: Citeseer. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.176.1056&rep=rep1&type=pdf

Bruggeman, D., Meyfroidt, P., & Lambin, E. F. (2016). Forest cover changes in Bhutan: Revisiting the forest transition. *Applied Geography*, *67*, 49–66. doi:10.1016/j.apgeog.2015.11.019

Buffum, B., Gratzer, G., & Tenzin, Y. (2008). The sustainability of selection cutting in a late successional broadleaved community forest in Bhutan. *Forest Ecology and Management*, *256*(12), 2084–2091. Retrieved from http://www.sciencedirect.com/science/article/pii/S037811270800594X

Chetri, A. (2014, November 20). Transportation cost of sea containers from Calcutta, India to Bhutan (Skype interview).

Cook, J. D. (2010). *Determining distribution parameters from quantiles*. Houston, Texas. Retrieved from http://biostats.bepress.com/cgi/viewcontent.cgi?article=1055&context=mdandersonbiostat

Covey, K., Carroll, C. J. W., Duguid, M. C., Dorji, K., Dorji, T., Tashi, S., … (2015). Developmental dynamics following selective logging of an evergreen oak forest in the Eastern Himalaya, Bhutan: Structure, composition, and spatial pattern. *Forest Ecology and Management*, *336*, 163–173. Retrieved from http://www.sciencedirect.com/science/article/pii/S0378112714005866

Dhamodaran, T. K., & Babu, S. (2011). Potential of community level utilization of coconut shell and stem wood for charcoal and activated carbon in Kerala. *Journal of the Indian Academy of Wood Science*, *8*(2), 89–96. Retrieved from http://link.springer.com/article/10.1007/s13196-012-0024-0

Dherani, M., Pope, D., Mascarenhas, M., Smith, K. R., Weber, M., & Bruce, N. (2008). Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis. *Bulletin of the World Health Organization*, *86*(5), 390. Retrieved from http://www.scielosp.org/scielo.php?pid=S0042-96862008000500017&script=sci_arttext&tlng=es

Emmerich, F. G., & Luengo, C. A. (1996). Babassu charcoal: A sulfurless renewable thermo-reducing feedstock for steelmaking. *Biomass and Bioenergy*, *10*(1), 41–44. doi:10.1016/0961-9534(95)00060-7

Ezzati, M., & Kammen, D. M. (2001). Indoor air pollution from biomass combustion and acute respiratory infections in Kenya: an exposure-response study. *The Lancet*, *358*(9282), 619–624. Retrieved from http://www.sciencedirect.com/science/article/pii/S0140673601057774

FAO. (1983). *Wood Fuel Surveys* (Forestry for local community development programme). Rome. Retrieved from http://www.fao.org/docrep/q1085e/q1085e00.htm#Contents

Gilani, H., Shrestha, H. L., Murthy, M. S. R., Phuntso, P., Pradhan, S., Bajracharya, B., & Shrestha, B. (2015). Decadal land cover change dynamics in Bhutan. *Journal of environmental management*, *148*, 91–100. doi:10.1016/j.jenvman.2014.02.014

GNHC. (2013). *Eleventh Five Year Plan 2013-2018: Volume 1: Main Document*. Thimphu.

Hapag-Lloyd (2014, November 4). Transportation cost of sea containers from NL to Calcutta, India (Email).

Hu, Z. W., Zhang, J. L., Zuo, H. B., Tian, M., Liu, Z. J., & Yang, T. J. (2011). Substitution of Biomass for Coal and Coke in Ironmaking Process. *Advanced Materials Research*, *236-238*, 77–82. doi:10.4028/www.scientific.net/AMR.236-238.77

Jadin, I., Meyfroidt, P., & Lambin, E. F. (2015). Forest protection and economic development by offshoring wood extraction: Bhutan's clean development path. *Regional Environmental Change*, 1–15. doi:10.1007/s10113-014-0749-y

Jenkins, T. L., & Sutherland, J. W. (2014). A cost model for forest-based biofuel production and its application to optimal facility size determination. *Forest Policy and Economics*, *38*, 32–39. doi:10.1016/j.forpol.2013.08.004

Kammen, D. M., & Lew, D. J. (2005). Review of Technologies for the Production and Use of Charcoal. *Renewable and appropriate energy laboratory report*, *1*. Retrieved from http://rael.berkeley.edu/old_drupal/sites/default/files/old-site-files/2005/Kammen-Lew-Charcoal-2005.pdf

Kubiszewski, I., Costanza, R., Dorji, L., Thoennes, P., & Tshering, K. (2013). An initial estimate of the value of ecosystem services in Bhutan. *Ecosystem Services*, *3*, e11-e21. Retrieved from http://www.sciencedirect.com/science/article/pii/S2212041612000563

Meyer, S., Glaser, B., & Quicker, P. (2011). Technical, economical, and climate-related aspects of biochar production technologies: a literature review. *Environmental science & technology*, *45*(22), 9473–9483. doi:10.1021/es201792c

MoAF. (2011). *Forest Development in Bhutan: Policies, Programmes and Institutions*. Thimphu, Bhutan.

MoAF. (2012). *Forestry -Facts, figures and trends 2011*. Thimphu, Bhutan.

MoAF. (2013). *Forest Resource Potential Assessment of Bhutan 2013*. Thimphu, Bhutan.

MoF. (2013). *Bhutan Trade Statistics 2012*. Thimphu, Bhutan.

MoF. (2014). *Bhutan Trade Statistics 2013*. Thimphu, Bhutan.

MoF. (2015). *Bhutan Trade Statistics 2014*. Thimphu, Bhutan.

Moktan, M. R. (2014). Social and Ecological Consequences of Commercial Harvesting of Oak for Firewood in Bhutan. *Mountain Research and Development*, *34*(2), 139–146. doi:10.1659/MRD-JOURNAL-D-12-00113.1

Moktan, M. R., Gratzer, G., Richards, W. H., Rai, T. B., & Dukpa, D. (2009). Regeneration and structure of mixed conifer forests under single-tree harvest management in the western Bhutan Himalayas. *Forest Ecology and Management*, *258*(3), 243–255. doi:10.1016/j.foreco.2009.04.013

Moktan, M. R., Gratzer, G., Richards, W. H., Rai, T. B., Dukpa, D., & Tenzin, K. (2009). Regeneration of mixed conifer forests under group tree selection harvest management in western Bhutan Himalayas. *Forest Ecology and Management*, *257*(10), 2121–2132. Retrieved from http://www.sciencedirect.com/science/article/pii/S0378112709001376

Mwampamba, T. H., Ghilardi, A., Sander, K., & Chaix, K. J. (2013). Dispelling common misconceptions to improve attitudes and policy outlook on charcoal in developing countries. *Energy for Sustainable Development*, *17*(2), 75–85. doi:10.1016/j.esd.2013.01.001

Neuhoff, D., Tashi, S., Rahmann, G., & Denich, M. (2014). Organic agriculture in Bhutan: potential and challenges: Organic Agriculture. *Org. Agr.*, *4*(3), 209–221. doi:10.1007/s13165-014-0075-1

Nkonya, E., Srinivasan, R., Anderson, W., & Kato, E. (2014). Assessing the Economic Benefits of Sustainable Land Management Practices in Bhutan. *IFPRI Discussion Paper*, *2014*(01361).

Norgate, T., & Langberg, D. (2009). Environmental and economic aspects of charcoal use in steelmaking. *ISIJ International*, *49*(4), 587–595. Retrieved from http://jlc.jst.go.jp/DN/JALC/00329273185?from=Google

Nørstebø, V. S., & Johansen, U. (2013). Optimal transportation of logs and location of quay facilities in coastal regions of Norway. *Forest Policy and Economics*, *26*, 71–81. doi:10.1016/j.forpol.2012.08.009

NRDCL. (2009). *Annual Report 2008*. Thimphu, Bhutan.

NRDCL. (2012). *Annual Report 2012*. Thimphu, Bhutan.

NRDCL. (2014). *Firewood prices 2008 - 2014 from NRDCL field divisions.*

NSB. (2014). *National Accounts Statistics 2014*. Thimphu, Bhutan. Retrieved from http://www.nsb.gov.bt/publication/download.php?id=1079

NSB & ADB. (2012). *Bhutan Living Standard Survey 2012 - dataset*. Thimphu, Bhutan.

Openshaw, K. (2010). Biomass energy: Employment generation and its contribution to poverty alleviation. *Biomass and Bioenergy*, *34*(3), 365–378. Retrieved from http://www.sciencedirect.com/science/article/pii/S0961953409002372

Rahut, D. B., Ali, A., & Behera, B. (2015). Household participation and effects of community forest management on income and poverty levels: Empirical evidence from Bhutan. *Forest Policy and Economics*, *61*, 20–29. doi:10.1016/j.forpol.2015.06.006

Rahut, D. B., Behera, B., & Ali, A. (2016). Household energy choice and consumption intensity: Empirical evidence from Bhutan. *Renewable and Sustainable Energy Reviews*, *53*, 993–1009. doi:10.1016/j.rser.2015.09.019

Remedio, E. M., & Domac, J. U. (2003). Socio-economic analysis of bioenergy systems: A focus on employment. *FAO Forestry Department. Wood Energy Programme, ed. Rome: FAO*, *53*. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.456.692&rep=rep1&type=pdf

Reumerman, P. J., & Frederiks, B. (2002). Charcoal Production with Reduced Emissions: A description of the CARBO GROUP charcoal production technology. *12th European Conference on Biomass for Energy, Industry and Climate Protection*,

RGoB. (2006). *Forest and Nature Conservation Rules of Bhutan*. Thimphu, Bhutan.

RGoB. (2008). *The Constitution of the Kingdom of Bhutan*. Thimphu, Bhutan.

RGoB. (2010). *Economic development policy of the kingdom of Bhutan*. Thimphu, Bhutan.

RMA. (2012). *Monetary Policy Statement June 2012*. Thimphu, Bhutan.

RMA. (2015). *Monthly Statistical Bulletin - February 2015 Issue*. Thimphu, Bhutan. Retrieved from http://www.rma.org.bt/monthly%20statistical%20bulletintp.jsp

RSTA. (2012). *Official hiring rates for trucks*. Thimphu, Bhutan.

RSTA. (2014). *Road Map Bhutan*. Thimphu, Bhutan.

Schindele, W. (2004). *Forest Resources Potential Assessment (FRPA) for Bhutan*. Bhutan-German Sustainable RNR Development Project. Altusried, Germany.

Siebert, S. F., & Belsky, J. M. (2015). Managed fuelwood harvesting for energy, income and conservation: An opportunity for Bhutan. *Biomass and Bioenergy*, *74*, 220–223. doi:10.1016/j.biombioe.2015.01.013

Siemons, R. V. (2014, November 3). Carbon Twin Retort - Technical and financial parameters (Expert Interview).

Siemons, R. V., & Baaijens, L. (2012). An Inovative Carbonisation Retort: Technology and Environmental Impact. *Scientific and Technical Journal of the Society of Thermal Engineers of Serbia*, (2).

Sukla, N. K., Guru, R. D., & Negi, Y. S. (1992). *Physical and Mechanical Properties of Some Bhutan Timbers* (Tshenden No. 1). Dehra Dun, India.

Sukla, N. K. & Negi, Y. S. (1994). *Physical and mechanical properties of woods tested at the Forest Research Institute*. Dehra Dun, India.

Suopajärvi, H., & Fabritius, T. (2013). Towards More Sustainable Ironmaking—An Analysis of Energy Wood Availability in Finland and the Economics of Charcoal Production. *Sustainability*, *5*(3), 1188–1207. doi:10.3390/su5031188

Thinley U. (2002). Reduced impact logging in Bhutan. In T. Enters, P. B. Durst, G. B. Applegate, P. C. S. Kho, & G. Man (Eds.), *Applying Reduced Impact Logging to Advance Sustainable Forest Management* (pp. 91–100).

Uddin, S., Taplin, R., & Yu, X. (2007). Energy, environment and development in Bhutan. *Renewable and Sustainable Energy Reviews*, *11*(9), 2083–2103. doi:10.1016/j.rser.2006.03.008

UN. (2015). *UN comtrade database*. New York. Retrieved from http://comtrade.un.org/

Wolfsmayr, U. J., & Rauch, P. (2014). The primary forest fuel supply chain: A literature review. *Biomass and Bioenergy*, *60*, 203–221. doi:10.1016/j.biombioe.2013.10.025

World Bank. (1985). *Staff appraisal report Bhutan Calcium Carbide Project* (No. 5430-BHT). Washington DC, USA.

World Bank. (1992). *Project Completion Report Bhutan Calcium Carbide Project* (No. 11359). Washington DC, USA.

World Bank. (2011). *Wood-Based Biomass Energy Development for Sub-Saharan Africa – Issues and Approaches* (Africa Renewable Energy Access program (AFREA)). Washington DC, USA.

Zulu, L. C. (2010). The forbidden fuel: Charcoal, urban woodfuel demand and supply dynamics, community forest management and woodfuel policy in Malawi. *Large-scale wind power in electricity markets with Regular Papers*, *38*(7), 3717–3730. doi:10.1016/j.enpol.2010.02.050

Chapter 6 Forest Policy Reforms in Bhutan

Synergies for Environmental Conservation and Rural Development

This chapter consists of the corresponding manuscript "Linking rural households to wood product value chains: An option for rural development?", which is prepared for submission to the Journal of Rural Studies.

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Abstract

Balancing environmental conservation and rural development is a challenge, particularly for low-income countries that depend on natural resources. One side effect of Bhutan's commendable regulatory framework for productive use of natural resources is relatively limited economic opportunities for rural areas. Changes in the regulations for forest management may offer better opportunities for rural areas without jeopardizing conservation objectives. This paper uses a computable general equilibrium (CGE) model to analyse the effects of forest policy scenarios that relax quotas for fuelwood production while respecting conservation objectives. The gains are mainly due to better utilization of labour resources, a channel that is considered thanks to an innovative formulation that captures the seasonality of labour demands. Across all scenarios, real household incomes increase thanks to increases in employment and fuelwood sales in the context of reduced subsistence use of fuelwood and increased consumption of cleaner sources of household energy. In addition, household health is likely to improve due to reduced indoor air pollution. The paper also discusses measures to ensure sustainable forest management in the context of the simulated quota regimes.

Keywords: Forest policy; Rural development; Forest Conservation; Seasonal underemployment; Wood value chains; Economy-wide modelling

6.1 Introduction

The development strategy of most low-income countries is built around the productive use of their natural capital, which is commonly reflected in high shares of the primary sector in total GDP. The extraction of minerals and oil, logging of forests for timber exports, or export-oriented agriculture are common means to earn revenues for investing in other forms of capital, e.g. physical capital (infrastructure). Through these investments, countries aspire to build economies that are characterized by an increasing share of the secondary and tertiary sectors in domestic production. When moving along this stylized economic development trajectory, many countries struggle with the underlying challenge for achieving sustainable economic development, i.e. balancing the trade-offs between resource exploitation and safeguarding fundamental ecosystem services – drinkable water, breathable air, and arable soils – that constitute the essential life-support functions for any society. In most cases, early economic development phases have been characterized by environmental deterioration that has to be compensated through significant investments in restoration and rehabilitation of the natural environment at later stages of economic development.

Bhutan constitutes a rare exception from this development paradigm. A country endowed with tremendous natural resources and environmental richness, it has been successful in achieving economic growth without large-scale environmental degradation. Still considered a least-developed country, with a GDP per capita of USD 9,561 (adjusted for purchasing power parity) (World Bank, 2018), more than 70% of the country is forested with a constitutionally manifested minimum forest cover of 60%. The land within protected areas (PA) management comprises about 43% with a very high degree of interconnectivity between individual PA. Bhutan is part of the 34 biodiversity hotspots in the world, among which it has the highest species density in the world with a high degree of endemic flora and fauna (Banerjee & Bandopadhyay, 2016; WWF Bhutan, 2016). Bhutan has also an abundant reservoir of water resources with over 3000 lakes, high altitude wetlands, and a wide net of rivers and streams that provide water for Bhutan and neighbouring countries (MoAF, 2012b). The total annual value of 22 different ecosystem services in Bhutan for 9 different land cover types was estimated at US$15.5 billion/year, most of which was attributed to forested land (Kubiszewski et al., 2013).

This success story has been mainly achieved by a careful exploitation of the countries hydropower potential, which has driven export earnings and allowed a transitioning of the economy with increasing economic weight of the secondary and tertiary sectors. However, the structure of economic growth in Bhutan has *inter alia* triggered significant rural-urban migration like in many other developing countries (Gosai & Sulewski, 2014). Particularly the younger generations are attracted by the urban areas due to attractive employment opportunities (Bajgai & Tshering, 2012).

In recent years, several publications have suggested that increasing the productive use of forest resources for enhancing income opportunities in rural areas and establishing domestic value-chains of wood products to substitute for imports could serve as an advantageous strategy for rural economic development (Arndt Feuerbacher, Siebold, Chhetri, Lippert, & Sander, 2016; Narain et al., 2014; Siebert & Belsky, 2015). Forestry allows to mitigate seasonal income gaps (Hogarth, Belcher, Campbell, & Stacey, 2013; Wunder et al., 2014) by providing employment during lean seasons (Beer & McDermott, 1996; Sarap & Sarangi, 2009). Against the back drop of increasing rural-urban migration, these income opportunities are underdeveloped for rural dwellers in Bhutan. Households face hardly any incentives to extract timber for commercial purposes, because Bhutan's current policy framework restricts households almost exclusively to subsistence use and production of timber.[37] According to the Bhutan Living Standard Survey (BLSS) 2012, households annual cash-income from wood products was only 4.19 US-$ compared to 12.20 US-$ from the sale of non-wood forest products (NWFP). In relative terms, income from the sale of wood products and NWFPs contributed 0.2% and 0.6% to the annual household income, respectively.[38]

This paper argues that Bhutan's regulatory framework should be adjusted to account for the transformation of domestic energy use in rural households. Traditionally, households have relied on fuelwood for cooking and heating, but this dependence is declining. Bhutan is very close to achieve its goal of 100% electrification by 2020. Due to the rich endowment with hydropower, electricity tariffs have always been low (about 0.04 USD kWh^{-1}) and since 2013 rural households even receive the first 100 kWh at no cost (BBS, 2013). Even before then, per-capita fuelwood consumption dropped by 19% from about 1.5 to 1.2 m^3 between 2003 and 2012 (NSB, 2003; NSB & ADB, 2012). Given that fuelwood is responsible for indoor air pollution, the legitimate question arises how to increase the efficiency of fuelwood use in the context of Bhutan. Efficient allocation of fuelwood is hampered under the current governance system,

[37] For the purpose of brevity, instead of referring to rural households we will just use the shorter "households" henceforth, except when the context demands explicit differentiation from either urban or all households.
[38] Accounting also for the large share of home production and home consumption, wood products and NWFP after all comprise 4.0% and 0.7% of household income.

because households face no opportunity cost of fuelwood use other than their labour needed to collect it.

Analysing the unique situation of the underutilization of forests in Bhutan, this paper contributes to the existing literature in several ways: first it analyses how modifications of Bhutan's forest policies could increase the productive use of forests. Linking rural households to the currently underdeveloped domestic fuelwood market would generate positive welfare effects. For the analysis, the paper focuses on the fuelwood value chain in Bhutan, which is characterized by high domestic subsistence consumption by households and a high demand for charcoal by metallurgic industries which is imported from India. Second, the policy scenarios are designed in compliance with the country's specific criteria for sustainable forest management. Third, as a methodological contribution the paper applies a novel economy-wide model that for the first time incorporates seasonal underemployment, which is a further development of an earlier CGE model for Bhutan, which incorporates seasonal labour markets.

The remainder of this paper is structured as follows: the next section will describe in more detail the forestry sector in Bhutan, especially the harvesting, utilization, and regulations pertaining to timber. Following, the modelling structure and database are presented. The forest policy scenarios and the chosen model approach are described in section four. Section five presents the results and the paper concludes with a discussion and policy implications.

6.2 The Forestry Sector in Bhutan

The priority to conserve the country's forest resources is reflected in Bhutan's constitution, which mandates that at least 60% of land area have to remain under forest cover (RGoB, 2008). In 1969, Bhutan's first economic policy was to declare all forest land to be government owned. Since then, a considerable body of forest policies has been developed with the primary objective to ensure forest conservation and prevent unsustainable extraction. This has shaped the value chains of fuelwood and logs in Bhutan (see Figure 6.1).[39] Forestry is split into two sub-sectors: the government-controlled commercial forestry sector and the rural forestry sector, which consists of forest activities performed by rural households individually or organized in community forestry groups (CFGs).

[39] In order to distinguish between timber in log and fuelwood form, we do not use the term roundwood, which comprises all wood in the rough (FAO, 2018). Fuelwood comprises predominantly firewood and wood-chips used as wood energy.

6.2.1 Commercial Forestry

In contrast to Bhutan's rich endowment in forest resources forestry accounts for less than 2% of GDP (Arndt Feuerbacher, C. Dukpa et al., 2017). Most of the supply of commercial logs and fuelwood is from the Natural Resource and Development Corporation Limited (NRDCL), a state-owned and controlled enterprise, and its subcontractors. The NRDCL operates forest management units comprising about 133,000 hectares, equivalent to about 5% of total forest area (MoAF, 2016a). Depending on the forest-type, the NRDCL mainly applies two silvicultural practices, the group selection system to harvest timber in conifer and mixed-conifer forests and the patch cut system in broadleaved forests. The Department of Forest and Park Services ensures that the NRDCL's annually extracted quantity complies with the overall conservation principle of maintaining the ecological productivity of forest areas (MoAF, 2011).

6.2.2 Rural Forestry

Rural forestry accounts for about 70% of the timber harvested in Bhutan in 2012, the reference year for the model developed in this paper. Due to data limitations, it is not possible to estimate the shares of timber extracted by CFGs or by households individually. Hence, we aggregate both in the rural forestry sub-sector. The majority of rural households are not members of CFGs and are allowed to extract fuelwood and logs according to the Forest and Nature Conservation Rules (referred to the *Forest Rules* hereafter). The Forest Rules only regulate the extraction of timber for subsistence use and do not have any provisions allowing households to sell. Households may extract logs every 25 years for house construction and every 12 years for house renovations. In case of fuelwood, the Forest Rules determine extraction quotas restricting households to 8 or 16 m^3 of stack volume annually depending whether they have access to electricity or not (RGoB, 2017).

If rural households use any mechanical devices (e.g., a power chain) to extract fuelwood, they have to pay a royalty tax, however at lower rates than buyers of commercial fuelwood. Households mechanically extract timber according to single-tree selection, for which they obtain a permit from the forest officer, who also marks the respective tree in the village's surrounding forest. No royalty is charged if households collect dry fuelwood (e.g., branches or dead wood) by hand in backload quantities.[40] Households primarily extract timber in the winter season, between October and March. In some regions this seasonal restriction is even enforced

[40] One backload equals approximately 30 kg.

by customary norms to avoid provocation of local deities that are believed to protect the population from natural disasters (Sears et al., 2017).

Participation in CFGs is so far the only option for households to sell wood products. The design of CFGs has so far boosted the sale of NWFPs more than wood products. In 2012, 2.3% of forest area was designated for CFGs with a total membership of about 22,000 households (22% of all rural households) (MoAF, 2013). Management plans regulate the timber extraction from community forests. After the members' subsistence needs are met, excess timber may be sold to the market including royalty charges. Unfortunately, there is no systematic administrative data available on the quantities of fuelwood and logs sold through CFGs. Instead, we can only derive a rough estimate from the 2012 BLSS data, according to which households' cash income from selling timber was about 23 million Nu. Using the average 2012 basic outprices of logs and fuelwood and assuming that 50% of the marketed timber is either sold in form of logs or fuelwood, we can infer that CFGs sold about 21,900 m^3 of fuelwood and 2,400 m^3 of logs.[41]

The CFGs are a participatory and community based instrument allowing for sustainable management. The extraction quota also allows for sustainable local use of forests, but is implemented more restrictively. Fuelwood collected under the extraction quota can only be consumed by the household who collected it, without the opportunity to sell any surplus. Once a household has consumed all of its allocated quota, it may purchase commercial fuelwood at the market price, which includes the full royalty rate.

6.2.3 Wood Product Value Chain

The wood product value chain is schematically illustrated in Figure 6.1. The percentages in the grey boxes show that the largest share of the rural forestry sector is used as subsistence timber (97%). Despite a higher quantity of fuelwood extracted (about 940,000 m^3), logs comprise most of the forestry sector's output value due to their much higher prices per m3. Logs are demanded by two sectors, wood processing (e.g. furniture) and the construction sector. Subsistence logs can only be used for rural construction activities, which is shown as part of the overall construction sector.

Subsistence fuelwood is only consumed by rural households and makes up 65% of total fuelwood extraction in Bhutan. Consumption of subsistence fuelwood also includes the use of fuelwood for economic activities by rural households such as processing of cereals, distilling

[41] The results from the subsequent analysis are not sensitive against assuming a 25% or 75% share.

of Ara (a local alcoholic beverage) or drying of cardamom. Only a small share of commercial fuelwood is consumed by urban households (23.1% or 75,700 m^3) and intermediate-demand comprises the remainder (76.9%).

Despite high import quantities, domestic charcoal production in Bhutan is negligible, as shown by its low use of commercial fuelwood (< 0.1%). Metallurgical industries demand charcoal and coke as chemical reduction agents, which makes both direct substitutes. Electricity is not a substitute for neither of them. Almost all of charcoal demand is met by imports from India. In 2012, 54,700 tons of charcoal were imported, equivalent to 388,300 m^3 of fuelwood using a conversion ratio of 7.1 m^3 ton^{-1}. Charcoal is the main wood-based import item, accounting for 60% of all wood-based imports. A recent analysis found that there is high potential for the establishment of large-scale charcoal production in Bhutan, which could be accommodated under the country's conservation objectives applying sustainable forest management practices and using improved carbonization technologies (Arndt Feuerbacher et al., 2016). However, the current low level of forest utilization and the reluctance to adapt the regulatory framework by policymakers constitute important bottlenecks (Narain et al., 2014; World Bank, 1992).

Exports of logs and fuelwood is banned by law (RGoB, 2017) and imports of logs and fuelwood made up only 1.4% and 0.7% of total supply in 2012, respectively (Arndt Feuerbacher, C. Dukpa et al., 2017; MoF, 2013b)(Arndt Feuerbacher, C. Dukpa et al., 201781b6bbc47b8e". Trade is thus not included in Figure 6.1. Given their limited importance, imports of fuelwood are also excluded from the analysis. Overall, the schematic representation shows how strictly Bhutan's wood product market is separated into products of commercial and subsistence use, which highlights the very limited market access for rural households. This strict separation is enforced by forest check posts where any vehicle carrying timber must produce a timber transit permit. Persons transporting forest products "may be stopped and examined at any time and place" to determine if the forest product was legally obtained (RGoB, 2017, p. 62). Given the constancy in forest cover the system of monitoring and enforcement of forest policies seems to be largely effective. However, there are also accounts of illegal tree felling and smuggling of forest products (MoAF, 2012b).

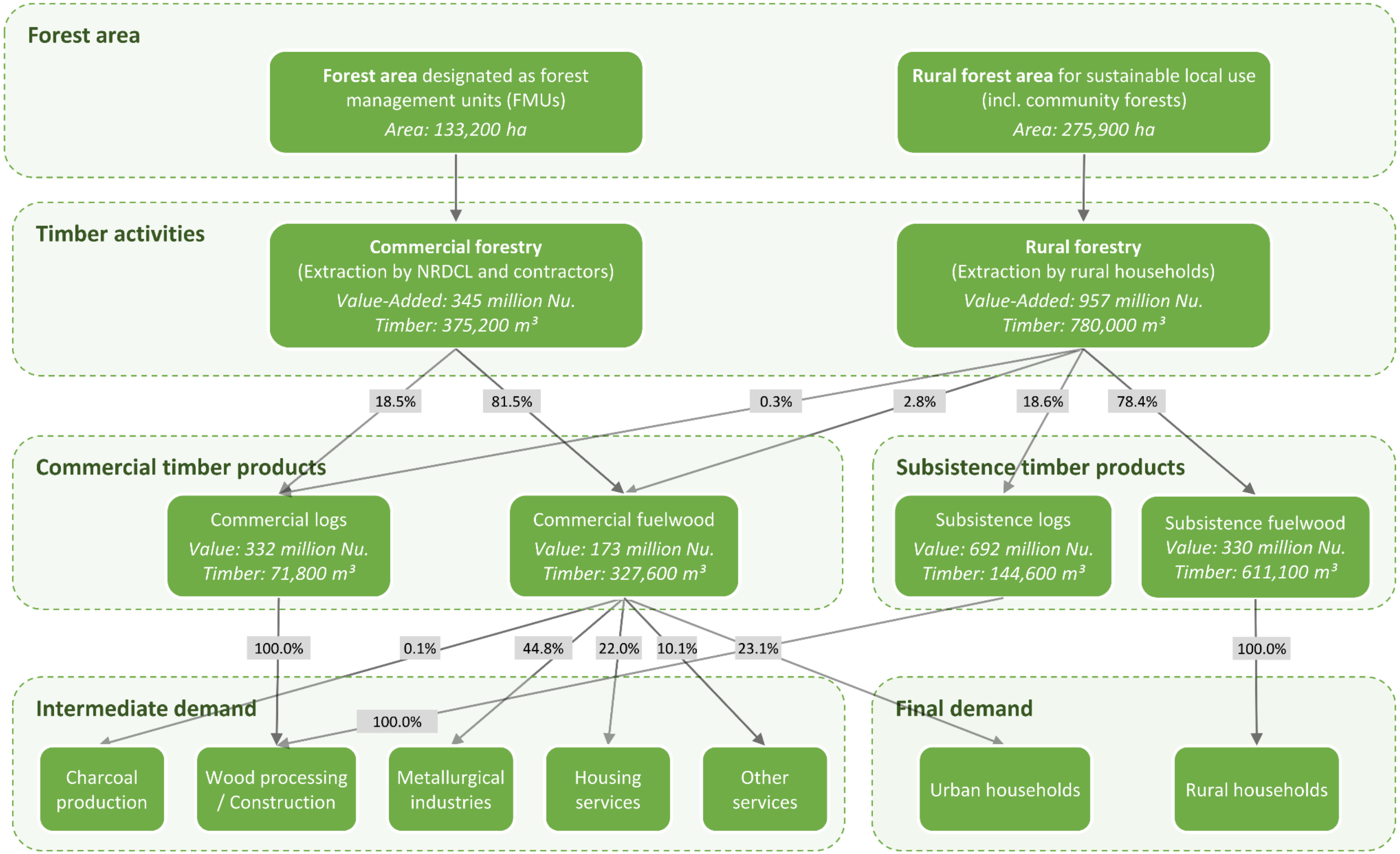


Figure 6.1. Schematic representation of Bhutan's wood product value chain for the year 2012

Note: 1 US-$ = 53.4 Ngultrum; values are reported in basic prices/CIF import prices and grey boxes show flow of wood products in m³.

6.3 Model Database and Framework

6.3.1 Model Database

The 2012 Social Accounting Matrix (SAM) for Bhutan (Arndt Feuerbacher, C. Dukpa et al., 2017) is modified to serve the purpose of this study. Data from the 2012 agricultural sample survey (MoAF, 2013a) and the BLSS 2012 (NSB & ADB, 2012) are used to disaggregate the rural economic activities of the SAM according to the country's three major agroecological zones (AEZs). AEZ1 is the humid, sub-tropical zone at altitudes below 1,200 meters above sea level (masl). AEZ2 is the dry-subtropical AEZ in altitudes between 1,200 and 1,800 masl. AEZ3 is the temperate zone in altitudes above 1,800 masl. In addition, within each AEZ, farm labour is disaggregated into monthly labour accounts reflecting seasonality of labour markets following the method documented in Arndt Feuerbacher and Grethe (2017). Lastly, a marginal charcoal production activity was introduced using the technology coefficients documented in Arndt Feuerbacher et al. (2016). An overview of the disaggregation of the seasonal 2012 Bhutan SAM is provided in Table 6.1:

Table 6.1. Account structure of seasonal 2012 Bhutan SAM

Category:	Accounts
Domestically produced commodities	Agriculture: Crops (27)[1], Livestock (6) [1], Forestry (20) [1,2], Industry: On-farm food processing (15) [1], Extractive industries (1), Food processing (3), Textile (4)[1], Wood processing, Charcoal production, Manufacturing (3), Electricity, Construction Services: Trade, Transportation, Government services (2), Other services (3)
Factors:	Labour: Skilled, Unskilled and Seasonal labour (36) [1] Land: Rainfed land (3)[1], Irrigated land (3)[1], Pasture land (3)[1], Forest area operated by NRDCL, Forest area accessed by rural households (12) Capital: Capital, Cattle (3)[1] and Other animals (3)[1]
Margins:	Trade and Transportation margins
Institutions:	Households: Urban (3), Rural (6)[1] Enterprises, Government
Taxes	Import tax, Excise tax, Sales tax, Income tax, Production tax, Forest royalty
Capital	Investments and Stock changes

Note: Number in parenthesis refer to the number of items, e.g. there are 27 crop sectors.
[1] Item (or part of it) is disaggregated by the three agroecological zones.
[2] Each of the six rural households performs three rural forestry activities (commercial fuelwood, subsistence fuelwood and logs). Non-wood forest product and commercial forestry are each treated as single sectors.

Using satellite data on the quantities of seasonal labour employment, we infer the days of seasonal underemployment per month assuming that full-employment is equivalent to 260 days of employment per year (i.e. five working days per week). Based on the monthly underemployment ratio, we estimate the seasonal variation in wages using a wage curve (Blanchflower & Oswald, 1995) as specified in equation (6.1):

$$\log\left(\frac{WF_t}{PPI}\right) = \gamma_t + \varepsilon_t * \log\left(UNEMP_t\right) \tag{6.1}$$

where WF_t is the seasonal wage in month *t* deflated by the Producer Price Index (PPI), γ_t is a scale parameter and ε_t is the elasticity of seasonal underemployment rate ($UNEMP_t$) with respect to the real wage rate. The wage curve is calibrated by assuming that the observed annual farm labour wage corresponds to that month with average seasonal employment. Due to the lack of own estimates, we assume $\varepsilon_t = -0.1$, which fits the range of elasticities reported for most countries by Blanchflower and Oswald (1995).

Figure 6.2 reports the calibrated seasonal wages in AEZ2. In AEZ2, the busiest months are June and October for paddy transplanting and harvesting, as well as December for the citrus harvest. Slack seasons are late winter and early spring in the months April, March and February. The seasonal labour calendar is different across each agroecological zone and follows closely the paddy cropping pattern.

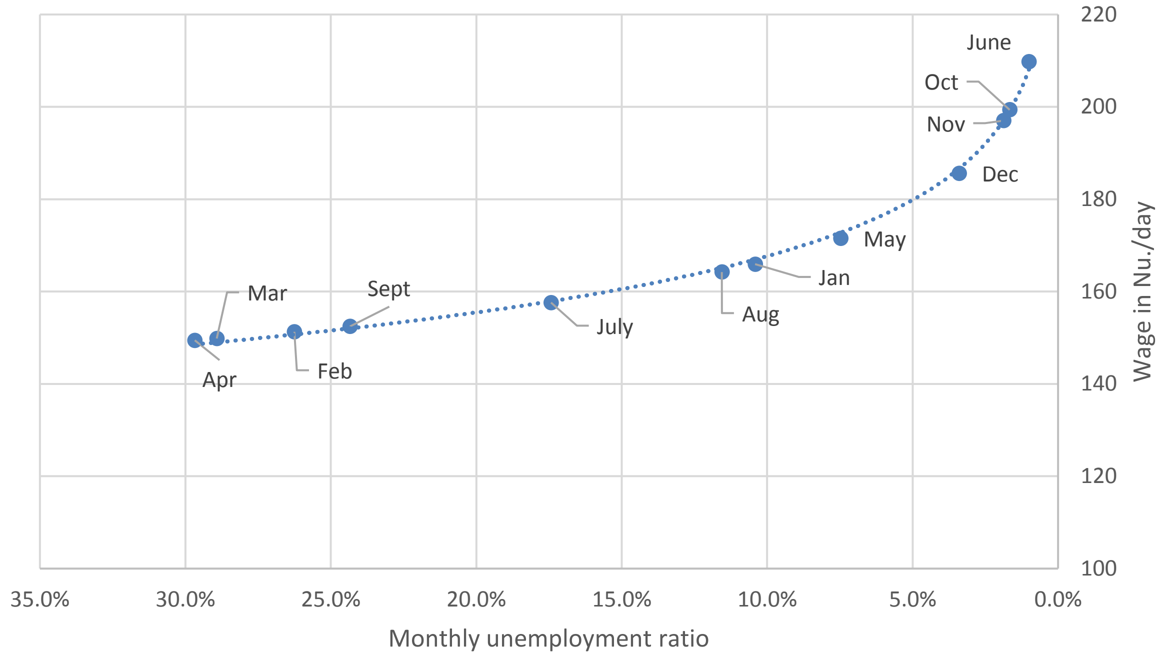


Figure 6.2. Seasonal underemployment and estimated seasonal wages in the dry sub-tropical zone (AEZ2) in Bhutan

Households are split into nine representative household groups. There are three urban households disaggregated by their predominant source of income: (1) Skilled labour, (2) unskilled labour, and (3) capital and transfers. Rural households are split into six groups distinguished by AEZ and electricity access. The share of factor and non-factor income in total household income is presented Appendix 6A.

The model database was adjusted to reflect the peculiarities of Bhutan's forest sector (Figure 6.1) with the previously mentioned simplification that commercial and subsistence logs are aggregated in one commodity. The formal forestry sector extracts commercial fuelwood and logs using one production activity, i.e. joint production governed by a Constant Elasticity of Transformation (CET) function governing the flexibility of output shares (Punt, 2013). Each of the six rural households extracts commercial fuelwood, subsistence fuelwood, and logs in separate production activities (i.e., there are 18 rural forestry activities extracting timber). This is necessary as the extraction of all three wood commodities by the informal (household) sector is subject to different policy regimes. Households within the same AEZ extract subsistence fuelwood or commercial fuelwood from the designated forest area for rural use. The rural forest area for log extraction is treated separately. The above described adjustments allow to depict the household-specific quantity restrictions and subsistence use of fuelwood.

6.3.2 The Bhutan model

The Bhutan model used for this study is an adjusted version of STAGE2, a single country, comparative-static CGE model, comprehensively described in McDonald and Thierfelder (2015). The agents in the model are production activities, households, incorporated enterprises, the government, and the capital market. Following Armington's insight (1969), for each sector the substitutability in demand between domestically produced and imported commodities is imperfect and specified by a Constant Elasticity of Substitution (CES) function. The allocation of domestically produced commodities between domestic and world markets (i.e. exports) is governed by CET functions.

In the production structure, inputs are nested at five levels. The structure is shown for agriculture and forestry activities in Figure 6.2 and the associated parameters are documented in Appendix 6B. At nest L1, we assume that other intermediate inputs and value added components are aggregated according to Leontief technology. Fixed shares also hold for the aggregation of intermediate inputs at L2.1. The value added nest at L2.2 and factor aggregates below (L3.2 and 3.3) are aggregated using CES technology. Rural timber extraction activities are labour intensive and use of machinery is limited to chainsaws and manual tools. We assume Leontief technology at the nest L2.2, i.e., labour demand increases proportionately to utilized forest land. Fertilizer and land are aggregated in nest L3.1[42], but there is no fertilizer input for forest activities and forest land entering at L4.2 is equal to L3.1.

At level 4.3, seasonal labour from the 12 time period enters the production structure. Elasticities at this level are activity specific and listed in Appendix 6C. Cropping activities for instance have a rigid demand for seasonal labour. In contrast, forestry activities have a higher degree of flexibility according to which labour can be substituted across time periods. Regularly employed labour (i.e. permanent labour) is aggregated over skill types in the nest L4.4.

The structure of production technology is slightly different for other production activities. For livestock activities, different types of animal feed are aggregated at Level L4.1 instead of

[42] For livestock activities L3.1 is an aggregate of feed and pasture land. At L4.1 compound feed and crop fodder is aggregated and pasture land enters at L4.2.

fertilizer. For activities that neither require fertilizer, feed, land or seasonal labour, levels L3.1 and L4.3 and below remain empty. The metallurgical activities are a special case, which require both charcoal and coke as sources of carbon. In their case, a CES nest at L3.1 is added at which these are aggregated to a carbon aggregate.

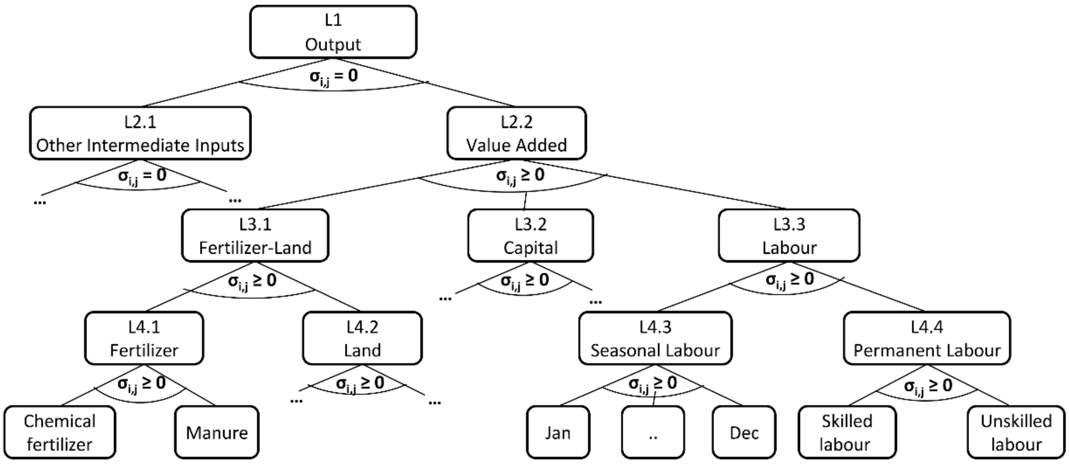


Figure 6.3. Nested production structure of agriculture and forestry activities in the Bhutan CGE model

In addition to the above changes in the production structure, the model was extended to include margins for exports and to allow for flexible output of multi-product activities using a CET specification, which is particularly relevant for the joint production of logs and fuelwood by the commercial forestry activity.

Household consumption in STAGE2 was modified to a LES-CES system. Household demand for ten commodity categories is modelled using a Linear-Expenditure-System (LES). Following Arndt Feuerbacher and Grethe (2017), household specific income elasticities are estimated using the BLSS 2012 cross-sectional household data and a system of seemingly unrelated regressions. Demand for individual commodities within the commodity categories is governed by CES functions and CES elasticities are reported in Appendix 6B.

<u>Model closures</u>

Our model uses the small country assumption, i.e. world market prices are fixed. Given the one-to-one peg of Bhutan's Ngultrum with the Indian Rupee, we further use a fixed nominal exchange rate, and fix foreign savings. The balance of payments are adjusted using flexible import tax rates, which vary proportionately. The model is investment-driven (investments are fixed in real terms) and savings rates of households and enterprises adjust proportionately. Real government consumption and net savings are fixed. The government account is adjusted using flexible direct tax rates, which vary additively. The model numéraire is the consumer price index (CPI). Capital supply is perfectly mobile allowing for a medium-term adjustment horizon. All types of labour (skilled, unskilled and seasonal labour) are perfectly mobile across those activities in which they were demanded in the base period, but there is no mobility across labour types, e.g., unskilled labour cannot become skilled labour. Seasonal labour is further segmented into AEZs and there are no provisions for seasonal migration between AEZs. Crop land is imperfectly mobile across cropping activities within the land types (irrigated, rainfed and orchard land) using a CET function.

We assume fixed employment levels for all factors, except for seasonal labour and rural forest land. Underemployment of seasonal labour is modelled using a wage curve as described in the previous section. Given the high degree of underutilization, rural forest land is supplied at constant factor prices using a perfect elastic horizontal supply up to the point of full utilization.

Factor supply by households is explicitly modelled and factor market clearing follows equation (6.2) for all factors f of subset NFR , i.e. all factors except rural forest land.

$$\overline{FSI}_{ins,f} = FSI_{ins,f} + UNEMP_f * ushr_{ins,f} \qquad f \in NFR \qquad (6.2)$$

Where $\overline{FSI}_{ins,f}$ is the fixed total potential supply of a factor f by institution ins, variable $FSI_{ins,f}$ denotes the actual factor supply and if underemployment is prevalent, an institution's share in unemployed factors is represented by the product of the total unemployed factor quantity, $UNEMP_f$, and the institution's share in the unemployed factor quantity, $ushr_{ins,f}$. Due to lack of data, the incidence of seasonal underemployment of farm labour within each AEZ is assumed identical between farm and landless households. However, the above setting principally allows for an endogenous change in factor endowment.

The institutional factor supply of rural forest land, identified by subset rf_f, is directly linked to the household specific timber extraction activity. In other words, each households' utilized factor endowment of rural forest land is equal to the respective forest land demanded by the household specific fuelwood extraction activities. This is achieved by mapping rural forest activities, arf_a, to institutions via the mapping IARF(a,ins) in the factor market clearing condition of rural forest land in (6.3).

$$FSI_{ins,rf} = \sum_{arf \forall IARF(arf,ins)} FD_{rf,arf} \tag{6.3}$$

The supply of forest land to each institution, $FSI_{ins,rf}$, is altered with changes in the quantity of unutilized forest land $UNEMP_{rf}$. However, maximum supply is constrained by the estimated availability of rural forest land usable under sustainable management criteria, $\overline{FS}_{rf}$.

$$\overline{FS}_{rf} = \sum_{ins} FSI_{ins,rf} + UNEMP_{rf} \tag{6.4}$$

Equation (6.4) only governs the maximum usable forest land and theoretically would allow for an open access regime by institutions within the boundaries of sustainable forest use. However, as will be explained in the modelling approach section, households' forest use will be further constrained by the extraction quota rent mechanism. In case all forest land is utilized, the forest land rent regime changes, i.e. the forest rent is not constant anymore, but is now determined endogenously. The share in income from total forest rent depends on the household specific factor demand, which means that household's share in forest rent is also determined endogenously.

6.4 Forest Sector Reform Scenarios

6.4.1 Forest Availability for Sustainable Rural Use

We simulate three forest sector reform scenarios that increase the linkage between rural households and the commercial market for fuelwood. This is achieved by introducing a commercial quota that allows rural households to sell higher quantities of fuelwood compared to the existing community forest policy regime. In order to embed the subsequent analysis within Bhutan's forest conservation framework, we estimate the available forest area for sustainable rural use within each of Bhutan's 205 sub-districts (gewogs).

Using the dataset of the 2016 Land Use and Land Cover Project (FRMD, 2017), which is based on Landsat 8 satellite data, we obtained information of forest cover differentiated by five forest types (Bluepine, broadleaf, chirpine, fir and mixed conifer). Forest area for sustainable rural use was defined as located within a 2 km radius of rural settlements and compliant with the sustainable forest management criteria of the MoAF (2013c) documented in Appendix 6E. In total, we estimate that 602,500 hectares are available for sustainable rural use (Figure 6.4) accounting for 22.1% and 15.7% of forest and land area, respectively.

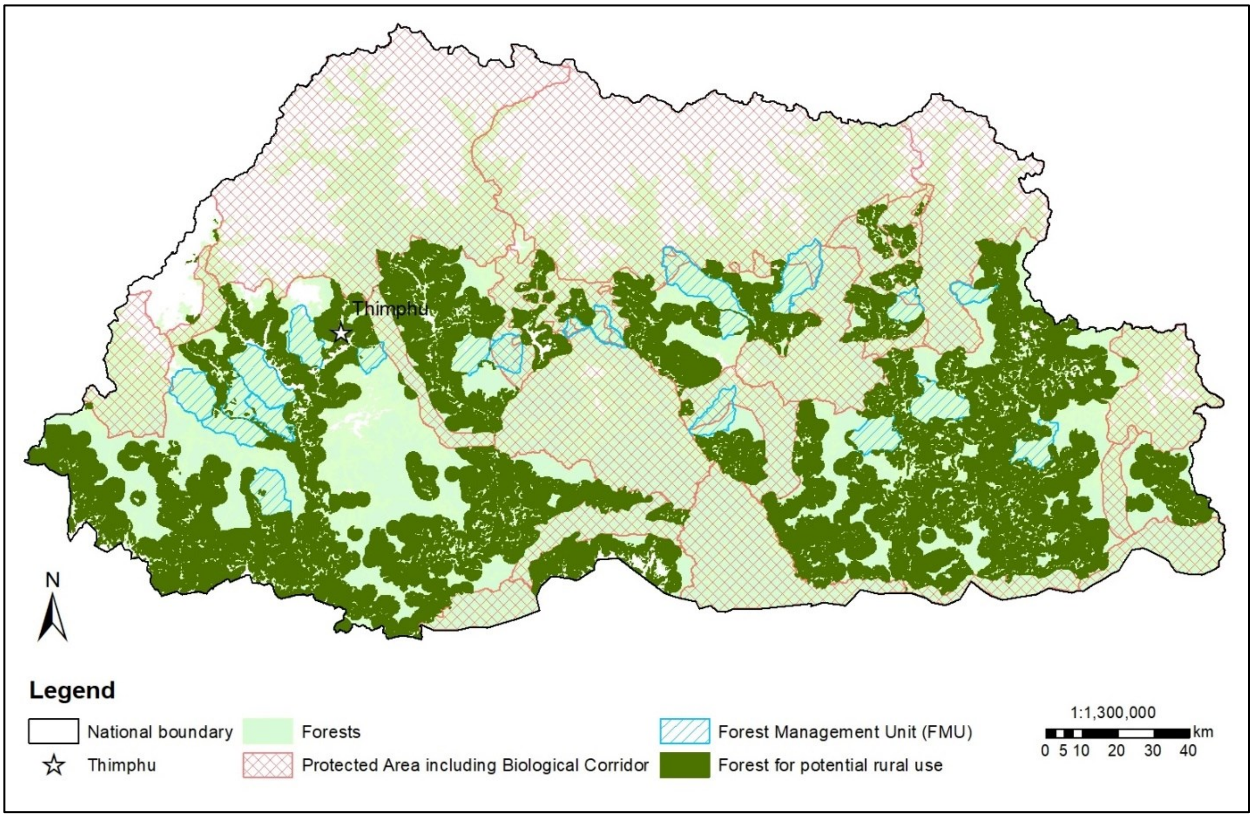


Figure 6.4. Map of Bhutan showing forest resource availability for sustainable rural use

Note: The spatial criteria for assessment is documented in Appendix 6E. Please note, existing community forest area is included in forest for rural use, but in rare incidences there are overlaps with forest management units.

Data on altitude levels of gewogs (NLC, 2014) was used to identify the availability of total rural forest area per AEZ (Table 6.2). The sustainable fuelwood harvest limit per household group is estimated by converting forest area into potential forest biomass with the forest-type specific annual allowable cut in m^3 $hectare^{-1}$ (Schindele, 2004). All households could fully exploit their extraction quota, without exceeding the sustainable harvest limit.

Table 6.2. Overview of distribution of rural household, forest resource availability and fuelwood harvest and utilization for the model base year 2012.

Rural household groups		Share in total rural households	Available forest resources[a*]	Sustainable fuelwood harvest limit[b]	Extraction quota	Fuelwood harvest	Sold Fuelwood
		% share	hectares	m³/ household	m³/ household	m³/ household	m³/ household
Electrified	AEZ1 (h1elec)	24.4%	152,617	17.0	8.0	4.7	0.2
	AEZ2 (h2elec)	29.0%	168,873	16.7	8.0	5.9	0.2
	AEZ3 (h3elec)	34.4%	157,659	9.4	8.0	6.8	0.2
Non-electrified	AEZ1 (h1nonelec)	5.7%	47,042	25.0	16.0	6.4	0.2
	AEZ2 (h2nonelec)	5.1%	60,456	24.7	16.0	8.4	0.3
	AEZ3 (h3nonelec)	1.4%	15,877	17.4	16.0	11.1	0.4
All rural households		**100.0%**	**602,523**	**15.2**	**9.0**	**6.2**	**0.2**

[a] Estimated according to spatial exclusion and sustainable forest management criteria defined in MoAF, 2013 and Schindele, 2005
[b] Computed by excluding households extraction of logs (2012 levels) and by distributing the harvest potential beyond the extraction quota allocation proportionately across household types within each AEZ.

6.4.2 Modelling Approach

We modify the model to depict the extraction and commercial fuelwood quota using mixed-complementarity problem equations. For the extraction quota this is shown in (6.5):

$$\overline{EQ}_{ins,rf} \geq \sum_{arf \forall IARF_{arf,ins}} FD_{rf,arf} \qquad (6.5)$$

Where $\overline{EQ}_{ins}$ denotes household's total extraction quota for commercial and subsistence fuelwood converted into usable forest area and $FD_{rf,arf}$ describes the rural forest area, rf, demanded by the household specific fuelwood extraction activities, arf. Equation (6.5) is enforced by the extraction quota rent adjuster $EQRADJ_{ins,rf}$, which is equal to zero at the beginning, because none of the extraction quotas are binding in the base.[43] For reasons of consistency of physical output, households' extraction of commercial and subsistence fuelwood is treated in separate activities, leading to a mismatch of the number of extraction quotas and the activities constrained by them (Each households faces one extraction quota, which restricts

[43] Technically, a further equation is required in order to link the household specific quotas to activities via the mapping IARF(arf,ins)

the combined output of two activities). Equation (6.6) matches the quota constraint by mapping $EQRADJ_{ins,rf}$ with the activity specific quota rent, $EQR_{rf,arf}$, via the maping $IARF(arf, ins)$.

$$EQR_{rf,arf} = \sum_{ins \forall IARF(arf,ins)} EQRADJ_{ins,rf} \tag{6.6}$$

The commercial quota for fuelwood $CQ_{arf,ccf}$ is implemented as shown (6.7):

$$\overline{CQ}_{arf,ccf} \geq \frac{QXAC_{arf,ccf}}{\overline{H}_{arf}} \tag{6.7}$$

where $QXAC_{ahf,ccf}$ describes rural households' output of commercial fuelwood, identified as a subset ccf_c of commodities *c*. The fixed variable $\overline{H}_{arf}$ contains the number of households involved in the household specific rural forestry activities. Technically, in the model the commercial quota is enforced by variations in the quota rent $CQR_{arf,ccf}$, whose household specific rate in the base is initialized between 26.7% and 43.8% (the rent is calibrated using land productivity differences between commercial fuelwood extraction by rural households and the formal forestry sector). Rents from both the extraction and commercial quota are redistributed to the respective households.

Due to the detailed disaggregation of forest products, we assume homogeneity for the aggregation of commercial fuelwood as well as charcoal from different sources. Consequently, the model aggregates domestic supply by different producers at perfect elasticity as well as total domestic supply and imports. In case of commercial fuelwood for instance, total domestic supply QXC_{ccf} is equal to the sum of the output of all domestic producers $QXAC_{a,ccf}$.

$$QXC_{ccf} = \sum_{a} QXAC_{a,ccf} \tag{6.8}$$

The chosen modelling approach allows to directly simulate the previously identified forest sector reforms by shocking the fixed variable for the commercial fuelwood quota, $\overline{CQ}_{arf,ccf}$, such that rural households are allowed to sell higher shares of their fuelwood quota. The extraction quota ensures at the same time that rural households are only extracting firewood subject to their eligibility.

6.4.3 Policy Scenarios

The three simulated scenarios presented in Table 6.3 contain different changes in the levels of the commercial and extraction quota and all include the permission of large-scale charcoal production as a component. In the moderate (*Mod*) and progressive (*Prog*) scenario, the extraction quotas remain as regulated by the forest rules, but a commercial quota is introduced allowing households to sell either 2 or 4 m³ of fuelwood per year. The third scenario is the community forestry (*Cof*) scenario resembling a scenario, in which all households are assumed to participate in CFGs. In this scenario, the entire estimated rural forest land is operated by CFGs, which means that the extraction quotas are set equal to the estimated sustainable fuelwood harvest limit as estimated in Table 6.2 (excluding the base extraction level of logs).

Table 6.3. Description of simulated policy scenarios

Scenarios / Rural household groups		***Mod* (“Moderate”)**		***Prog* (“Progressive)**		***Cof* (“Community forestry”)**	
		Extr. quota	***Comm. Quota***	***Extr. quota***	***Comm. quota***	***Extr. quota***	***Comm. quota***
Electrified	AEZ1	8.0	2.0	8.0	4.0	17.0	4.0
	AEZ2	8.0	2.0	8.0	4.0	16.7	4.0
	AEZ3	8.0	2.0	8.0	4.0	9.4	4.0
Non-electrified	AEZ1	16.0	2.0	16.0	4.0	25.0	4.0
	AEZ2	16.0	2.0	16.0	4.0	24.7	4.0
	AEZ3	16.0	2.0	16.0	4.0	17.4	4.0

Note: Quotas are expressed in m³ per household and year. All scenarios include the permission of large-scale charcoal production.

6.5 Results of Forest Policy Scenario Simulations

This section presents the simulation results of the three forest policy scenarios Table 6.3). First, we report the direct effects of the scenarios, i.e. how rural households react towards the policy shocks, before we present the economy-wide implications of the forest policies.

6.5.1 Changes in Fuelwood Extraction and Use

Introducing commercial quotas and eliminating the extraction quota system, in case of the community forestry scenario, result in a strong boost of fuelwood extraction by rural households. Overall fuelwood extraction increases by 25.7% in the moderate scenario, and by 36.8% and 55.0% in the progressive and community forestry scenarios. The largest part of the increase in extraction is sold to the commercial fuelwood value chain, as shown in Figure 6.5. Bold and italic printed values in the upper part of the stacked bars highlight that the commercial quota is exhausted by the households. Generally, households cannot utilize all of the commercial quota if the extraction quota becomes a binding constraint. This is only the case for electrified households, particularly for those in AEZ3, who even extract up to the sustainable harvest limit in the community forestry scenario. Non-electrified households exhaust the commercial quota in all incidences thanks to their initially high extraction quota.

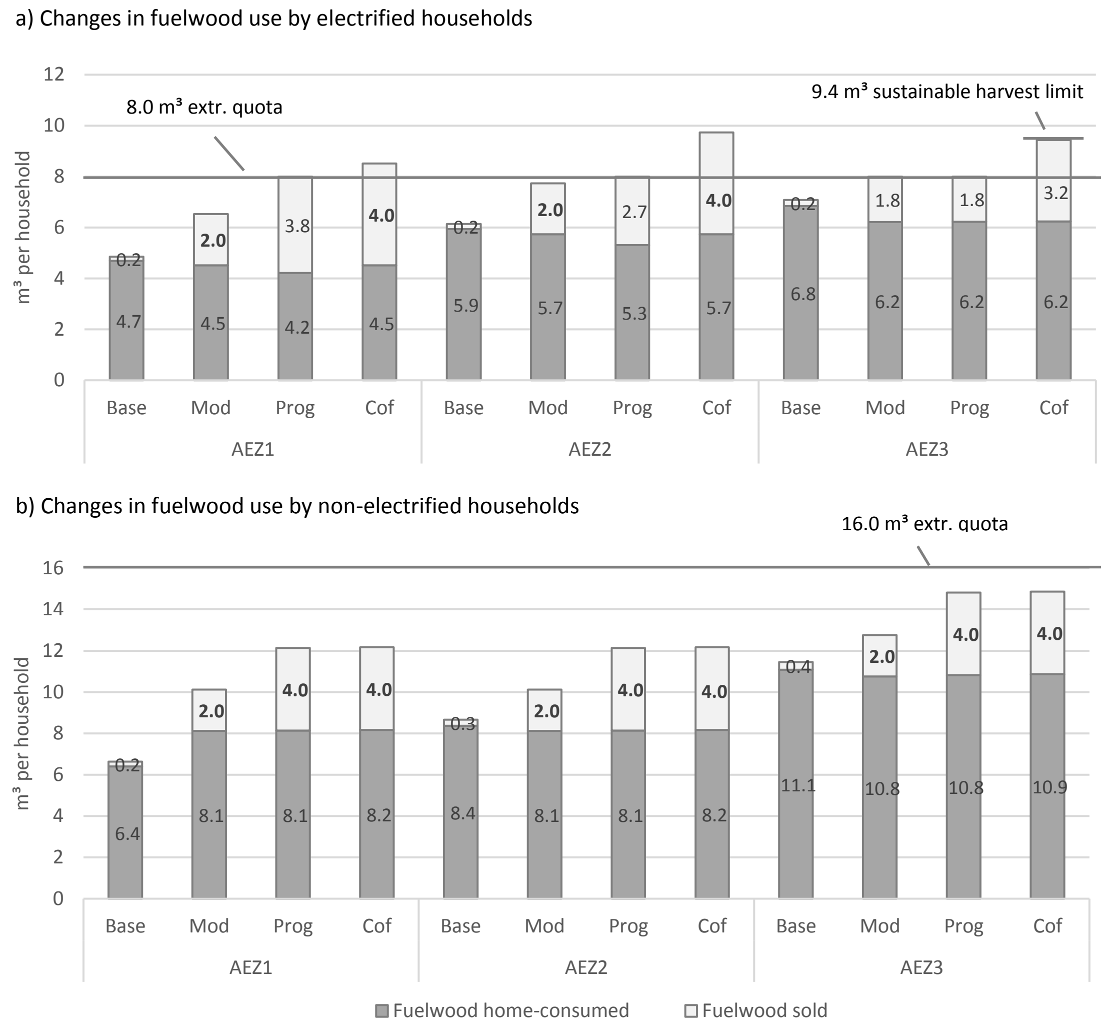


Figure 6.5. Simulated changes in fuelwood subsistence consumption and sale by household type

Note: Bold printed values of fuelwood sale that the commercial quota was fully exploited. No commercial quota exists in the base and sale of fuelwood originates from community forestry schemes. Subsistence consumption is calculated as the difference between fuelwood quantity extracted and quantity sold.

6.5.2 Changes in Purchaser Prices and Energy Consumption

Providing an alternative use of fuelwood, the commercial quotas increase the opportunity cost of fuelwood if household's overall access to fuelwood becomes constrained (i.e. a binding extraction quota). This is reflected in the strong increases of shadow prices[44] of subsistence fuelwood (Table 6.4), explaining the reduction in subsistence use by electrified households. As the shadow price increases, electrified households approach a point in which the marginal benefit of selling fuelwood is offset, which limits households' ability to use all of their commercial quota. Non-electrified households face no direct incentive to reduce their fuelwood consumption, since their extraction quota never becomes a binding constraint. Prices for fuelwood consumed by non-electrified households increase only modestly due to higher extraction cost as seasonal wages increase. The community forestry scenario is a special case, in which only the electrified households in AEZ3 are constrained by the sustainable harvest limit, all other households are able to use the entire commercial quota.

Table 6.4. %-Changes in purchaser prices

Purchaser prices		Mod	Prog	Cof
Crops*		0.1	0.1	0.2
Livestock*		0.2	0.3	0.5
Forestry*		0.8	1.2	1.6
Logs and NWFP*		0.0	0.0	0.0
Subsistence fuelwood	Electrified AEZ1	0.5	***10.6***	1.1%
	Electrified AEZ2	0.4	***11.5***	0.8%
	Electrified AEZ3	***7.3***	***7.2***	***7.2%***
	Non-electrified AEZ1	0.5	1.0	1.1%
	Non-electrified AEZ2	0.4	0.4	0.8%
	Non-electrified AEZ3	0.2	0.2	0.5%
Commercial fuelwood		-0.1	-0.1	-0.1
Food processing*		-0.1	-0.1	-0.1
Manufacturing*		0.0	0.0	0.0
Charcoal		0.0	0.0	0.0
LPG and kerosene		0.0	0.0	0.0
Electricity		0.2	0.4	0.5
Construction and other services*		0.0	0.0	0.1

* Indicates change in aggregate. Note: Percentage changes of subsistence fuelwood printed in italic and bold refers to exhausted extraction quotas.

[44] Since subsistence fuelwood is not marketed, we interpret the reported purchaser prices (Table 6.4) as shadow prices.

Despite the strong supply increase, commercial fuelwood prices drop only slightly. This is owed to the very elastic demand for fuelwood by charcoal production, which absorbs almost all additional fuelwood (use of fuelwood is shown in Appendix 6F). Due to the homogeneity assumption for domestic and imported charcoal, charcoal prices are hardly affected. Fossil-fuels (incl. LPG and kerosene) and coke are only imported. Their purchaser prices thus remain stable, as the import cost is exogenously determined except for the price of trade and transportation margins. The price for electricity increases moderately, which reflects the higher demand by rural households.

Given forestry's small share in GDP (2%), all remaining sectors are only indirectly affected by the policy scenarios. Prices for crops increase only slightly. Accounting for seasonal labour, our model setup allows to consider the seasonal complementarity of cropping and forestry activities, as they are largely performed during different time periods of the year. Consequently, the effect on crop production is low. Livestock production is affected at a slightly higher degree, as livestock activities have a more constant labour demand across all seasons.

With the incentive of selling fuelwood, households reduce their fuelwood consumption and shift towards cleaner energy sources (Table 6.5). At the national level, home consumption of fuelwood declines by 2.2% and 2.1% in the moderate and community scenario, and by 5.5% in the progressive scenario. Instead, consumption of cleaner fuels, electricity as well as LPG and Kerosene, increases. The fuel-switch to cleaner fuels potentially generates high health related co-benefits of reduced indoor air pollution, which are not included in our model. These benefits would be lower for non-electrified households, who face a lower incentive to substitute away from fuelwood and who, additionally, can only use LPG and kerosene as alternative fuels.

Table 6.5. Percentage change in energy consumption by rural households

		Mod	Prog	Cof
Electrified households				
Fuelwood	AEZ1	-0.1%	-6.9%	-0.3%
	AEZ2	0.1%	-7.3%	0.1%
	AEZ3	-6.0%	-5.8%	-5.6%
Other fuels	AEZ1	0.7%	6.6%	1.5%
	AEZ2	0.6%	7.4%	1.3%
	AEZ3	3.7%	3.7%	4.0%
Electricity	AEZ1	0.4%	6.1%	0.8%
	AEZ2	0.3%	6.8%	0.6%
	AEZ3	3.4%	3.2%	3.3%
Non-electrified households				
Fuelwood	AEZ1	0.0%	-0.2%	-0.1%
	AEZ2	0.5%	0.7%	1.0%
	AEZ3	0.6%	1.2%	1.6%
Other fuels	AEZ1	0.8%	1.5%	0.9%
	AEZ2	1.1%	1.7%	2.5%
	AEZ3	1.2%	1.7%	2.7%
All rural households				
Fuelwood		-2.2%	-5.5%	-2.1%
Other fuels		2.2%	4.8%	2.8%
Electricity		1.8%	4.9%	1.9%

6.5.3 Changes in Factor Income

As explained in the methods section, we disaggregated rural labour into seasonal periods to account for periods of seasonal underemployment, which predominantly coincide with timber extraction activities. Given the high prevalence of forest underutilization, we also allow for a perfect horizontal supply of unutilized forest area. As expected, the supply of rural forest land and seasonal labour increases, when we shock households' access to the commercial fuelwood value chain (Table 6.6). Utilization of rural forest land increases by up to 43.3% in the community forestry scenario. The demand for labour by rural forest activities changes in fixed proportions (i.e. Leontief technology) to the utilized rural land. Yet, as in the base fuelwood extraction activities account for just 3.4% of total rural employment, the effect is relatively small in terms of total employment.

Table 6.6. Factor supply changes of rural labour and forest land

Factor supply changes		% changes compared to base		
Seasonal labour		**Mod**	**Prog**	**Cof**
Summer labour	AEZ1	0.3%	0.4%	0.7%
	AEZ2	0.3%	0.4%	0.7%
	AEZ3	0.1%	0.1%	0.2%
Total summer labour		0.2%	0.3%	0.5%
Winter labour	AEZ1	0.9%	2.0%	1.9%
	AEZ2	0.6%	0.7%	1.2%
	AEZ3	0.6%	0.6%	1.3%
Total winter labour		0.7%	1.0%	1.4%
Total seasonal labour		**0.4%**	**0.6%**	**1.0%**
Forest land accessed by rural household				
	AEZ1	30.9%	57.6%	64.7%
	AEZ2	22.4%	29.0%	47.4%
	AEZ3	13.7%	14.6%	30.5%
Total rural household forest land		**20.2%**	**28.4%**	**43.3%**

The increased supply of forest land and rural labour leads to a factor endowment effect with higher factor income. On average, the endowment effect explains about 50% of household income changes equally across all scenarios (see also Appendix 6G). Figure 6.6 shows the total percentage changes of household incomes and the decomposition in its main income sources with incomes indexed to the national CPI. For all rural households, incomes increase, albeit at varying degrees. The progressive and community forestry scenarios have the highest impact, increasing household income from 0.4% to 0.9% and from 0.6% to 1.0%, respectively. The moderate scenario results in smaller gains, from 0.3% to 0.5%. Non-electrified households generally benefit from higher increases in household income, as they are less constrained by the extraction quota. On average, in all three scenarios higher income levels from forest land and winter labour make up at least two-thirds of the average increase in rural household income. Income from quota rents is only received if at least one of the two quotas becomes binding. The quota rent can comprise a substantial share (up to 33%) of the increase in household income, especially if the extraction quota is exhausted as in case of electrified households.

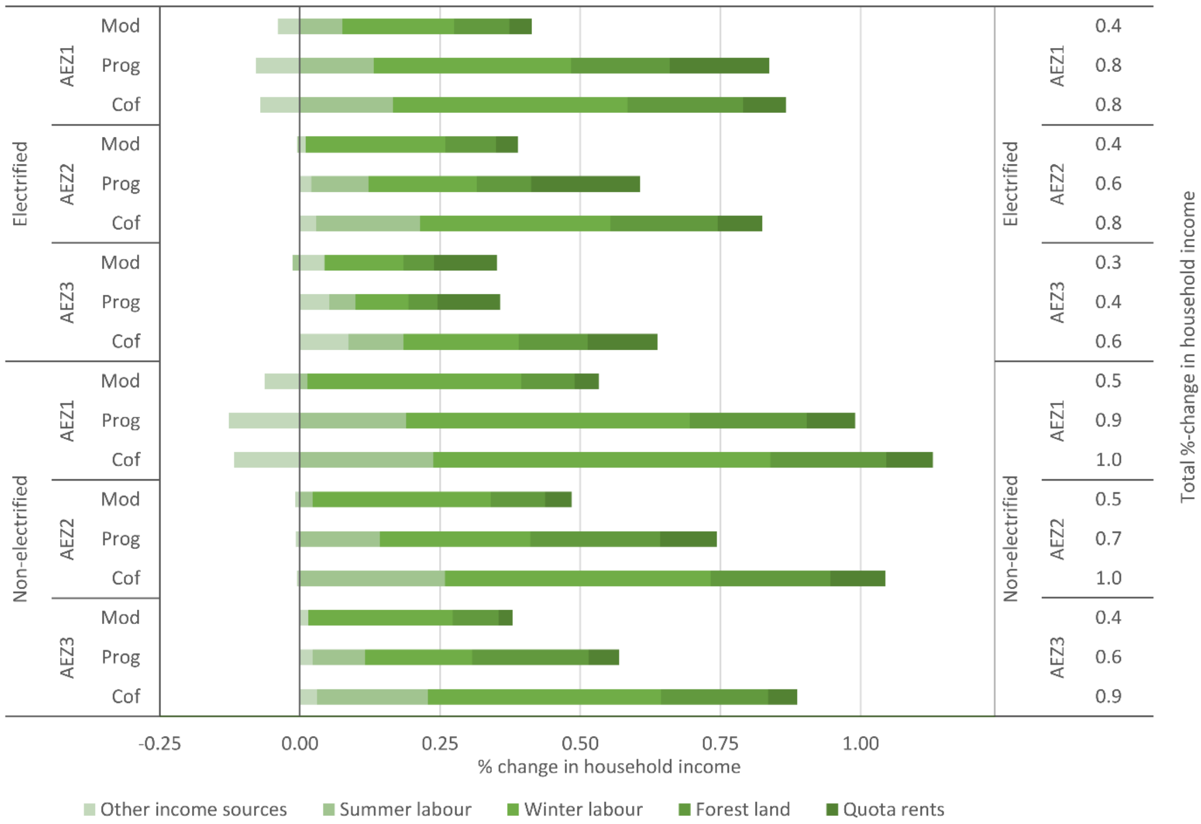


Figure 6.6. Decomposition of percentage change in rural household income

6.5.4 Economy-wide Changes

The forest policies have important implications for the degree of forest utilization in Bhutan. In the base, about 15.4% of forest area are utilized by either the NRDCL (4.9%) or rural households (10.5%) (Table 6.7). Total forest utilization increases to 17.5% in the moderate scenario up to 19.9% in the community forestry scenario, which is all due to the increases in forest use by rural households. Forest use by NRDCL (i.e. the commercial forestry sector) remains almost stagnant. In the progressive scenario, supply of commercial fuelwood by rural households would become almost as high as by the NRDCL and even surpass it in the community forestry scenario. Changes in forest area utilized and harvested biomass are linear, as the model assumes a constant annual allowable cut specific to each AEZ. A linear relationship also holds for the ratio of fuelwood input and charcoal production. We assume a conversion factor of 7.1 m³ of fuelwood per ton of charcoal. Since almost all additionally supplied commercial fuelwood is carbonized, the reforms allow for high degree of substitution of charcoal imports. At the lower end, i.e. the moderate scenario, almost half of charcoal imports are substituted by domestic production, and even higher reductions are achieved in the progressive and community forest scenario.

Table 6.7. Simulated changes in physical timber output, forest utilization and charcoal

	Base	Mod	Prog	Cof
Forest utilization				
Forest use (in hectares)	419,244	476,919	500,528	543,119
by NRDCL	133,210	133,210	133,210	133,210
by rural households	286,034	343,709	367,319	409,909
% change in forest utilization		13.8%	19.4%	29.5%
Forest use (in % of total forest)	15.4%	17.5%	18.4%	19.9%
by NRDCL	4.9%	4.9%	4.9%	4.9%
by rural households	10.5%	12.6%	13.5%	15.0%
Timber output				
Total forest biomass (m^3)	1,148,041	1,309,941	1,379,959	1,494,911
% change in timber extraction		14.1%	20.2%	30.2%
Logs (m^3)	216,491	216,455	216,470	216,476
Commercial fuelwood (m^3)	320,435	496,112	585,911	679,956
by NRDCL	298,574	298,107	297,882	297,597
by rural households	21,862	198,006	288,029	382,359
Subsistence fuelwood (m^3)	598,038	-14,957	-58,686	-53,638
Charcoal production (tons)	20	23,679	35,714	48,414
Import share of charcoal supply (%)	100.0%	58.1%	38.0%	17.7%

On the macro level, the forest policies lead to a slight growth in GDP (measured at factor cost) ranging between 0.1% and 0.4% (Table 6.8). The aggregate rural employment level rises within a range of 0.4% to 1.0%, because of increased employment during the lean season periods. Thanks to higher rural household incomes, aggregate consumption increases and demand for non-tradable goods and services slightly rise. Consistent with the pre-specified macro closure rules, the quantity of government consumption and investment remain constant. The two adjusting taxes, import duties and income, change in opposite directions. The foreign savings would decrease if they were set flexible running an alternative model closure. Consequently, in our main macro closure setting with fixed foreign savings, import duties have to decline accordingly. To balance the internal account (government savings), direct taxes increase. These changes are, however, moderate, with direct tax revenue increasing between 0.5 and 0.9%.

Imports decrease mainly because of the substitution of charcoal imports. Interestingly, if it was not for this substitution effect, total imports would have increased slightly between 0.1% and 0.3%. Import demand increases particularly for food items, other fuels and general machinery (which includes e.g. saw chains required by the forestry activities). Exports decline, as industries with high export shares reduce output due to the reallocation of capital and unskilled labour to the domestic charcoal sector and due to higher domestic demand for non-tradable goods and services.

Table 6.8. Model results of simulated forest policies

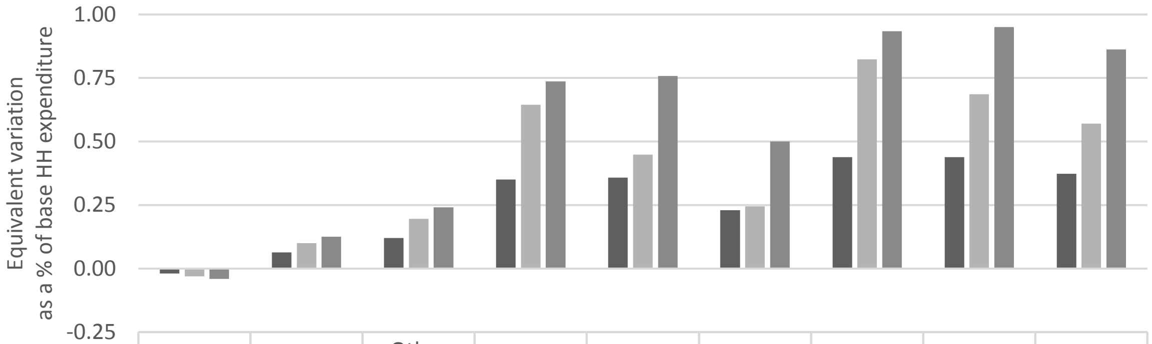
Real macro-economic indicators (at constant prices)	% share in GDP, expenditure	%-changes to base (in real terms)		
		Mod	Prog	Cof
GDP, factor cost	96.5	0.1	0.2	0.3
Labour employment		0.2	0.3	0.5
Rural labour employment		0.4	0.6	1.0
GDP, expenditure		0.1	0.1	0.2
Consumption	100.0	0.2	0.2	0.4
Government	46.6	0.0	0.0	0.0
Investment	16.7	0.0	0.0	0.0
Import	69.2	-0.4	-0.6	-0.9
Export	67.9	-0.8	-1.2	-1.6
Absorption	35.4	0.1	0.1	0.1
Real sector value added	**% share in GDP, at factor cost**	**Sector growth rates (% change)**		
		Mod	**Prog**	**Cof**
Agriculture and Forestry	10.7	0.6	0.8	1.4
Agriculture	8.4	-0.1	-0.2	-0.2
Crops	7.1	-0.1	-0.2	-0.2
Livestock	1.3	-0.1	-0.1	-0.1
Forestry	2.3	3.2	4.5	6.9
Fuelwood extraction by RH	0.3	22.4	31.8	48.6
Log extraction by RH	1.4	0.0	-0.1	-0.1
Mining	1.7	-0.9	-1.4	-1.9
Manufacturing	9.4	1.8	2.8	3.8
excl. Charcoal	9.4	-0.5	-0.8	-1.0
Electricity	12.5	-1.0	-1.5	-2.1
Construction	23.5	0.0	0.1	0.1
Services	42.2	0.0	0.0	0.1

Note: RH = Rural households

As already highlighted in section 6.5.2, a higher decline in agricultural output could have been expected ex-ante, since agriculture competes for the same type of labour as forestry. However, by including seasonal labour markets in our model, we explicitly account for the fact that rural forestry mostly demands labour outside the cropping season. In line with expectations, strong growth is triggered in the forestry sector, particularly for fuelwood extraction by rural households, whose share in GDP increases from previously 0.3% up to 0.5% in the community forestry scenario. The processing of fuelwood into charcoal results in further growth in the manufacturing sector, ranging from 2.4% to 4.8%. This growth is explained by the high value added share in charcoal production of 55% (measured in value terms) (Arndt Feuerbacher et al., 2016), which is more than the intermediate input share of fuelwood (36%). As previously mentioned, the allocation of production factors to charcoal production, mainly capital, results in a decline in output of other industries, which include mining, all remaining manufacturing sectors and power generation.

6.5.5 Welfare Implications

The effects of the forest policies on household welfare are predominantly positive. Welfare effects measured in equivalent variations over base household expenditure are determined by two main components: (1) changes in purchasing power as the price of household's consumption basket changes and (2) changes in discretionary income. In our case, price changes are largely small except for the shadow price of fuelwood in the moderate and progressive scenarios and changes in discretionary income are the main determinant of welfare changes. The largest welfare benefits occur in the progressive and community forestry scenarios, particularly for non-electrified households (Figure 6.7). The moderate scenario also leads to consistent welfare increase for all rural households, but only at about half the rate. The level of welfare increases are largely dependent on how much fuelwood households are allowed to sell, but the extraction quota also has a large influence, as the example of electrified households in AEZ3 shows. Unskilled urban households consistently benefit from increases in their welfare, since the boost in charcoal production results in an increase of unskilled wages. Urban households with other income benefit from slightly higher returns to capital and also from the general slight reduction in saving rates. Skilled urban households suffer a modest decline in welfare, since the wages of skilled labour drops.



	Skilled	Unskilled	Other Income	AEZ1	AEZ2	AEZ3	AEZ1	AEZ2	AEZ3
	Urban			Rural electrified			Rural non-electrified		
Mod	(0.02)	0.06	0.12	0.35	0.36	0.23	0.44	0.44	0.37
Prog	(0.03)	0.10	0.20	0.64	0.45	0.24	0.82	0.69	0.57
Exp	(0.04)	0.13	0.24	0.74	0.76	0.50	0.93	0.95	0.86

Figure 6.7. Welfare effects (Equivalent variations) as a share of base household expenditure

6.6 Discussion

The forest policies simulated in our model result in arguably minor economic growth measured as change in real GDP, which is explained by the small share of forestry within GDP of just 2.3%. But the value added growth for the agriculture and forestry sector would be substantial, reaching 1.4% (Table 6.8). Since forests play a key role for rural livelihoods in Bhutan, the policies may yield non-trivial welfare benefits for rural households, particularly for the non-electrified households, which are typically the least privileged ones. As Bhutan is approaching 100% electrification within the next years, the privilege of a higher extraction-quota granted to non-electrified households will become redundant.

We found the endowment effect to be the most important determinant of changes in household income. Allowing the model to endogenously increase the supply of seasonal labour and rural forest land is implemented with the implicit assumption of zero opportunity costs, i.e. the previously unutilized factors did not generate any value elsewhere. In case of labour, this can be argued for those months with very high incidences of underemployment, where additional employment opportunities do not crowd out leisure and neither compete with reproducing activities outside the production boundary. In case of land, this issue is more complex, as forests provide a whole range of ecosystem services, which are not comprehensively included in the model. Furthermore, assuming constant productivity (i.e. constant wages) of rural forest land may not properly account for very region-specific circumstances, in which for example unutilized forest land is at further distances or within less accessible pockets of the surrounding forests. Yet, since we only included forest area within 2 km radius of rural settlements, this factor should arguably play a minor role.

The incomplete representation of ecosystem services particularly merits further discussion. The model only includes direct and monetized forest services, i.e., the supply of timber and NWFP, while indirect and non-marketed services are not included, such as water purification carbon sequestration and storage, biodiversity, or recreation. These ecosystem services are of vital importance not least in the context of of Bhutan's reliance on hydropower (Sears et al., 2017). Increased timber extraction, either by increasing intensification or expanding forest utilization, could require managing trade-offs between the provision of these various ecosystem services, although sustainable forest management is characterized by providing multiple benefits simultaneously (Siebert & Belsky, 2015). Not including indirect and non-monetized ecosystem services is a limitation of our model approach. Methodologically, it is one of the frontiers of economy-wide modelling, but requires data on ecosystem services that are not yet available for Bhutan.

From a policy perspective, the main driver impacting the magnitude of benefits is the size of both the extraction and commercial quota. Households only reduce subsistence consumption when facing a trade-off between home-consumption and selling of fuelwood. This is due to the very elastic supply of fuelwood, since the supply of the underlying production factors for fuelwood harvesting, seasonal labour and forest land, are relatively unconstrained and in case of forest land, supplied at perfect elasticity. Hence, the extraction quota has to become a binding constraint if the principle policy objective is to provide incentives for lower fuelwood consumption. This might require a more nuanced approach to policy design that takes the regional differences (e.g., population density, availability of forest resources, climatic conditions, etc.) into account, something that would come at the cost of increased complexity.

Bhutan's has the objective to electrify all households by 2020 (Yangka & Diesendorf, 2016). Since a reform of power tariffs in 2013, all rural households receive the first 100 units of electricity for free. The importance of fuelwood as a domestic energy source is diminishing in the future, which makes the linkage between rural households and the wood value chain even more relevant. Our findings suggest that the establishment of a domestic charcoal industry is an important component of the simulated forest policies to increase the market for fuelwood in Bhutan. Our modelling approach made it possible to assess the economy-wide impacts on Bhutan's labour market and manufacturing sector. Wages of seasonal and unskilled labour benefitted, but in the former case were buffered by seasonal underemployment. The contribution to GDP by manufacturing grew, since charcoal represents a profitable industry with value-added comprising a high share of output. These results rebuke earlier claims, arguing that charcoal production in Bhutan is neither feasible due to labour shortages (World Bank, 1992) nor advisable in terms of its lack of potential to contribute to economic growth (Jadin, Meyfroidt, & Lambin, 2016).

Domestic charcoal production can become a cornerstone in Bhutan's policy to remain carbon neutral, as charcoal is the only available substitute for the use of coke in the metallurgical industries. It also contributes to the government's objective of increasing economic diversification away from hydropower generation (RGoB, 2010). While the profitability of charcoal was assessed previously (Arndt Feuerbacher et al., 2016), uncertainties remain (e.g., access to finance, availability of technology) that are not part of the model presented here. Other potential uses of fuelwood have not been taken into account, but could potentially offer better opportunities. This would imply even higher benefits from policies resulting in increased fuelwood supply and our results would thus represent a lower boundary.

6.6.1 Implementation Barriers and Possible Modifications of the Simulated Forest Policies

The moderate and progressive scenario are modifications of the existing quota system, under which most rural households in Bhutan are extracting timber for their subsistence use today. The decision-making unit in these cases is the household itself, deciding on how much fuelwood to extract for subsistence use and how much to sell on the market via the commercial quota. The execution of the current system shows that households with only elderly or physically impaired members may need to hire-in labour to extract their fuelwood quota. This would require wage payment, but at the same time, the household would benefit from the land rent and possible revenue of selling any excess fuelwood.

In the community forestry scenario, the implementation becomes more complex since an adequate and equitable system of benefit sharing has to be established. Current experiences with CFGs in Bhutan show that equitable distribution of benefits and fair sharing of the labour burden are among the key challenges of community forest management (R. Dorji & Schmidt, 2014). In contrast to the household-based extraction quota system, the decision making on the resource use is surrendered to a management board at the village level. The CFG may distribute annual fuelwood entitlement to its members, with each household deciding how much it may home-consume or leave to be sold via the CFG. However, challenges remain how to fairly share the burden of timber extraction across households. While a CFG offers potential synergies concerning the management and logistics of fuelwood extraction and marketing, the system is also vulnerable to issues of mistrust and corruption as shown by evidence of elite capture in existing community forestry schemes (Moktan, Norbu, & Choden, 2016).

Alternatively to the simulated scenarios, the extraction of commercial fuelwood on the village level could also be coordinated by NRDCL officials employing villagers as wage workers. This would minimize the risk of unsustainable extraction, as villagers would not receive income based on the output quantity. Yet, in terms of equity, this approach would have its drawbacks as only households with physically fit workers would benefit.

Improper use of silvicultural practices and incompliance with the quota system are the arguably two most important threats associated with the simulated policies. In the current system, forest field officers oversee that rural households extract fuelwood in compliance with proper silvicultural practices (tree marking by forest officials, single-tree selection, exclusion of watershed areas and steep slopes, etc.). Increasing wood and timber extraction as modelled in this paper would require additional effort by the forest service to monitor compliance with forest law. Intuitively, this may increase the costs to the Forest Service, but could be off-set by the application of modern technology (e.g. remote sensing based forest monitoring, mobile monitoring teams that are employed using artificial intelligence-based optimization, or real-time tracking of logs and wood products).

An effective enforcement of the quotas depends on the efforts invested in setting up adequate forest resource monitoring and governance schemes. Monitoring can be performed with remote-sensing and groundtruthing techniques employing the existing resources and personnel of the Department of Forest and Park Services (DoFPS). The setup of the governance system has to account for vested interests of the local population and commercial entities. The compliance with household’s commercial and extraction quota may be undermined if households sell fuelwood to private traders, who are likely to face conflict of interests. Instead, state-owned institutions such as the NRDCL could serve as fuelwood brokers with the mandate to ensure compliance with household extraction quotas. Corruption at all levels may pose a challenge, despite the strong anti-corruption efforts in Bhutan, earning the country the remarkable 26th rank on the Corruption Perception Index (Transparency International, 2018). However, the concern for forest conservation is also deeply enrooted in the public sphere. Thus, grave incompliances can easily escalate to become state affairs in a small and environmentally conscious country such as Bhutan.

Illegal logging is already a challenge in some areas of Bhutan, but the country's simple and manageable road network is relatively easy to monitor and prevents transporting illegally harvested timber over larger distances.[45] Careful monitoring of forest resources may also allow ex-post adjustment at the sub-district (i.e. gewog) level. At the extreme end, communities could (temporarily) be excluded from selling any timber products following (repeated) records of self-inflicted forest degradation. Sanctions could also be put in place in case communities neglect efforts of afforestation, which is particularly important for broadleaved forests.

Following the existing quota system, both the moderate and progressive scenario did not account for any regional differences in determining the quotas, although fuelwood requirements and resource availability vary strongly throughout the country. Studying a village without electricity access in the Alpine region at about 2,900 m altitude, S. Wangchuk, Siebert, and Belsky (2014) found households to consume more than three times (54 m^3 year-1) the quantity of fuelwood allowed (16 m^3 year-1). Their case is hardly representative due to the remote location, high heating requirement in alpine regions and very large household sizes (11.3 versus the average rural household size of 4.8). Nevertheless, the case highlights the need to apply existing methods (Schindele, 2004; S. Wangchuk et al., 2014) to assess the site-specific sustainable fuelwood quantities relying on biophysical and socioeconomic criteria and climatic conditions, instead of merely using access to electricity as the only indicator.

6.6.2 Co-benefits of Reduced Indoor Air Pollution

Since most households burn fuelwood in traditional ovens, indoor air pollution remains a major health concern in Bhutan (Rahut, Ali, & Behera, 2016; Uddin et al., 2007; T. Wangchuk et al., 2015). The moderate and progressive scenario create situations in which households face a trade-off regarding their fuelwood utilization. They now have an incentive for an alternative use of their fuelwood (i.e., selling it to the national market) and partially switch to cleaner fuels.

[45] According to anecdotal evidence, forest checkpoints function well, but are closed during night times, potentially allowing for illegal movement.

If households decide to consume less and sell more fuelwood, this would reduce their exposure to indoor air pollution (assuming constant cooking and heating technologies). These benefits are not included in the model, but could result in more efficient allocation of forest resources. Given the very low cost of electricity, increasing household incomes, and the planned electrification of all households by 2020 (Yangka & Diesendorf, 2016)(Yangka & Diesendorf, 2016), subsistence use of fuelwood will become less attractive. However, without the presence of any alternative use such as selling it through e.g. a commercial quota, the lower shadow price for subsistence use by rural households may lead to suboptimal social outcomes.

6.7 Conclusions

The role of forests for rural livelihoods in Bhutan is changing given the country-wide low-cost provision of electricity. So far, forest policies have strictly separate rules for timber for subsistence and commercial use. With the economic gradient between urban and rural areas, forests can constitute an important resource for providing much needed economic opportunities in rural areas. While forest conservation has to be ensured, our results suggest that this does not contradict scenarios of increased forest utilization. Introducing a commercial quota in addition to the existent extraction quota may provide an effective incentive to rural households, not only to increase fuelwood extraction, but also to increase the efficiency of their fuelwood use. Reforming the rules under which fuelwood is extracted by rural households would result in predominantly positive welfare impacts. These benefits are largely due to that they put unutilized forest area and underemployed seasonal labour into use. The charcoal component of the policy scenarios generates growth in the manufacturing sector, benefitting unskilled urban households and contributing to the objective of economic diversification. Rural households' reduction in fuelwood consumption and shift towards cleaner fuels result in lower indoor air pollution and lower incidences of airborne diseases. This represents a very important co-benefit of the forest policies, which we did not explicitly value. In contrast, our analysis does not account for the cost of forest non-monetary ecosystem services; if they were included, overall welfare gains would be reduced. This would particularly be the case if the forest policies are not accompanied by proper safeguards and monitoring efforts. While beyond the scope of this study, these limitations and associated data gaps may be addressed by future research.

In addition to the three simulated forest policy scenarios, there are numerous further options for policymakers to design policies that link rural households with the wood value chain and which allow for more efficient fuelwood use, providing incentives to switch to cleaner fuels. For instance, only a low commercial quota may be introduced or the introduction can be limited to pilot regions, which could be gradually scaled up if the system is working as envisaged. This could help to overcome political resistance, to identify unknown pitfalls and to showcase the practical feasibility of commercial quotas. At the national level, we have shown that linking rural households to wood value chains contributes to the government's efforts in strengthening rural livelihoods and providing much needed sources of cash income.

6.8 Appendix

Appendix 6A Household Income Sources

Table 6.9. Household income sources

Household groups		Population	% share in total household income						
			Permanent labour	Winter labour	Summer labour	Capital	Forest land	Other factors	Transfers
Urban	Skilled	125,304	82.4	0.0	0.0	13.0	0.0	0.2	4.4
	Unskilled	195,722	89.6	0.0	0.0	7.0	0.0	0.2	3.2
	Other income	121,308	18.3	0.0	0.0	63.5	0.0	0.0	18.1
Rural	AEZ1 electrified	117,429	42.6	9.6	8.8	6.6	1.3	20.2	10.8
	AEZ1 non-electrified	128,781	30.7	14.0	12.9	6.5	2.4	25.7	7.8
	AEZ2 electrified	145,166	39.8	11.2	10.7	6.0	2.2	15.6	14.5
	AEZ2 non-electrified	25,345	28.6	15.7	15.1	3.1	3.6	23.3	10.6
	AEZ3 electrified	164,283	38.3	8.7	9.9	14.8	1.8	16.4	10.2
	AEZ3 non-electrified	7,923	17.2	17.8	20.4	11.5	3.7	23.3	6.2

Appendix 6B Model parameters

Table 6.10. Model parameters

System	Nest / Functional form	Parameter value	Description	Source
Production system structured as regular nested CES functions (as in Figure 6.3)	L1	Leontief (σ=0)	Aggregation of intermediate-inputs and value added	Assumption
	L2.1	Leontief (σ=0)	Aggregation of intermediate-inputs	Assumption
	L2.2	0.1 ≤ σ ≥ 1.7	Aggregation of value added	Thomas Hertel, McDougall Robert A., Narayanan G., & Aguiar, 2016Thomas Hertel et al., 2016
	L3.1	0.4	Land extensification margin	Bouët et al., 2014Bouët, Femenia, & Laborde, 2014
	L3.2	0.1 ≤ σ ≥ 1.7	Capital-labour aggregation	Thomas Hertel et al., 2016Thomas Hertel, McDougall Robert A., Narayanan G., & Aguiar, 2016
	L4.1	1.1	Chemical fertilizer and animal manure aggregation	Ali & Parikh, 1992
	L4.2	NA	Aggregation of land-types	*
	L4.3	1.5	Agricultural capital aggregation	Assumption
	L4.4	NA	Permanent and seasonal labour aggregation	*
	L5.1	0 ≤ σ ≥ 1.5	Aggregation of monthly seasonal labour	See assumptions in Table 6.1
	L5.2	1.5	Aggregation of skilled and unskilled labour	Assumption
Demand System	LES	$0.5 \leq \eta_{i,h} \geq 1.8$	Linear expenditure system (LES) for commodity groups	See section Appendix 3C
	CES	0.8 ≤ σ ≥ 1.5	Aggregation of single commodities to groups	Assumptions
Trade regimes	CES	0.9 ≤ σ ≥ 4.4	Armington aggregation of imports	Thomas Hertel et al., 2016Thomas Hertel, McDougall Robert A., Narayanan G., & Aguiar, 2016
	CET	2	Constant elasticity of transformation (CET) of exports	
Land supply	Asymptotic	0.8	Land supply curve	Eickhout, van Meijl, Tabeau, & Stehfest, 2009Eickhout et al., 2009

Appendix 6C Seasonal Labour Activities and Elasticities

Table 6.11. Seasonal labour activities and elasticities

Activity	%-share in total seasonal output value	Person-days (in thousand)	%-share in total person-days employed in production	Type of seasonal labour demand	Seasonal labour substitution elasticity (σ)
Paddy	12.7	6,065	16.0	Rigid	0 (i.e., fixed shares as in Leontief technology)
Double cropping of maize	1.8	1,102	2.9		
Single cropping of maize	5.2	2,971	7.8		
Other cereals and oilseeds	2.5	1,100	2.9		
Vegetables - first season	4.5	786	2.1		
Vegetables - second season	4.5	1,107	2.9		
Potato - first season	5.9	1,411	3.7		
Potato - second season	0.2	96	0.3		
Spices	4.3	453	1.2		
Fruits	10.1	1,032	2.7		
Total cropping activities	***51.6***	***16,124***	***42.5***		
Cattle husbandry	9.6	8,249	21.8	Flexible	0.1
Other animals	5.3	2,049	5.4		0.1
Dairy production	12.5	3,914	10.3		0.5
Total livestock activities	**27.4**	**14,212**	**37.5**		
Cereal milling	1.0	146	0.4		1.5
Cereal processing	2.6	345	0.9		1.5
Ara* production	4.0	786	2.1		1.5
Total food proc. activities	**7.6**	**1,277**	**3.4**		
Community forestry	8.6	4,164	11.0	Flexible	1.5
Textile weaving	4.8	2,123	5.6		3
Total non-farm activities	**13.4**	**6,287**	**16.6**		
Total seasonal activities	**100.0**	**37,899**	**100.0**		

Appendix 6D Commodity Groups and Substitution Elasticities

Table 6.12. Commodity groups and substitution elasticities

Commodity Category	Description	Substitution elasticity
Cereals	Rice; Maize; Other cereals and oilseeds	1.5
Vegetables	Potato; Other vegetables	1.5
Fruits	Fruits	1.5
Animal products	Milk; Beef; Dairy; Other animal products	1.5
Beverage and Spices	Spices; Non-wood forest products; Beverages; Alcohol and tobacco; Ara	1.2
Processed Food	Grain-mill products; Processed fruit; Lodging	1.2
Energy	Subsistence fuelwood, Commercial fuelwood, other fuels; Electricity	0.8/1.5
Other goods	Minerals; Clothing; Processed wood; Chemicals; Transportation fuels; General Machinery; Other manufactured goods	0.8
Basic services	Health; Housing; Education and other public services	0.8
Other services	Trade; Transportation; Construction; Other services	0.8

Note: Other fuels comprises LPG cooking gas and kerosene.

Appendix 6E Spatial Criteria for Sustainable Forest Management

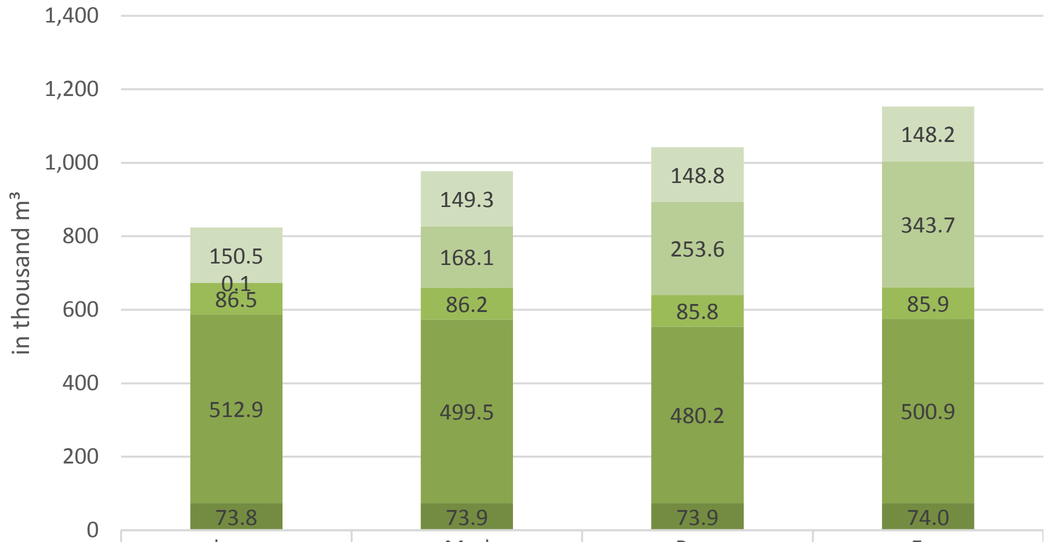
Table 6.13. Spatial criteria for forest resources potential assessment

Spatial criteria	Spatial buffer / exclusion area
Roads (Highways, feeder roads, farm roads, etc.	>200 m
Major drainages	> 30 m
Rural settlements	< 2000 m
Slope of terrain	< 35°
Altitude above meters of sea level	< 4,000 m
RAMSAR wetland sites	Excluded
Existing botanical, recreational parks and heritage forests	Excluded
Forest Management Units and Working Schemes (WS)	Excluded
Protected area and biological corridors	Excluded

Based on MoAF, 2013c.

Please note: The criteria presented above were either spatially buffered by applying a radius, as reported in the second column, or were entirely excluded from the resource assessment. In case of rural settlements, all forest area that were located more than 2km away from a rural settlement were excluded.

Appendix 6F Changes in Fuelwood demand



	base	Mod	Prog	Exp
Other Manufacturing	150.5	149.3	148.8	148.2
Charcoal	0.1	168.1	253.6	343.7
Agriculture	86.5	86.2	85.8	85.9
Rural Households	512.9	499.5	480.2	500.9
Urban Households	73.8	73.9	73.9	74.0

Figure 6.8. Changes in fuelwood demand

Appendix 6G Endowment Effects

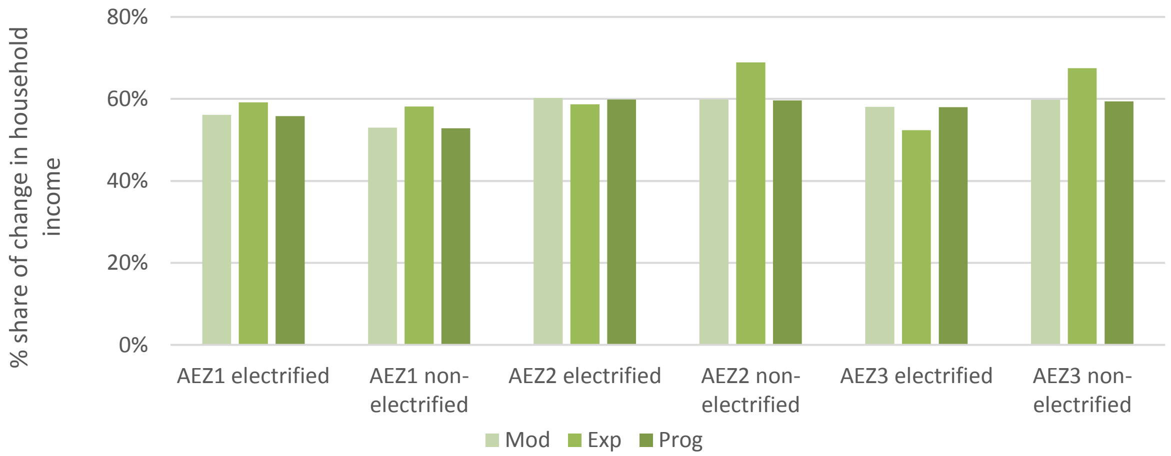


Figure 6.9. Endowment effects as a percentage share of change in household income

Appendix 6H Impacts on Farm Labour and Forest Land

Table 6.14. Changes in prices and quantity of farm labour and forest land

Factor price and supply change per forest policy scenario		% factor price change			% quantity change		
		Mod	Prog	Cof	Mod	Prog	Cof
	Skilled labour	0.0	0.0	0.0	0.0	0.0	0.0
	Unskilled labour	0.0	0.0	0.0	0.0	0.0	0.0
Seasonal labour in AEZ 1	Jan	1.0	0.8	0.3	1.1	1.9	2.2
	Feb	0.7	0.6	0.2	1.4	2.6	3.0
	Mar	0.5	0.4	0.2	2.0	3.7	4.3
	Apr	0.5	0.4	0.2	2.1	3.8	4.4
	Mai	0.2	0.1	0.1	0.5	1.0	1.2
	Jun	0.3	0.2	0.2	0.1	0.1	0.1
	Jul	0.2	0.0	0.3	0.0	0.0	0.0
	Aug	0.2	0.1	0.1	0.2	0.4	0.5
	Sep	0.2	0.1	0.1	0.4	0.7	0.8
	Okt	0.2	0.1	0.1	0.4	0.7	0.9
	Nov	0.4	0.2	0.3	0.0	0.0	0.0
	Dec	2.2	1.7	0.6	0.0	0.0	0.0
Seasonal labour in AEZ 2	Jan	0.7	0.2	0.7	0.7	0.9	1.5
	Feb	0.5	0.1	0.4	1.3	1.5	2.7
	Mar	0.4	0.1	0.4	1.4	1.6	2.9
	Apr	0.4	0.1	0.4	1.4	1.6	2.9
	Mai	0.3	0.1	0.2	0.1	0.2	0.3
	Jun	0.6	0.1	0.6	0.0	0.0	0.0
	Jul	0.2	0.1	0.2	0.3	0.3	0.6
	Aug	0.2	0.1	0.2	0.2	0.2	0.4
	Sep	0.2	0.1	0.1	0.3	0.3	0.6
	Okt	0.4	0.1	0.4	0.0	0.1	0.1
	Nov	0.4	0.1	0.4	0.1	0.1	0.1
	Dec	1.1	0.3	1.0	0.3	0.4	0.7
Seasonal labour in AEZ 3	Jan	0.4	0.1	0.5	1.1	1.1	2.5
	Feb	0.3	0.1	0.4	0.4	0.5	1.1
	Mar	0.2	0.0	0.2	0.0	0.0	0.1
	Apr	0.2	0.0	0.2	0.1	0.0	0.2
	Mai	0.0	0.0	0.0	0.0	0.0	0.0
	Jun	0.1	0.0	0.1	0.0	-0.1	0.0
	Jul	0.2	0.0	0.2	0.3	0.3	0.6
	Aug	0.3	0.1	0.3	0.2	0.2	0.4
	Sep	0.7	0.2	0.8	0.0	0.0	0.0
	Okt	0.1	0.0	0.1	0.1	0.1	0.2
	Nov	0.3	0.1	0.3	0.9	0.9	2.1
	Dec	0.5	0.1	0.6	1.1	1.1	2.5
	Forest land (AEZ1)	0.0	0.0	0.0	36.3	67.8	76.1
	Forest land (AEZ2)	0.0	0.0	0.0	28.4	36.8	60.3
	Forest land (AEZ3)	0.0	0.0	0.0	16.8	18.0	37.6

6.9 References

Ali, F., & Parikh, A. (1992). Relationships among labor, bullock, and tractor inputs in Pakistan agriculture. *American Journal of Agricultural Economics*, *74*, 371–377. Retrieved from http://ajae.oxfordjournals.org/content/74/2/371.short

Armington, P. S. (1969). A theory of demand for products distinguished by place of production. *Staff Papers*, *16*, 159–178. Retrieved from http://link.springer.com/article/10.2307/3866403

Bajgai, R. C., & Tshering, S. (2012). *Rural-urban migration: A challenge in preserving socio-cultural practices and values: Case of Barapangthang village* (Proc. of the 2nd Int. Seminar on Population and Development). Kanglung, Bhutan.

Banerjee, A., & Bandopadhyay, R. (2016). Biodiversity Hotspot of Bhutan and its Sustainability. *Current Science*, *110*, 521. https://doi.org/10.18520/cs/v110/i4/521-528

BBS. (2013). Free electricity to rural households. Retrieved from http://www.bbs.bt/news/?p=32694

Beer, J. H. de, & McDermott, M. J. (1996). The economic value of non-timber forest products in Southeast Asia. Netherlands Committee for IUCN, Amsterdam, The Netherlands. *The Economic Value of Non-Timber Forest Products in Southeast Asia. 2nd Ed. Netherlands Committee for IUCN, Amsterdam, the Netherlands.*, -.

Blanchflower, D. G., & Oswald, A. J. (1995). An Introduction to the Wage Curve. *Journal of Economic Perspectives*, *9*, 153–167. https://doi.org/10.1257/jep.9.3.153

Bouët, A., Femenia, F., & Laborde, D. (2014). *Taking into account the evolution of world food demand in CGE simulations of policy reforms: the role of demand systems* (Presented at the 17th Annual Conference on Global Economic Analysis, Dakar, Senegal). Retrieved from https://www.gtap.agecon.purdue.edu/resources/download/6876.pdf

Dorji, R., & Schmidt, K. (2014). *Review of Community Forestry and Analysis of its Strengths and Weaknesses for Future Directions*. Thimphu, Bhutan.

Eickhout, B., van Meijl, H., Tabeau, A., & Stehfest, E. (2009). The impact of environmental and climate constraints on global food supply. *Economic Analysis of Land Use in Global Climate Change Policy*, *14*, 206.

Feuerbacher, A., Dukpa, C., & Grethe, H. (2017). *A 2012 Social Accounting Matrix (SAM) for Bhutan with a detailed representation of the agricultural sector: Technical Documentation* (Working Paper No. 94). Berlin. Retrieved from Department of Agricultural Economics, Faculty of Life Sciences, Humboldt-Universität zu Berlin website: https://www.agrar.hu-berlin.de/de/institut/departments/daoe/publ/wp/wp94.pdf

Feuerbacher, A., & Grethe, H. (2017). *Incorporating seasonality of labour markets in a general equilibrium framework*. Paper presented at the 20th Annual Conference on Global Economic Analysis, Purdue, USA.

Feuerbacher, A., Siebold, M., Chhetri, A., Lippert, C., & Sander, K. (2016). Increasing forest utilization within Bhutan's forest conservation framework: The economic benefits of charcoal production. *Forest Policy and Economics*, *73*, 99–111. Retrieved from http://www.sciencedirect.com/science/article/pii/S1389934116302556

FRMD. (2017). *Land Use and Land Cover of Bhutan 2016, Maps and Statistics*. Thimphu, Bhutan.

Gosai, M. A., & Sulewski, L. (2014). Urban attraction: Bhutanese internal rural–urban migration. *Asian Geographer*, *31*, 1–16. https://doi.org/10.1080/10225706.2013.790830

Hertel, T. W., McDougall Robert A., Narayanan G., B., & Aguiar, A. H. (2016). Chapter 14 - Behavioral parameters. In B. G. Narayanan, A. Aguiar, & and R. McDougall. (Eds.), *Global Trade, Assistance, and Production: The GTAP 9 Data Base* (p. 14). Purdue, USA.

Hogarth, N. J., Belcher, B., Campbell, B., & Stacey, N. (2013). The Role of Forest-Related Income in Household Economies and Rural Livelihoods in the Border-Region of Southern China. *World Development*, *43*, 111–123. https://doi.org/10.1016/j.worlddev.2012.10.010

Jadin, I., Meyfroidt, P., & Lambin, E. F. (2016). Forest protection and economic development by offshoring wood extraction: Bhutan's clean development path. *Regional Environmental Change*, *16*, 401–415. https://doi.org/10.1007/s10113-014-0749-y

Kubiszewski, I., Costanza, R., Dorji, L., Thoennes, P., & Tshering, K. (2013). An initial estimate of the value of ecosystem services in Bhutan. *Ecosystem Services*, *3*, e11-e21. Retrieved from http://www.sciencedirect.com/science/article/pii/S2212041612000563

MoAF. (2011). *Forest Development in Bhutan: Policies, Programmes and Institutions*. Thimphu, Bhutan.

MoAF. (2012). *Forestry -Facts, figures and trends 2011*. Thimphu, Bhutan.

MoAF. (2013a). *Agriculture Sample Survey 2012 - Microdata*. Thimphu, Bhutan.

MoAF. (2013b). *Forest Resource Potential Assessment of Bhutan 2013*. Thimphu, Bhutan.

MoAF. (2016). *Forest Facts & Figures*. Thimphu, Bhutan.

MoF. (2013). *Bhutan Trade Statistics 2012*. Thimphu, Bhutan.

Moktan, M. R., Norbu, L., & Choden, K. (2016). Can community forestry contribute to household income and sustainable forestry practices in rural area? A case study from Tshapey and Zariphensum in Bhutan. *Forest Policy and Economics*, *62*, 149–157. Retrieved from http://www.sciencedirect.com/science/article/pii/S1389934115300411

Narain, U., Toman, M., & Jiang, Z. (2014). *Note on Green Growth for Bhutan* (World Bank License: CC BY 3.0 IGO). Washington DC, USA. Retrieved from World Bank website: https://openknowledge.worldbank.org/handle/10986/20402

NLC. (2014). *Altitude data of gewog centres in Bhutan*. Thimphu, Bhutan.

NSB. (2003). *Bhutan Living Standard Survey 2003*. Thimphu, Bhutan.

NSB, & ADB. (2012). *Bhutan Living Standard Survey 2012 - dataset*. Thimphu, Bhutan.

Punt, C. (2013). Modelling multi-product industries in computable general equilibrium (CGE) models. Stellenbosch: Stellenbosch University. Retrieved from https://scholar.sun.ac.za/handle/10019.1/79959

Rahut, D. B., Ali, A., & Behera, B. (2016). Domestic use of dirty energy and its effects on human health: Empirical evidence from Bhutan. *International Journal of Sustainable Energy*, *36*, 983–993. https://doi.org/10.1080/14786451.2016.1154855

RGoB. (2008). *The Constitution of the Kingdom of Bhutan*. Thimphu, Bhutan.

RGoB. (2010). *Economic development policy of the kingdom of Bhutan*. Thimphu, Bhutan.

RGoB. (2017). *Forest and Nature Conservation Rules and Regulations of Bhutan*. Thimphu, Bhutan.

Sarap, K., & Sarangi, T. K. (2009). Malfunctioning of forest institutions in Orissa. *Economic and Political Weekly*, 18–22. Retrieved from http://www.jstor.org/stable/25663535

Schindele, W. (2004). *Forest Resources Potential Assessment (FRPA) for Bhutan*. Bhutan-German Sustainable RNR Development Project. Altusried, Germany.

Sears, R. R., Phuntso, S., Dorji, T., Choden, K., Norbu, N., & Baral, H. (2017). *Forest ecosystem services and the pillars of Bhutan's Gross National Happiness* (Occasional Paper No. 178). Bogor, Indonesia.

Siebert, S. F., & Belsky, J. M. (2015). Managed fuelwood harvesting for energy, income and conservation: An opportunity for Bhutan. *Biomass and Bioenergy*, *74*, 220–223. https://doi.org/10.1016/j.biombioe.2015.01.013

Transparency International. (2018). Corruption Perception Index 2017. Retrieved from Transparency International

Uddin, S., Taplin, R., & Yu, X. (2007). Energy, environment and development in Bhutan. *Renewable and Sustainable Energy Reviews*, *11*, 2083–2103. https://doi.org/10.1016/j.rser.2006.03.008

Wangchuk, S., Siebert, S., & Belsky, J. (2014). Fuelwood Use and Availability in Bhutan: Implications for National Policy and Local Forest Management. *Human Ecology*, *42*, 127–135. https://doi.org/10.1007/s10745-013-9634-4

Wangchuk, T., Mazaheri, M., Clifford, S., Dudzinska, M. R., He, C., Buonanno, G., & Morawska, L. (2015). Children's personal exposure to air pollution in rural villages in Bhutan. *Environmental Research*, *140*, 691–698. https://doi.org/10.1016/j.envres.2015.06.006

World Bank. (1992). *Project Completion Report Bhutan Calcium Carbide Project* (No. 11359). Washington DC, USA.

World Bank. (2018). *World Development Indicators*. Dataset. Washington DC, USA. Retrieved from http://data.worldbank.org/data-catalog/world-development-indicators

Wunder, S., Angelsen, A., & Belcher, B. (2014). Forests, Livelihoods, and Conservation: Broadening the Empirical Base. *World Development*, *64*, S1-S11. https://doi.org/10.1016/j.worlddev.2014.03.007

WWF Bhutan. (2016). What We Do: WWF Bhutan. Retrieved from http://www.wwfbhutan.org.bt/_what_we_do/

Yangka, D., & Diesendorf, M. (2016). Modeling the benefits of electric cooking in Bhutan: A long term perspective. *Renewable and Sustainable Energy Reviews*, *59*, 494–503. https://doi.org/10.1016/j.rser.2015.12.265

Chapter 7 Synthesis and Outlook

This last chapter summarizes the methodological and empirical findings of the four studies and provides a general discussion of the results. Furthermore, limitations of the studies are highlighted and an outlook for future research and model development is presented. The chapter closes with general conclusions.

7.1 Seasonal Labour in Economy-wide Models

The methodological research objective of this thesis is to assess the relevance of depicting seasonality of labour markets within economy-wide model frameworks. The following research questions were derived from this objective in section 1.3.1.

1. *Does the seasonality of labour matter for economy-wide model outcomes in agrarian economies?*
    a. *Is there a systematic bias if economy-wide models do not capture the seasonality of labour markets?*
    b. *What are the implications of seasonality for households' labour supply decision along the intensive margin (i.e. labour-leisure trade-off)?*

The depiction of seasonal labour markets has so far been neglected within economy-wide models and specifically within CGE models. The neglect of seasonal labour constraints is essentially identical with assuming homogeneity of labour units across periods, which in turn allows for perfect intertemporal substitution of labour units. From an ex-ante perspective, this assumption is of course problematic, but in the literature there has been no investigation into whether this assumption leads to negligible or substantial distortions of model outcomes.

7.1.1 Methodological Findings

The research questions on the role of seasonality of labour for general equilibrium model outcomes are tackled in Chapter 3. First, an existing 2012 SAM for Bhutan is extended to incorporate seasonal labour markets. Second, the comparative-static CGE model framework of STAGE2 (Scott McDonald & Thierfelder, 2015) is modified to depict demand and supply of seasonal labour. The role of seasonal labour markets is isolated by using two different model setups: one setup with annual labour markets and another setup with seasonal labour markets, with all other parameters and settings remaining identical (*ceteris paribus* condition). Both setups are used to simulate the impacts of a scenario in which India would impose a cereal export ban on its trade partners, including Bhutan.

By varying the intensity of the shock in positive and negative directions, it is clearly demonstrated that the neglect of seasonality of labour and leisure leads to systematic bias of model results. These findings affirm research question 1a. In the field of micro-level modelling, it was already recognized that ignoring seasonality leads to model distortions (Hazell & Norton, 1986). The systematic bias is caused by the assumption of labour homogeneity, which contradicts the common logic that "a unit of labour at the time of harvesting is not replaceable by a unit of labour at a slack period" (Sen, 1966, p. 440).

The findings in Chapter 3 also contribute to address research question 1b. By assuming separability of labour demand and supply, models with annual labour markets ignore that a labour unit demanded in a certain period also has to be matched with a labour unit supplied during the very same period. Ignoring these seasonal constraints thus misrepresents the labour mobility across activities, with patterns of seasonal labour demand and the labour supply via households' labour-leisure trade-off playing an important role. The logic of models with annual labour markets allows for an effective increase in labour endowment, which results in overestimation of the agricultural sector's supply response, and leads to biased welfare results. This shows that seasonality of labour clearly matters for model outcomes.

The main analysis simulates a policy shock with asymmetric effects on the agricultural sector, as only the import cost of cereals is affected. Simulating scenarios with rather symmetric impacts, as for instance a ± 10% exogenous change in the productivity of all land types, the differences between the annual and seasonal model become much less pronounced. This does not contradict our findings, which have shown that seasonality of labour matters mostly when we are interested in the reallocation of labour across activities, which is a common feature of cases of structural change. Scenarios of trade liberalization would trigger such structural changes, but past economy-wide studies in this field have ignored the role of seasonal labour markets. It is thus likely, that these studies have overestimated developing economies' supply responsiveness and, therefore, also have generated distorted welfare effects.

7.1.2 Seasonal Labour Markets in Economy-wide Models: Limitations and Outlook

The relevance of seasonality is salient regarding the high share of the world's population that is working in economic activities influenced by climatic seasonality such as agriculture. This thesis has presented a first approach to include seasonal labour in an economy-wide model framework, and thus has paved the way for analysis of seasonal labour markets in different contexts. Yet there are quite some limitations and possible model extensions which may be addressed by future research.

The role of gender would present a promising avenue, as research has shown that women and men bear very different responsibilities in farm operations and household chores (Fontana & Wood, 2000; Wodon & Beegle, 2012). Extending the approach in Chapter 3 by decomposing labour into gender would have an impact on the degree of the intertemporal substitution of labour, as women might be less flexible in increasing their labour supply due to a higher share in essential reproduction activities. Furthermore, disaggregating labour by gender would increase the rigidity of seasonal patterns, since female and male labour are imperfect substitutes. However, the empirical foundation for the parametrization of the gender decomposition is a challenge. As Boeters and Savard (2013, p. 1681) point out: "[gender] roles are highly varying across countries and in many cases also over time, it is not likely that deep substitution parameters can be identified through econometric techniques".

The reliance on parameters is perceived to be a general limitation by CGE models, particularly in the case of developing countries for which empirical point estimates are often not available (McKitrick, 1998; Mitra-Kahn, 2008). This is also the case for Bhutan, specifically, and for extending the labour market to incorporate seasonality in general. Using the available household data, a LES was estimated for Bhutan to provide an econometric foundation for the model's demand system. For other parameters, available point estimates reported in the literature were used. Still, in case of a few parameters, neither point estimates nor data were available from the literature, which would be needed to conduct an original estimation. This concerns, for instance, the intertemporal substitution elasticities of labour demand. For these model parameters, the issue of identifying a reasonable initial level of parameters remains, and the robustness of the methodological findings was checked conducting sensitivity analysis.

Generally, there is a large scope for further methodological development. The analysis does not account for seasonal migration between the zones due to the peculiar characteristics of Bhutan. This can be considered a limitation to generalize the approach, since seasonal migration is an important feature in rural labour markets in other countries. Provided the necessary data is available, this would be an interesting subject for future research. Depending on the characteristics of migration patterns, migration mechanisms could arguably dampen or exacerbate the effects of seasonal rigidity.

Moreover, if data on seasonal production and consumption patterns was available, the present model could also be extended into a dynamic framework accounting for sequential decision-making (Fafchamps, 1993). Such a model would solve over sub-annual periods, and could also incorporate more details, such as farmers' adjustment towards exogenous shocks that occur after the planting season (e.g. the effects of a drought). With increased availability of year-round time-use data, models could be developed that disaggregate leisure into actual time spent on leisure and into households' various reproduction activities. Ideally, such research would include gender as a dimension, given women's distinct role in reproduction activities. The research in this area would contribute to a better understanding of how households can respond to changes in wages, since some reproduction activities can be substituted more easily with market commodities (e.g., food preparation versus purchasing prepared food) than others (e.g., child raising versus day-care centres).

There are further possible policy scenarios in the context of developing countries in general and for Bhutan specifically, for which seasonality would have strong implications. In some regions, for instance in the Sahel zone, increasing heat stress is reducing workers' productivity during the hottest periods of the year. Assessing these impacts of climate change would require a model that accounts for seasonality. Public employment schemes are often designed to counter rural underemployment, which also would require to incorporate seasonality. The benefits of agricultural technology, for instance machinery or irrigation, also affect different periods of the year. In the case of Bhutan, one can find further potential applications. For example the impacts of the Mountain Hazelnut Venture, which is a large-scale contract farming scheme. In total, about 10 million seedlings will be planted by farmers on an area accounting for about 10% of arable land in Bhutan (S. Watson, personal communication, September 2017). Most hazelnuts will be harvested within a short time window of just six weeks around the time of the maize and potato harvest period, which is likely to exacerbate existing labour peaks. Another interesting area for seasonality of labour is presented by Bhutan's approach towards tourism.

Modifications in the tourism policy could create incentives for tourists to stay in remote rural areas of Bhutan, which is characterized by its pristine nature. Such a policy could provide attractive employment opportunities to the rural areas, especially during the dry and less crowded winter season.

7.2 Natural Resource Policies and Rural Development in Bhutan

The empirical research objective is to assess the impacts of natural resource policies in Bhutan on seasonal rural livelihoods in the context of environmental conservation and rural development. While natural resources management encompasses a broad range of primary economic sectors, the studies conducted in this thesis exclusively refer to policies related to the management of renewable natural resources utilized by crop, livestock and forestry activities.

7.2.1 Empirical Findings

Three case studies are conducted that address novel research questions which emerge from Bhutan's rather unique country context. The first study tackles Bhutan's 100% organic policy, investigating the country's position in implementing such a large-scale conversion and assessing the economy-wide implications, inter alia, investigating the trade-offs with other policy objectives. The remaining two studies focus on Bhutan's forest policies, investigating scenarios in which synergies between forest conservation and productive management of forests are achieved.

7.2.1.1 Economy-wide Implications of Converting to 100% Organic Agriculture

Bhutan is the first country in the world announcing a 100% conversion to organic agriculture. Given that about 50% of Bhutan's labour force is employed in agriculture, it is reasonable to expect substantial consequences from such a far-reaching natural resource policy. The following three research questions were identified ex-ante to the study (c.f. section 1.3.2):

2. *What are the implications of Bhutan's 100% organic conversion policy on rural livelihoods and the economy as a whole?*
    a. *Is the agricultural sector in Bhutan in a favourable condition to convert to 100% organic?*
    b. *What are the trade-offs or synergies of the 100% organic policy?*

In Chapter 4, the research questions are assessed using a two-step approach. The first step uses the only available on-farm dataset in Bhutan, in which about 6,200 farmers report the usage of agrochemicals and yields on a crop-level basis. Analysing this dataset reveals that organic crop yields are on average 24% lower than conventional yields. In case of paddy, the results show a substantial yield gap, which contradicts earlier analysis which did not find any yield differences using similar data from Bhutan (Tashi & K. Wangchuk, 2016). The assessed crop yield gaps, whether for paddy or other crops, generally compare well to the studies included in the most recent meta-analysis (Ponisio et al., 2014).

In the second step, a CGE model for Bhutan is developed extending the STAGE2 model framework by incorporating agroecological zones, crop nutrients and field operations. Despite the relatively low dependency on agrochemicals, the large-scale conversion policy leads to a strong contraction in agricultural output. This result is mainly driven by the large yield gap and wide-spread use of agrochemicals for the cultivation of potatoes, paddy and maize. An apparent, but unintended consequence of the 100% organic policy is a large reduction in the country's degree of cereal self-sufficiency, which results in a trade-off with the objective to make Bhutan less dependent on cereal imports. The bottom line is that the policy results in adverse impacts on household welfare and food security, despite some benefits for current organic-by-default farmers in the low-altitude zone.

The conclusion of this study is that a 100% conversion to organic agriculture would result in a reduction in GDP and households' welfare, triggering substantial trade-offs with the objectives of food self-sufficiency and rural development. Strong efforts would be required to improve current organic farming practices to reduce the current level of yield gaps, which also implies that Bhutan has not yet achieved a favourable position to undertake such an ambitious endeavour. Furthermore, awareness about the benefits of organic products has to be increased among urban consumers, in order to create price premiums and to prevent the conversion policy from undermining current efforts of increasing the degree of commercialization of smallholders.

7.2.1.2 Increasing Forest Utilization under Bhutan's Forest Conservation Framework

Bhutan is widely lauded for its successful forest conservation. While 70% of the land area is under forest cover, only about 15% of forest area is utilized for productive management. The low degree of forest utilization makes Bhutan highly dependent on wood-based imports from

India, mainly in the form of charcoal. Against this background, the following research questions were identified in section 1.3.2:

3. *How can forest policies contribute to economic diversification and rural development without jeopardizing Bhutan's forest conservation agenda?*
    a. *Is sustainable charcoal production economically viable in Bhutan?*
    b. *Do rural forest policies that link rural households with the fuelwood value chain increase resource efficiency and rural welfare?*

The overarching question is tackled in both studies in Chapter 5 and 6. The research question 3a is addressed in Chapter 5 where different analyses are combined to assess the economic viability of domestic charcoal production in Bhutan. First, the forest resource availability for commercially managed forest management units is estimated for each district in Bhutan. Second, a transport model is developed to determine the most cost-efficient locations for charcoal production units. Third, the intermediate results on sustainable forest biomass supply and optimal production location are combined in an investment model to determine the district-specific profitability of charcoal production.

The results show that almost two-thirds of charcoal imports could be substituted by domestic charcoal production, requiring an increase in commercial forest utilization from 5% of forest area to 15%. Monte Carlo simulations and sensitivity analysis confirm the robustness of the results and reveal that variations in transportation and labour cost only have minor effects on profitability. Charcoal production would represent a high value-added activity, with an average value-added share of 50.8%, contradicting opposite claims in literature (Jadin et al., 2015). Furthermore, the results show that by using a decentralized approach, increases in forest area under commercial forest management would contribute to economic diversification and growth in Bhutan, without jeopardizing its highly acclaimed forest conservation agenda.

Unlike the other case studies in this thesis, the study in Chapter 5 does not rely on an economy-wide model. This has drawbacks, since prices are assumed to be fixed and neither forward nor backward linkages are included in the assessment. However, this has also distinct advantages. In contrast to CGE models, the combination of a transportation and investment model allows the representation of transportation barriers at a more disaggregated level, explicitly accounting for the actual spatial distances and the differences in transportation costs, depending on whether the route is hilly or flat. Moreover, disaggregating the analysis by district allows for pinpointing of those regions, with the most promising potential for charcoal production. The multi-period investment analysis also explicitly accounts for the cost of capital, allowing for a financial analysis, which is a limitation in general-equilibrium frameworks.

Chapter 6 investigates how simulated changes in households' access to the fuelwood value chain affect the resource efficiency of fuelwood use and rural welfare. This study contributes to the literature on sustainable resource management and the role of forests for rural livelihoods in the rather rare context of forest underutilization. The analysis builds on the methodological developments from Chapter 3 by modifying the seasonal CGE model to incorporate seasonal underemployment. The seasonal SAM is also adjusted to include a marginal charcoal production sector using the input-output data for a hypothetical charcoal industry, which were estimated in Chapter 5.

The simulated forest policies introduce a commercial fuelwood quota, allowing households to sell a limited annual quantity of fuelwood. In order to operate within sustainable boundaries, we estimate the potential of rural forest utilization using satellite data and spatial criteria for sustainable forest management. The results show that household income would increase predominantly due to additional employment opportunities in the winter months and increased rent from forest utilization. In contrast to the findings in Chapter 4, the commercial fuelwood supply potential from rural forestry would even allow for a higher degree of domestic charcoal production, substituting up to 80% of charcoal imports. The efficiency of fuelwood use is improved when rural households face the opportunity cost of selling the fuelwood, which is reflected by the increase in shadow prices.

The estimated benefits for rural households are likely to be at the lower bound, as we do not account for potential health co-benefits due to reduced indoor air pollution. The benefits of the forest policy scenarios also hinge on effective monitoring and governance systems that ensure compliance with sustainable forest management criteria and that minimize any potential trade-offs with the provision of non-market ecosystem services. The analysis of linking households with fuelwood value chains in Chapter 6 also highlights the relevance of depicting seasonal labour markets. Building on the methodological work on seasonal labour markets, the study allows for the modelling of seasonal underemployment. Such a nuanced approach would not be possible in a model with annual labour markets, since this setting would not allow separating the periods of labour shortages in the cropping season with seasons characterized by slack labour.

7.2.2 Natural Resource Policies in Bhutan: Limitations and Outlook

All three empirical studies relate to the interdependence of natural resource management, rural development and environmental conservation. Although, the models adequately record market transactions, they do not include any non-market goods and services, which for instance stem from ecosystem services. The incorporation of ecosystem services is a general limitation within the field of economy-wide modelling and is at the frontier of the state-of-the-art research. Including ecosystem services is partially a problem of data availability, since the valuation of ecosystem services is associated with various methodological challenges. Bhutan's 100% organic agriculture policy would certainly reduce negative externalities that stem from the use of agrochemicals, even though the intensity of use is low. Forest policies leading to a higher degree of forest utilization might also involve adverse impacts on forests' capacity to generate ecosystem services. The magnitude of such impacts is highly dependent upon the silvicultural practices and site-specific conditions. This would probably require a generalizable biophysical model, which would provide estimates of how increases in forest utilization affect the wide range of forest ecosystem services.

The 100% organic study highlights the need for better data to analyse the magnitude of yield gaps and to assess the potential for price premiums in both domestic and foreign markets. Unfortunately, there are only few studies that analyse the productivity of cropping systems in the context of Bhutan (Chettri et al., 2003; Ghaley & Christiansen, 2010). More research would be needed to assess how organic agriculture can be optimized in the specific environment of Bhutan. This would require better data and understanding of farmers' current farming systems, since at the national level there is data paucity concerning farmers' practices as regards to crop rotations and soil fertility management. At the other end of the value chain, little knowledge is available on consumers' awareness and preferences for organically produced food in Bhutan. Domestically produced food is already perceived to be produced without the use of pesticides, and consumers discriminate against imported foodstuffs from India with the notion that they are produced with heavy use of agrochemicals. Future studies could generate more insights into how much more consumers in Bhutan would pay for certified organic products compared to the quasi organic-by-default produce.

7.2.3 General Policy Implications

Finding sustainable pathways for rural development and environmental conservation is a challenge and natural resource policies are the key to how both are related to each other. Bhutan has embarked on an ambitious quest of environmental conservation, announcing its intent to remain carbon neutral, to maintain at least 60% forest cover, to protect its location as a biodiversity hotspot, and to convert to 100% organic agriculture, among many other objectives. Meanwhile, the country still faces challenges to alleviate rural drudgery and poverty. Some of Bhutan's natural resource policies, which are led by environmental conservation objectives, have profound impacts on rural livelihoods. Due to the various geographic constraints, farmers' in Bhutan have limited options to gain a livelihood. While there are various efforts of the government to strengthen rural livelihoods, efforts are also needed to ensure coherence across policies. Otherwise, the inherent danger is that policies and associated investments neutralize one another. The country's stance toward economic development, led by the philosophy of GNH, is unique and seeks its equals. Nevertheless, political decisions and initiatives need to be analysed and understood in a holistic framework, which satisfies the multi-dimensional objectives of GNH.

While any aspects of the political economy go beyond the scope of this thesis, they are certainly important to understand the political processes and agenda setting in Bhutan. Like in many other countries, perceptions of how policies should shape the agricultural sector are subject to the individuals' values and subjective reality. Farmers in Bhutan face a very different reality than those living in the growing urban areas of the country. Some of the farming constraints have been tackled by the studies at hand, but there are many more ranging from human-wildlife conflict, low productivity of livestock over climate change impacts, to remaining competitive with agricultural goods imported from India. There is a general public awareness about the drudgery in rural areas, but there is the risk of pursuing an order of priorities which will harm rural livelihoods in the long run.

Due to its Buddhist culture and GNH philosophy, Bhutan has a distinct public consciousness concerning environmental conservation and animal welfare. This is highly laudable and allows the country to avoid unsustainable growth trajectories that other countries have pursued instead. The examples of Bhutan's reluctance towards agrochemical use and productive forest management were studied in detail. However, there are further areas in which the GNH philosophy is at odds with the improvement of rural livelihoods. Slaughtering of animals is generally stigmatized and thus not practiced due to Buddhist values. Farmers thus arguably forgo substantial productivity potential. Because hunting is banned, farmers also face immense crop damages due to limited options in scaring off wild animals. However, Bhutan's farmers are competing with Indian farmers, who benefit from subsidies and often use agrochemicals at high intensity. The Bhutanese farmers thus face an uphill battle.

Being a small but open economy, it might be tempting for policymakers to enforce high environmental standards within the country, which will result in problems of leakage of environmental externalities. Charcoal is such a case, which is imported from India, where per capita availability of forest resources is much smaller (FAO, 2017) and where deforestation is recorded in regions close to Bhutan (Lele & Joshi, 2009). The problem of leakage might apply for almost any good that is not produced domestically. However, there are cases in which this problem is not caused by the absence of comparative advantages but by a country's regulatory framework. This not only holds for charcoal, but also for the production of meat. As long as consumers in Bhutan are willing to consume beef, and as long as beef is predominantly imported from Northern India where animal welfare conditions are unknown, standards of animal welfare are beyond the control of the Bhutanese policymakers. These are challenges for policymakers not only in Bhutan, but in virtually any country within today's globally integrated world economy.

Many of the above-mentioned challenges have not been investigated in this thesis. Yet, the results of the 100% organic study have shown, that a policy shock adding to the burden of farmers in Bhutan results in adverse effects for rural livelihoods, and in particular, for the economy as a whole. Policymakers have to analyse and address the root causes of why the younger generations leave the rural areas, not only from the perspective of agronomists or agricultural engineers, but also from the socio-economic perspectives. Economy-wide modelling might be a helpful tool for the analysis of policies within the context of Bhutan. The findings presented in this study allow to identify further research gaps (e.g., the role of price premiums, relationships between productive forest management and ecosystem services) and to design specific policy interventions and public investments (e.g., knowledge on organic farming practices, technologies for charcoal production). The magnitude of models results can be subject to debate, but it is the sign of results that should raise awareness among policymakers that policy objectives are interconnected, in both competing (i.e. a trade-off) and complimentary (i.e. synergetic) relationships. The findings of this thesis are not meant to be conclusive, as many of the above mentioned limitations merit further research. However, maybe they will help to spark a debate on how Bhutan can utilize both its unique culture and values together with its rich natural resource endowment on its middle path to become a green and socio-equitable economy.

7.3 General Conclusions

This dissertation contributes to the field of economy-wide modelling of rural labour markets and the economy-wide analysis of natural resource policies. Literature on how to model labour markets in agrarian economies within economy-wide model frameworks is scarce and the absence of depicting seasonality of labour was identified as a major research gap within the literature. The findings of this thesis show that taking seasonality of labour into account has highly important implications for model outcomes. Its relevance is particularly high in developing agrarian countries. Bhutan is a case in which seasonality is a key feature of labour markets and where the absence of seasonality results in systematic bias of model outcomes.

Although the data requirements for building a CGE model with seasonal labour markets are demanding, incorporating seasonality allows to depict mechanisms that are otherwise sidestepped in the traditional model with annualized labour markets. This has especially been demonstrated for the case of labour supply along the intensive margin (labour-leisure trade-off) and also along the extensive margin by using a wage-curve to model seasonal underemployment. There are many further research avenues, which can be based on the approaches developed in this thesis and which will hopefully allow to address the various highlighted limitations.

Bhutan was also selected as a case-study to investigate the impacts of natural resource policies on rural livelihoods within the potentially conflicting context of rural development and environmental conservation. There has hardly been any empirical research studying how natural resource policies in Bhutan affect rural livelihoods and how they could possibly be altered in order to avoid trade-offs, and instead realize synergies between the objectives of rural development and environmental conservation. Despite being a very small country, the case of Bhutan offers many intriguing questions within this field. In this thesis, model approaches were developed to study the implications of Bhutan’s 100% organic agriculture policy and changes in the country’s forest policies.

The 100% organic study was the first of its kind using an economy-wide model with a detailed depiction of the field operations. The insights on how such a large-scale conversion affects other policy objectives and rural livelihoods and the underlying methodological approach will be of use for future studies within this field, whether in Bhutan or any other country. The two studies that are simulating changes in Bhutan's forest policies have shown that there is still scope to realize synergies between increasing forest utilization and forest conservation. Depending on the policy design, forest utilization can be pursued through commercial forestry or by linking rural households with value chains, whereas the latter has benefits for rural development and efficiency of resource use.

As a summary of both the methodological and empirical findings, economy-wide model approaches with a detailed depiction of natural resource-based activities are pertinent tools in order to inform how policymakers can balance multiple objectives, such as rural development and environmental conservation. In this regard, this thesis has made the contribution of investigating the role of seasonal labour markets in economy-wide models. However, as highlighted in the above discussion of limitations, there are many further areas, such as accounting for the role of ecosystem services, that have to be addressed by future research.

7.4 References

Boeters, S., & Savard, L. (2013). The labor market in computable general equilibrium models. *Handbook of Computable General Equilibrium Modeling*, *1*, 1645–1718. Retrieved from https://ideas.repec.org/h/eee/hacchp/v1y2013icp1645-1718.html

Chettri, G. B., Ghimiray, M., & Floyd, C. N. (2003). Effects of farmyard manure, fertilizers and green manuring in rice-wheat systems in Bhutan: results from a long-term experiment. *Experimental Agriculture*, *39*, 129–144.

Fafchamps, M. (1993). Sequential labor decisions under uncertainty: An estimable household model of West-African farmers. *Econometrica: Journal of the Econometric Society*, 1173–1197. Retrieved from http://www.jstor.org/stable/2951497

FAO. (2017). FAOSTAT database. Retrieved from http://www.fao.org/faostat/en/

Fontana, M., & Wood, A. (2000). Modeling the Effects of Trade on Women, at Work and at Home. *World Development*, *28*, 1173–1190. https://doi.org/10.1016/S0305-750X(00)00033-4

Ghaley, B. B., & Christiansen, J. L. (2010). On-farm assessment of mineral nitrogen and cultivar effects on rice productivity in Bhutan highlands. *Acta Agriculturae Scandinavica, Section B - Plant Soil Science*, *60*, 460–471. https://doi.org/10.1080/09064710903156295

Hazell, P. B. R., & Norton, R. D. (1986). *Mathematical programming for economic analysis in agriculture*: Macmillan New York. Retrieved from http://agrecon.mcgill.ca/courses/320/hazell/mathprogfront.pdf

Jadin, I., Meyfroidt, P., & Lambin, E. F. (2015). Forest protection and economic development by offshoring wood extraction: Bhutan's clean development path. *Regional Environmental Change*, 1–15. https://doi.org/10.1007/s10113-014-0749-y

Lele, N., & Joshi, P. K. (2009). Analyzing deforestation rates, spatial forest cover changes and identifying critical areas of forest cover changes in North-East India during 1972-1999. *Environmental Monitoring and Assessment*, *156*, 159–170. https://doi.org/10.1007/s10661-008-0472-6

McDonald, S., & Thierfelder, K. (2015). A Static Applied General Equilibrium Model: Technical Documentation: STAGE Version 2: January 2015. *Model Documentation*.

McKitrick, R. R. (1998). The econometric critique of computable general equilibrium modeling: the role of functional forms. *Economic Modelling*, *15*, 543–573.

Mitra-Kahn, B. H. (2008). Debunking the myths of computable general equilibrium models. Retrieved from http://www.academia.edu/download/2913349/4i5u50tdmoybjlj.pdf

Ponisio, L. C., M'Gonigle, L. K., Mace, K. C., Palomino, J., Valpine, P. d., & Kremen, C. (2014). *Data from: Diversification practices reduce organic to conventional yield gap: Diversification practices reduce organic to conventional yield gap.*

Tashi, S., & Wangchuk, K. (2016). Organic vs. conventional rice production: comparative assessment under farmers' condition in Bhutan. *Organic Agriculture*, *6*, 255–265. https://doi.org/10.1007/s13165-015-0132-4

Wodon, Q., & Beegle, K. (2012). Labor shortages despite underemployment? Seasonality in time use in Malawi. In M. C. Blackden & Q. Wodon (Eds.), *World Bank Working Paper: Vol. 73. Gender, Time Use, and Poverty in Sub-Saharan Africa* (pp. 97–116). Washington, DC: World Bank.

Appendix A Theoretical Framework for Seasonal Labour Supply and Demand

This technical appendix documents the theoretical framework used for incorporating seasonality of labour supply and demand into the behavioural equations of a CGE model. First, the basic theories of labour supply and demand are recapitulated, before the entry points for seasonality are identified and elaborated.

A.1 Seasonal Labour Supply

A.1.1 Theory of Labour Supply

Drawing from textbook knowledge (Franz, 2013)(Franz, 2013) a standard and neo-classical model for a utility maximizing individual is formulated.

$$U = U\left(X, F, R, \mu\right) \tag{8.1}$$

In which U is an individual's utility. X is a bundle of consumption goods, F represents leisure hours, R is a vector comprising certain characteristics of the individual such as age, gender and health condition. While the characteristics in R are observable, μ reflects individual preferences that are not observable, but which explain the remaining differences of an individual's labour supply decision which were not captured by the observed factors (Franz, 2013). μ does not only comprise factors determining an individual's direct preference for either work or leisure, it possibly also includes individual capabilities of performing reproduction activities such as raising children, house maintenance or cooking.

Equation (8.1) is maximized under the following budget and time constraints:

$$P * X \le w * L + V \tag{8.2}$$

$$T = F + L \tag{8.3}$$

where P is the weighted price of consumption bundle X, w is the hourly wage, L is hours worked and V is any non-labour income such as remittances, capital or land rents. Total hours worked is constrained by the total time endowment T.

The utility function to be maximized is slightly modified by substituting $F = T - L$:

$$\max_{X,L} U\left[X,(T-L),R,\mu\right] \tag{8.4}$$

subject to the conditions 1) $X > 0$; 2) $L \geq 0$ and 3) $w*L+V \geq P*X$

Equation (8.4) can be expressed as a Lagrangian function Z

$$Z = U(X,(T-L),R,\mu) + \lambda(w*L+V-P*X) \tag{8.5}$$

As the maximization problem consists of both inequality constraints and non-negativity restrictions we solve equation (8.5) according to the following Kuhn-Tucker conditions (Chiang & Wainwright, 2005):

$$\frac{\partial U}{\partial X} - \lambda P = 0 \quad (8.6) \qquad \text{for} \quad X > 0 \quad X*\left(\frac{\partial U}{\partial X} - \lambda P\right) = 0 \tag{8.7}$$

$$\frac{\partial U}{\partial L} + \lambda W \leq 0 \quad (8.8) \qquad \text{for} \quad L \geq 0 \quad L*\left(\frac{\partial U}{\partial L} + \lambda w\right) = 0 \tag{8.9}$$

$$w*L+V-P*X \geq 0 \quad (8.10) \qquad \text{for} \quad \lambda \geq 0 \quad \lambda*\left(w*L+V-P*X\right) = 0 \tag{8.11}$$

Following the condition $L \geq 0$, there are two possible states (1) the individual supplies labour, $L > 0$, or (2) does not participate in the labour force, $L = 0$. Rearranging equation (8.6) to solve for λ and substituting it in equation (8.8) yields:

$$\frac{\partial U}{\partial L} + \frac{\partial U}{\partial X}\frac{w}{P} \leq 0 \tag{8.12}$$

As the negative marginal utility of supplied hours equals the marginal utility of leisure $-\frac{\partial U}{\partial L} = \frac{\partial U}{\partial F}$ equation (8.12) can be reformulated to arrive at the equilibrium condition for the two previously described states (Franz, 2013):

$$\frac{\frac{\partial U}{\partial F}}{\frac{\partial U}{\partial X}} = \frac{w}{P} \text{ if } L > 0 \text{ holds} \tag{8.13}$$

$$\frac{\frac{\partial U}{\partial F}}{\frac{\partial U}{\partial X}} \geq \frac{w}{P} \text{ if } L = 0 \text{ holds} \quad (8.14)$$

This shows, that the individual only supplies hours if the marginal rate of substitution of leisure and consumption equals to the real wage level. If the ratio of marginal-utility of leisure and consumption exceeds the real wage level as in equation (8.14), no hours are supplied by the individual.

The individual's total supply of hours is limited by the total time endowment T. In the theoretical model described above it is not specified whether T equals a period of a week, month or year. As we are concerned with the role of seasonal labour markets in CGE models, we start with setting T equal to one year. This, obviously, would not allow specifying at what point in time within the year a household supplies hours or consumes leisure, respectively. In a formal employment situation, an employee however would be obliged to supply hours according to regular pattern, with the exception of a potential longer period of holiday or sick leave. In an informal employment situation or for own account workers as it is particularly the case in peasant farming, there are no permanent work contracts and a regular supply of hours over the course of a year appears to be unlikely due to reasons of seasonality of crop cycles and diversification of income sources.

A.1.2 Entry Point for Seasonal Labour Supply

To incorporate seasons, we subdivide the scalar T into a j dimensional vector $T_j^{'}$ such that $T = \sum_{t=1}^{j} T_j^{'}$ where set t denotes a period and j the number of periods. Without regarding aspects of sequential decision making, we assume that the individual recursively maximizes utility and thus determines its seasonal labour supply over each period t over the total time horizon T. This would lead us to equation (8.15):

$$Z = T = \sum_{t=1}^{j} U_t\left(X_t, \left(T_j^{'} - L_t\right), R, \mu\right) + \lambda(w_t * L_t + V_t - P_t X_t\Big) \quad (8.15)$$

This results in a recursive-dynamic maximization of utility and eventually in a form of model in which an equilibrium is solved for each season and thus for (potentially) very small periods (e.g. one month). Assuming seasonal (or sub-annual) equilibria is highly problematic and questionable (Ginsburgh & Keyzer, 2002). Short-term equilibria are hard to observe and furthermore require seasonal stockholding specifications. A further ramification of such a model formulation would be to model seasonal consumption X_t and seasonal non-labour income V_t. Data on seasonal consumption is often inexistent or incomprehensive. Seasonal non-labour income occurs infrequent (e.g. for capital or land rents) and reliable data is again scarce, particularly in a developing country context where seasonality of labour is most relevant.

Another issue of seasonal consumption is the time horizon for which consumption decisions are made. Food is consumed within a short time period and if not could be thought of postponed consumption. However, expenditures on more durable items such as clothes, which however do not account for capital expenditure, would be distorted in a model with seasonal consumption. Modelling seasonal consumption would require distinguishing between goods consumed within e.g. a month and goods providing utility beyond the duration of a month, but which are not considered capital goods (e.g. clothes). These theoretical considerations and challenges of data availability are the main reasons to discard a recursive-dynamic model with utility maximization across seasons. Instead, an alternative approach is proposed in which utility is maximized from annual consumption and leisure, which is however disaggregated into j periods. The Lagrangian utility maximization function for such a model with $j=2$ is presented in equation (8.16):

$$Z = U\left(X, \left(T_1^{'} - L_1\right), \left(T_2^{'} - L_2\right) R, \mu) + \lambda(w_1 * L_1 + w_2 * L_2 + V - PX\right) \tag{8.16}$$

In equation (8.16) we simply treat the hours supplied during periods t as separate variables, which also requires to differentiate wages by period, represented by w_t. The observed and unobserved characteristics remain fixed. Analogous to the derivation of equation (8.1), we can obtain the equilibrium conditions under which a household supplies labour.

$$\frac{\frac{\partial U}{\partial F_1}}{\frac{\partial U}{\partial X}} = \frac{w_1}{P} \quad L_1 > 0 \text{ holds} \tag{8.17}$$

$$\frac{\frac{\partial U}{\partial F_2}}{\frac{\partial U}{\partial X}} = \frac{w_2}{P} \quad \text{if } L_2 > 0 \text{ holds} \tag{8.18}$$

As the marginal utility of consumption and the price of the consumption bundle is equal across both equations, it becomes directly obvious that for each period t the marginal utility of leisure needs to equal the respective seasonal wage. The pointwise separability of seasonal leisure and annual consumption in equation (8.5) is problematic as we assume households to maximize utility over time horizon T, thus for the sake of time-consistency we assume non-separability of leisure consumption. Using a nested structure, leisure from each period t is aggregated to composite leisure $\bar{F}$ and households maximize utility consuming composite leisure and goods. Composite leisure $\bar{F}$ is specified through a constant elasticity of substitution (CES) function with constant returns as presented below.

$$\bar{F}\left(F_t\right) = A * \left[\sum_{t=1}^{j} \delta_t * F_t^{-\rho}\right]^{-\frac{1}{\rho}} \tag{8.19}$$

$$\bar{F}\left(T_t^{'} - L_t\right) = A * \left[\sum_{t=1}^{j} \delta_t * \left(T_t^{'} - L_t\right)_t^{-\rho}\right]^{-\frac{1}{\rho}} \tag{8.20}$$

where A is a shift parameter, δ_t is a calibrated share parameter and ρ is the substitution parameter. In equation (8.20), we substituted leisure again with the difference between total time endowment and labour supply. The degree of substitution of seasonal leisure depends on substitution parameter ρ, which is determined by the elasticity of substitution σ, as $\rho = 1/\sigma - 1$ reflecting an individual's preferences regarding the intertemporal distribution of leisure. Assuming non-separability for seasonal leisure thus allows for substitution of leisure from different periods.

As the marginal utility of consumption and the price of the consumption bundle is equal across both equations, we can directly see for each period t that the marginal utility of leisure needs to equal the respective seasonal wage. In an economy, where economic activities demand labour at constant rate (i.e. no fluctuation) and where individuals have constant preferences for leisure over the course of a year, we would neither observe any differences in seasonal wages nor in marginal utility of leisure. Hence, individuals would supply constant quantity of hours in each period. However, even in a very developed economy such as Germany there are seasons in which individuals have higher preferences for leisure (e.g. during the festive season). In such a case, labour supply is below the annual average and wages are above average. Arguably, this holds only for a very short time period and seasonality thus has very limited relevance for industrialized economies characterized by formal labour markets. However, there is a very different case for agrarian economies. For example, in Bhutan, rural households face limited employment opportunities during the winter months resulting in seasonal underemployment. Holding preferences for leisure constant, we can then expect wages and marginal utility of leisure (due to diminishing utility of leisure) to drop. However, during the planting or harvesting season, labour is in high demand, resulting in labour shortages and wages to increase.

The seasonal wage is determined by both supply and demand of labour. As there are limited phenomena for seasonal variations in preferences for leisure, the relevance of seasonality of labour is largely explained by fluctuations in labour demand. Thus, we therefore turn to the basic economic theory of production and how seasonal labour can be incorporated in a comparative static framework.

A.2 Seasonal Labour Demand

A.2.1 Forms of Production Function in CGE Models

A production function such as $X = f\left(F_1,...,F_n\right)$ describes the physical output quantity of good X dependent on the physical input quantity of n production factors F. In CGE models, production functions are predominantly specified by Leontief, Cobb-Douglas or Constant Elasticity of Substitution (CES) functions (Pauw, 2003). Under a Leontief specification, as show in Figure A.1, production factors are demanded in fixed portions and the elasticity of substitution σ is equal zero. In contrast, the Cobb-Douglas allows for an imperfect elasticity of substitution $\sigma = 1$ while the CES function allows for varying degrees of substitution.

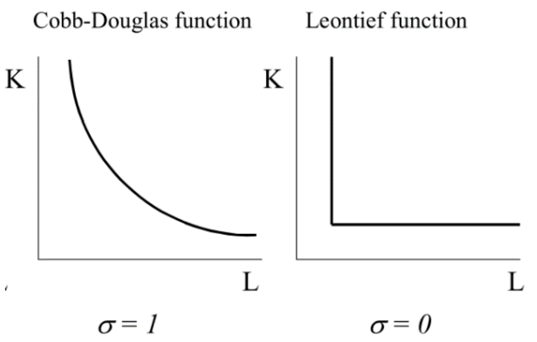


Figure A.1. Graphical representation of factor substitution

Source: Pauw, 2003

Cropping activities require operations such as ploughing, planting, weeding and harvesting to be carried out in predetermined time periods without or if with only very limited substitution possibilities. Their demand for factors can thus be specified using a Leontief or a CES function with a low degree of substitution (Board, 2009).

$$X^{Leontief}\left(L,K\right)=\min\left\{\frac{L}{\theta_L}\frac{K}{\theta_K}\right\} \qquad \text{for } L,K\in F \text{ and } \theta_F>0 \tag{8.21}$$

$$X^{CES}(L,K)=A*\left[\delta*L^{-\rho}+(1-\delta)*K^{-\rho}\right]^{-\frac{\varepsilon}{\rho}} \tag{8.22}$$

L and K are elements of the factor set F and represent the labour and capital. For the Leontief production function in equation (8.21), θ_F describes the unit input requirement for each factor to produce one unit of output X. In the CES production function in equation (8.22), A is a shift parameter, δ is a calibrated share parameter and ρ is the substitution parameter, and ε is a parameter determining the function's degree of homogeneity. If $\varepsilon=1$, the CES function is linearly homogenous and the elasticity of substitution σ can be calculated:

$$\sigma=\frac{1}{\left(1+\rho\right)},0\le\sigma\le\infty \tag{8.24}$$

As long as $-1\le\rho\le\infty,\rho\ne 0$. The Cobb-Douglas can be considered a special case of a CES function, for which $\rho=0$ and thus $\sigma=1$. In case of a Cobb-Douglas function, the value (or budget) shares remain constant.

In case of a Leontief production function, a factor's marginal physical product[46] (MPP_F) is always equal zero as long as the other factor remains fixed. Hence, we cannot derive the first order conditions of profit maximization using the equilibrium condition in which the factor price must equal the factor's marginal revenue product $\left(MRP_F\right)$. Instead, we can derive a cost function from equation (8.21) for a output level X (Border, 2001):

$$c\left(X,w,r\right)=\left(\theta_L*w+\theta_K*r\right)*Xw \tag{8.25}$$

Note that equation (8.25) already provides the cost minimizing input combination for each output level X. The cost function can be differentiated with respect to the factor prices, for example labour wages.

[46] Which is synonymous with marginal productivity.

$$\frac{\partial c\left(X,w,r\right)}{\partial w}=\theta_L * X \tag{8.26}$$

So the marginal cost of production with respect to wages equals the output level multiplied with the input coefficient, which equals the minimum input of labour needed to produce level X. $\theta_L * X$ is also the optimal input of labour L^* at output level X as any excess input of labour would be wasted. Hence, we can also state that the factor demand under the condition of cost minimization is: $L^*\left(X,w\right)=X*\theta_L$ or $K^*\left(X,r\right)=K*\theta_K$

In contrast to the Leontief production function, we can partially differentiate a CES production function to obtain MPP_F. Using labour as an example, MPP_L can be substituted by dividing the marginal revenue product by the product price MRP_L/P. For a CES function with constant returns $\varepsilon=1$, we thus obtain the following the first-order condition:

$$MPP_L=\frac{MRP_L}{P}=\left(-\frac{1}{\rho}\right)*A\left[\delta*L^{-\rho}+(1-\delta)*K^{-\rho}\right]^{-\frac{1}{\rho}-1}*\left[\delta*\left(-\rho\right)*L^{-\rho-1}\right] \tag{8.27}$$

Since $w=MRP_L$ we can rewrite and simplify equation (8.27) further:

$$w=P*A\left[\delta*L^{-\rho}+(1-\delta)*K^{-\rho}\right]^{-\frac{1}{\rho}-1}*\left[\delta*L^{-\rho-1}\right] \tag{8.28}$$

$$w=P*X*A\left[\delta*L^{-\rho}+(1-\delta)*K^{-\rho}\right]^{-1}*\left[\delta*L^{-\rho-1}\right] \tag{8.29}$$

Equation (8.29) is the formulation of the first-order condition as implemented in STAGE2. However, as Pauw (2003) points out, this formulation solves the output level and factor demand simultaneously, while the former (8.28) would allow for a model setting in which the output level can be treated exogenously.

A.2.2 Entry Point for Seasonal Labour Demand

As previously in the labour supply section, seasonal labour is introduced into the production functions by subdividing labour into j periods t. The Leontief and CES production functions demanding seasonal labour are presented below:

$$X^{Leontief}\left(L_t,K\right)=\min\left\{\frac{L_1}{\theta_{L_1}},...,\frac{L_j}{\theta_{L_j}},\frac{K}{\theta_K}\right\} \tag{8.30}$$

$$X^{CES}(L_t, K) = A * \left[\sum_{t=1}^{j} \delta_t * L_t^{-\rho} + \delta_k * K^{-\rho} \right]^{-\frac{\varepsilon}{\rho}} \tag{8.31}$$

The cost-minimizing demand for labour in season t using a Leontief specification is simply:

$$L_t^*\left(X, w_t\right) = X * \theta_{L_t} \tag{8.32}$$

While in case of a CES function the corresponding first order condition for L_t is:

$$w_t = P * A * \left[\sum_{t=1}^{j} \delta_t * L_t^{-\rho} + \delta_k * K^{-\rho} \right]^{-\frac{1}{\rho}-1} * \left[\delta_1 L_t^{-\rho-1} \right] \tag{8.33}$$

In contrast to the Leontief specification, the first-order condition for L_t thus also depends on the substitutability with other factors, seasonal labour in other periods and capital.

A.3 References

Board, S. (2009). *Firm's Problem*. Los Angeles, USA. Retrieved from http://www.econ.ucla.edu/sboard/teaching/econ11_09/econ11_09_lecture5.pdf

Border, K. C. (2001). *Examples of Cost and Production Functions*. Pasadena, USA. Retrieved from Caltech website: people.hss.caltech.edu/~kcb/Notes/CostFunctionExamples.pdf

Chiang, A. C., & Wainwright, K. (2005). *Fundamental Methods of Mathematical Economics // Fundamental methods of mathematical economics* (4th International Edition // 4. ed., internat. ed., [reprint.]). *McGraw-Hill international edition*. New York, USA: McGraw-Hill.

Franz, W. (2013). *Arbeitsmarktökonomik* (8., aktualisierte und ergänzte Auflage). *Springer-Lehrbuch*. Berlin, Heidelberg: Springer Gabler.

Ginsburgh, V. A., & Keyzer, M. (2002). *The structure of applied general equilibrium models* (1st MIT Press paperback ed.). Cambridge, Mass.: MIT Press.

Pauw, K. (2003). *Functional Forms Used in CGE Models: Modelling Production and Commodity Flows* (PROVIDE Project Background Paper No. 5). Elsenburg, South Africa.

Appendix B 2012 Social Accounting Matrix for Bhutan

This chapter consists of the corresponding working paper "A 2012 Social Accounting Matrix (SAM) for Bhutan with a detailed representation of the agricultural sector", which was published in the working paper series of the Department of Agricultural Economics, Humboldt-Universität zu Berlin in 2017 (see also: https://www.agrar.hu-berlin.de/en/institut-en/departments/daoe/publ-en/working-paper-of-the-department/wp94.pdf)

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Abstract

This paper develops a 2012 Social Accounting Matrix (SAM) for Bhutan with a detailed representation of the agricultural sector. Given the availability of extensive household, labour force and agricultural survey data as well as a large dataset of audited company reports, a bottom-up approach is applied to estimate the 2012 SAM, including the estimation of 2012 supply and use matrices. In case of missing data, the SAM relies on information from Bhutan's 2007 supply and use table. The bottom-up approach allows for a detailed depiction of economic activities and their interlinkages with markets and institutions. The SAM consists of a total of 221 accounts, including 108 commodity, 52 activities, 31 factor and 16 household accounts. There are 14 agricultural and 5 post-harvest activities producing 48 agricultural commodities. Agricultural commodities are differentiated by marketed and home-produced-home-consumed (HPHC) commodities to account for the large prevalence of subsistence farming in Bhutan and the differences in prices due to transportation and trade margins. Important features of farming systems and rural livelihoods in Bhutan such as the role of manure, bullock draught power, crop residues, community forestry and brewing of ara, a widely consumed local alcoholic beverage in rural made of cereals, are depicted. Given the increasing importance of hydropower generation within Bhutan's economy, the SAM also represents significant level of detail of the electricity generation sector and the input structure of energy intensive industries. The final SAM is estimated using an information-theoretic, cross-entropy approach. Taking a Bayesian perspective, uncertainties of cell entries' prior values are set such that they reflect the availability and quality of data sources.

Keywords: Social Accounting Matrix, Bhutan, agriculture, economic structure

JEL: E160, E170

List of Abbreviations for 2012 Social Accounting Matrix

ADB	Asian Development Bank
AEZ	Agroecological zone
AFS	Annual Financial Statements
AMC	Agricultural Machinery Center
ASS	Agricultural Sample Survey
BBPL	Bhutan Board Products Ltd
BCCL	Bhutan Calcium Carbide Limited
BDBL	Bhutan Development Bank Limited
BFAL	Bhutan Ferro Alloy Limited
BLSS	Bhutan Living Standard Survey
BNBL	Bhutan National Bank Ltd.
BOBL	Bank of Bhutan Ltd
BoP	Balance of Payments
BPC	Bhutan Power Corporation
BTL	Bhutan Telecom Ltd.
BTS	Bhutan Trade Statistics
CDCL	Construction Development Corportation Ltd.
CGE	Computable General Equilibrium
CIF	Cost, Insurance and Freight
COTI	Countries Other Than India
CPC	Central Product Classification
CSI	Cottage and small industries
DGPC	Druk Green Power Corporation
DHI	Druk Holding Investment
DM	Dry matter
DPL	Dungsam Polymers Ltd.
EBOPS	Extended Balance of Payments Services
ENT	Enterprise
FCB	Food Corporation of Bhutan
FOB	Free on Board
GAMS	General Algebraic Modelling System
GDP	Gross Domestic Product
GVA	Gross Value Added
HH	Household
HPHC	Home Produced Home Consumed
HS	Harmonized System
HV	High Voltage
ILO	International Labour Organization
ISCO	International Standard Classification of Occupations
ISIC	International Standard Industrial Class.
K	Potassium
KCL	Kuensel Corporation Limited
LC	Livestock Census
LMIS	Labour Market Information System
LU	Livestock Unit
LV	Low-voltage
MLI	Medium and large industries
MoAF	Ministry of Agriculture and Forests
MoEA	Ministry of Economic Affairs
MoF	Ministry of Finance
MoLHR	Ministry of Labour and Human Resources
N	Nitrogen
NA	National Accounts
NRDCL	Natural Resources Development Corporation Limited
NRR	National Revenue Report
NSB	National Statistics Bureau of Bhutan
Nu.	Ngultrum (1 US-$ = 53.40 Nu.)
P	Phosphorus
PCAL	Penden Cement Authority Limited
PPC	Plant Protection Chemicals
RGoB	Royal Government of Bhutan
RICBL	Royal Insurance Corporation of Bhutan Ltd
RMA	Royal Monetary Authority
RNR	Renewable Natural Resource (RNR)
RoW	Rest of the World
SAM	Social Accounting Matrix
SOE	State Owned Enterprise
STCBL	State Trading Corporation Bhutan Ltd.
SUT	Supply Use Table

B.1 Introduction

A social accounting matrix (SAM) is a detailed snapshot of an economy's circular flow. Depending on its disaggregation level, it may contain more or less detail. It is referred to as a social accounting matrix, because in contrast to other economic statistical frameworks such as national accounts, input-output and supply and use tables it does also capture transactions of households and other institutions within the economy. A SAM is an essential database for multiplier analysis and economy-wide models such as computable general equilibrium (CGE) models.

For most countries, SAMs have been developed already. Bhutan is one of few countries for which until recently no SAMs have been developed so far. The first SAM for Bhutan has been developed by Feuerbacher (2014), based on the year 2007 largely drawing from a supply and use table (SUT) developed by the Asian Development Bank (2012). The 2007 SAM however does not have a detailed representation of the agricultural sector. Instead it has one single agricultural activity producing five commodities. The objective of this SAM development is to produce a SAM with a recent base year and with a detailed depiction of the agricultural sector. To achieve this objective, this technical documentation pays pronounced detail on how the information on agricultural activities and commodities is derived and estimated.

Ideally, a SAM is developed for the most recent year, particularly if a country's economic structure is undergoing a transformational process as it is the case for Bhutan. Three decades ago, in 1981, agriculture still accounted for about 61% of GDP (UNCTAD, 2016). However, industrialization is catalysed by the rapid growth within Bhutan's electricity sector as Figure B.1 shows. While agriculture only makes up 16% of GDP in 2012 according to the national accounts, it still is the largest sector in terms of employment provide work for almost 60% of labour force in 2012 (ADB & NSB, 2013). The year 2012 was chosen at the beginning of the SAM development process as it is the year with most recent data on national accounts, household consumption and trade.

The final SAM consists of a total of 221 accounts. There are 108 commodity accounts, of which 48 are directly produced by agricultural activities and post-harvest activities. Including forestry commodities, a total of 52 commodities are represented in the SAM that are produced by farm households. Commodities are disaggregated according to marketed and home-produced-home-consumed commodities, in order to account for transport and trade margins as well as sales taxes only in case of marketed goods. The SAM includes 52 activities, of which 14 are agricultural activities and five are post-harvest activities. 31 factors are represented, of which there are ten labour, 12 capital and nine land factors. Households are disaggregated "strategically" into a total of 16 accounts by source of income, nationality (Bhutanese versus foreign) and area (urban versus rural). In addition, there are two enterprise accounts differentiated by private or public ownership. The remaining 14 accounts consist of two margin accounts (trade and transportation), the government and six tax accounts, the capital account (savings and investments), stock changes and the rest of the world (RoW) account.

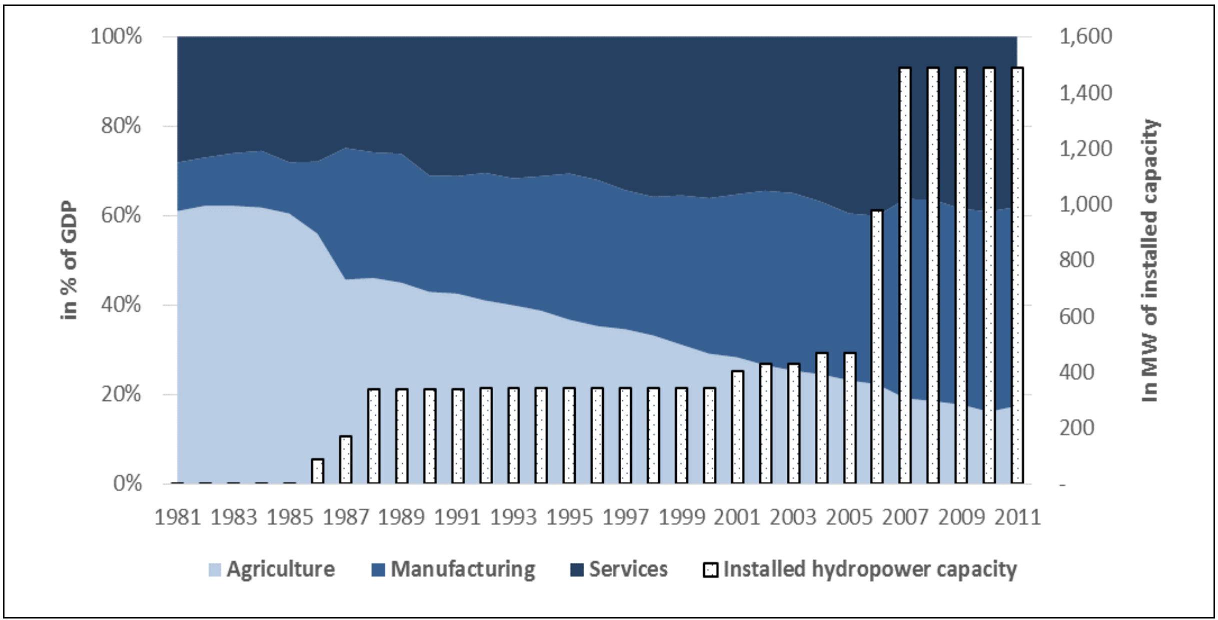


Figure B.1. Bhutan's structural transformation since 1981

Source: NSB, 2012; UNCTAD, 2016

Social-Accounting-Matrices as a Statistical Framework[47]

The underlying concept of SAMs is already captured by the "Tableau Economique" of the French economist François Quesnay (Pyatt & Round, 1985). A SAM is a representation of an economy's circular flow (as presented in Figure B.2). It is an accounting framework of economic agents' expenditure and income within a given time period, usually a year (Dervis et al., 1982). Expenditure of agents is recorded in the column accounts of the matrix, while analogously income is recorded in row accounts as shown in the schematic representation in

[47] This chapter draws from Feuerbacher, 2014.

Table B.1. All economic agents are represented in the SAM by assigning them with a respective column and row account. Total expenditure of an account needs to equal that account's total income received, which makes a SAM a consistent dataset and compliant with a fundamental law of economics: each recorded expenditure needs to relate to a corresponding income (Pyatt, 1988).

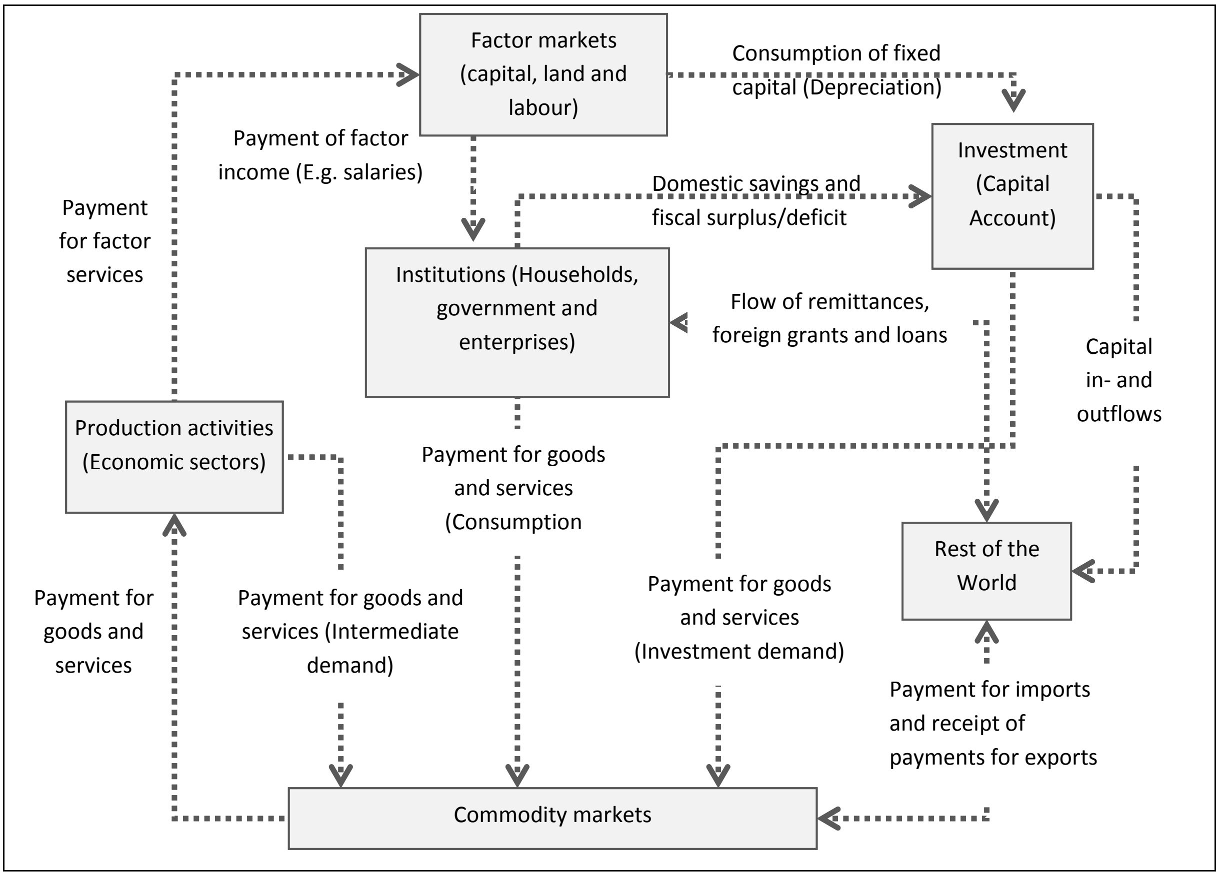


Figure B.2. Circular flow of transactions within an economy

Source: adapted from Pyatt, 1988

The development of the concept of a SAM is attributed to Richard Stone, who in 1984 was awarded the Nobel Prize for his work on the national account system. Stone published the first ever SAM in 1960, which is based on the economy of Great Britain (Stone, 1962). Comprising all economic agents, SAMs became the underlying databases for economy-wide models such as computable general equilibrium (CGE) models. This extended the scope of economy-wide modelling, as previous models are based on input-output tables that did not incorporate the linkage between economic output and living standards.

Table B.1. Schematic representation of a macro-SAM

		A	C	B	D	E	F	G	H	
		Commodities	Margins	Activities	Factors	Households and enterprises	Government	Investments	Rest of the world	Total
1	Commodities		Margins	Intermediate consumption (Use-Matrix)		HH and ENT consumption	Gov. consumption	Investment demand	Exports	Total demand
2	Margins	Margins								Margins
3	Activities	Output (Supply-Matrix)								Domestic output
4	Factors			Payment for factor services					Factor returns from abroad	Total factor income
5	Households and enterprises				Factor returns		Gov. transfers to HH		Inward remittances	Total income of HH and ENT
6	Government and tax accounts	Taxes on products		Taxes less subsidies on production		Income from property; tax income		Government borrowing	Taxes and transfers from RoW	Total government income
7	Savings				Capital depreciation	HH and ET savings	Government savings		Balance of transactions with RoW	Total savings
8	Rest of the world (RoW)	Imports			Factor returns to RoW	Transfers to RoW	Gov. transfers to RoW	Balance of transactions with RoW		Total expenditure to RoW
9	Total	Total supply	Margins	Cost of domestic production	Total factor income	Total HH and ENT expenditure	Total Government expenditure	Total investment	Total income from RoW	

B.2 Data Sources and 2012 Macro-SAM

B.2.1 Data Sources

The data used to develop the Bhutanese SAM is obtained from various sources such as macroeconomic data reported in national accounts (NA), balance of payments (BoP), supply and use tables (SUT); government reports on revenue and budget; survey data from living standard surveys, labour-force surveys, agricultural production surveys and any other sources containing information on the transaction between agents within the economy. All monetary flows are recorded or converted to Bhutan's national currency, the Ngultrum (abbreviated by Nu.). The average annual Nu-US-Dollar exchange rate for the year 2012 is 53.40 (Nu./US-$).

Table B.2 lists the main datasets used for the SAM development. In order to ease reading, data sources are not referred to by author name and year of publication in the subsequent chapters, but instead are cited according to the abbreviations as presented below.

Table B.2. Data sources used for the construction of the 2012 Bhutan SAM

Author, Year	Title	Comment	Abbr.
Asian Development Bank and National Statistics Bureau (ADB & NSB, 2013)	Bhutan Living Standard Survey (BLSS) 2012 microdata		BLSS 2012
ADB & NSB, 2013	Supply and use table (SUT) 2007		SUT 2007
Ministry of Agriculture and Forests (MoAF, 2013a)	Agricultural sample survey (ASS) data 2012		ASS 2012
MoAF (2014)	Agricultural sample survey (ASS) data 2013		ASS 2013
MoAF (MoAF, 2013d)	Livestock Census (LC) data		LC 2012
MoAF (2009)	Renewable Natural Resource (RNR) Census 2009 microdata	Refers to data collected in 2008	RNR 2009
Ministry of Economic Affairs (2015a)	Corporate annual reports 2012		CAR 2012
MoEA (2015b)	Cottage and small industries (CSI) 2013		CSI 2013
MoEA (2015c)	Medium and large industries (MLI) 2012		MLI 2012
Ministry of Finance (2012a; MoF, 2013a)	Annual Financial Statements (AFS) 2011/2012 and 2012/13		AFS 2012
MoF (2014)	Bhutan Trade Statistics (BTS) 2013		BTS 2013
MoF (2013c)	National Revenue Report (NRR) 2012-2013		NRR 2013
National Statistics Bureau (NSB, 2014)	National Accounts (NA) 2014 – report	Used to extract the national account statistics for 2012	NA 2012
Royal Monetary Authority (2013, 2014b)	Annual report 2011/12 and 2012/13	Used to compute balance of payment data for 2012	BoP 2012

Source: Own compilation.

In Bhutan, a significant share of official statistics is reported per fiscal year periods. The fiscal year runs from first of July of one year to end of June of the next year. As the SAM is based on the 2012 calendar year, data that is only available for fiscal year periods needs to be converted to calendar year basis. If quarterly information is available from the fiscal year, all quarters in 2012 are summed up to arrive at 2012 annual numbers. This is for instance the case to derive the 2012 balance of payments statistics using the Royal Monetary Authority's (RMA) annual reports for 2011/12 and 2012/13. If only information from two fiscal years is available, then the simple mean of both years is computed (e.g. average of both 2011-12 and 2012-13 is equivalent to 2012). The National Statistics Bureau (NSB) of Bhutan also explicitly applies this simple mean approximation procedure when including figures published on a fiscal year, for instance when including export data from the Royal Monetary Authority to compute national account statistics (NSB, 2011).

In a perfect world, all data from different sources would be consistent to each other. However, in reality data entails measurement errors. This is why a balanced SAM, in which each account's expenditure equals income, needs to be estimated either using a manual approach (if there are few and small deviations) or using statistical procedures. For the development of this SAM an information theoretic approach applying cross-entropy methods is used to estimate the final SAM from a prior-SAM (S. Robinson, Cattaneo, & El-Said, 2001).

B.2.2 A 2012 Macro-SAM for Bhutan

The 2012 macro-SAM for Bhutan is compiled based on macro aggregates following a top-down process. This leads to deviations compared to aggregating data sources from bottom-up. National accounts data are sometimes difficult to reconcile with data from individual sectors. For example, gross output calculated for certain crops (e.g. paddy, maize, citrus and apple) using estimated agricultural production and farm-gate prices vary substantially from the gross output statistics reported by the national account statistics.

In general, a bottom-up approach is used for the development of the 2012 micro SAM for Bhutan, primarily for those accounts and cell-entries where – according to the authors' judgement – detailed and representative data is available. The unbalanced prior macro-SAM in Table B.3 is thus primarily a reflection of macroeconomic statistics and is particularly helpful to develop a micro SAM that is – given a certain error margin – consistent with macroeconomic indicators such as gross domestic output, total economic output, government spending, trade deficit. Cell entries of the unbalanced prior macro-SAM in Table B.3 that are computed as residuals are highlighted in bold and blue font colour.

Table B.3. Unbalanced prior 2012 macro-SAM for Bhutan

		A	B	C	D	E	F	G	H	I	J	
		Commodities	Margins	Activities	Factors	House-holds	Enter-prises	Govt.	Taxes	Invest-ments	Rest of the world	Total
1	Commodities		13,376	**73,587**		42,690		18,691		66,253	34,388	248,985
2	Margins	13,376										13,376
3	Activities	165,538										165,538
4	Factors			90,740							900	91,640
5	Households				44,238		8,944	1,502			692	55,377
6	Enterprises				37,976							37,976
7	Govt.						5,278		14,616		9,733	29,627
8	Taxes	5,813		1,211		1,072	6,520					14,616
9	Savings				7,328	**10,079**	8,944	9,434		1,949	**28,135**	65,869
10	Rest of the world (RoW)	61,925			2,098	1,535	8,291					73,849
11	Total	246,652	13,376	165,538	91,640	55,377	37,976	29,627	14,616	68,202	73,849	

Source: Own compilation.
Note: In Million Nu.

The underlying data sources, imputations or assumptions of each cell entry of the unbalanced prior macro-SAM are documented in Table B.4.

Table B.4. Used data sources and imputations of the unbalanced prior 2012 macro SAM

Cell entry:		Data source / Imputation method:
A2/ B1	Trade and transport margins	Estimated using SUT 2007 and margins between purchaser and farm-gate prices for agricultural goods
A3	Gross output of domestic activities (Supply-matrix)	Gross value of output measured in basic prices and based on the NA 2012.
A8	Taxes on products	Estimated on basic price basis and includes sales tax, excise tax and custom duty as reported in the NRR 2013.
A10	Imports of goods and services	Measured in basic prices (CIF terms) and based on the BTS 2013 and UN COMTRADE data for 2012; Re-imports are subtracted.
C1	Intermediate consumption (Use-matrix)	Measured in purchaser prices and imputed as a residual by subtracting total payment to factors and taxes from total gross output.
C4	Payment for factor services	Total compensation of employees and operating surplus as reported by the NA 2012. Includes both factors owned domestically and abroad
C8	Taxes less subsidies on production	Includes taxes, fees and royalties as reported by the NRR 2013. In case of non-incorporated businesses, it also includes the business income tax
D5	Factor returns paid to households	Estimated using the share of labour in GDP and adding an assumed 10% to adjust for mixed income and unincorporated capital
D6	Factor returns paid to enterprises	Residual of total factor return after subtracting factor returns to households, labour from abroad and consumption of fixed capital
D9	Consumption of fixed capital	Capital depreciation is based on the NA 2012
D10	Return to labour from abroad	Based on the BoP 2012.
E1	Household consumption	Final consumption expenditure of households in purchaser prices reported by the NA 2012.
E8	Direct taxes paid by households	Personal income taxes paid by households as reported by the NRR 2013.
E9	Household savings	Imputed as a residual.
E10	Household transfers to RoW	Outward remittances to institutions (i.e. households) abroad, data is based on BoP 2012.
F5	Dividends paid to households	Assumed to be 50% of the residual after subtracting payment of direct taxes, dividends to the government and transfers to RoW.
F7	Dividends paid to the government	As reported in the AFS 2012.
F8	Direct taxes paid by enterprises	Based on the NRR 2012.
F9	Retained earnings (savings) by enterprises	Assumed to be 50% of the residual after subtracting payment of direct taxes, dividends to the government and transfers to RoW.
F10	Enterprise payments to RoW	Based on the BoP 2012.
G1	Government consumption	Current expenditure of government as reported in the NA 2012.
G5	Government transfers to households	Current and capital grants to individuals and non-profit organizations based on AFS 2012.
G9	Government savings	Net government savings calculated as a residual
H7	Tax revenue	As reported in AFS 2012.
I1	Investment demand	Equal to the gross capital formation as reported in NA 2012.
I9	Stock changes	A prior value of 2% of GDP is assumed for changes of inventory
J1	Export of goods and services	Measured in purchaser prices (FOB terms) and based on BTS 2013 and UN COMTRADE data for 2012; Re-exports are subtracted.
J4	Factor returns from RoW	Income from factors employed abroad based on BoP 2012.
J5	Transfers from RoW to househ.	Inward remittances based on BoP 2012.
J7	Transfers from RoW to government	External grants received in cash (budget support, development aid) as reported in the NRR 2013.
J8	Taxes/royalties earned from RoW	Mostly royalties charged from international tourists, based on NRR 2013.
J9	Capital account deficit with RoW	Inflow of foreign capital calculated as a residual.

In the unbalanced prior 2012 macro-SAM shown in Table B.4 income of commodities exceeds expenditure by Nu. 2,333 Million (i.e. 0.95% of commodity's total) and investments exceed savings by the identical amount. This deviation could be manually balanced by subtracting Nu.

2,333 Million from the investment account in cell I1. Instead, we estimate the balanced prior macro-SAM using the *SAM Estimation Program, Version 3.3* developed by Scott McDonald and Sherman Robinson (2006). The estimation procedure is largely based on earlier methods of using cross-entropy techniques for SAM estimation (S. Robinson et al., 2001) and the same procedure will also be used to estimate the final micro SAM in section 9.

The program is grounded in Bayesian statistical philosophy, i.e. the compiled and unbalanced prior SAM represents prior values. The estimation program allows to enter pre-defined error bounds (denoted by σ), within which the program is able to change cell entries. This procedure allows to fix cell entries by assigning an error of zero ($\sigma = 0$). We assign a higher error margin ($\sigma = 0.5$) for the stock changes entry in cell I9 (Stock changes are recorded in a separate account during the estimation procedure). The program is coded in the General Algebraic Modelling System (GAMS) software package and the data is imported from an excel sheet, in which various estimation settings can be controlled. The program is run using the CONOPT solver.

The balanced prior macro-SAM as shown in Table B.5 is used for the compilation and estimation of the micro-SAM. However, as the estimation of the final micro SAM largely follows a bottom-up approach, the final macro-SAM derived from micro-SAM will be still different from the balanced prior SAM. These deviations will be presented and discussed in section B.9.2.

Table B.5. Balanced prior 2012 macro-SAM

	Commodities	Margins	Activities	Factors	House-holds	Enter-prises	Govt.	Taxes	Invest-ments	Rest of the world	Total
Commodities	-	13,381	73,706	-	42,650	-	18,660	-	64,338	34,264	246,999
Margins	13,381	-	-	-	-	-	-	-	-	-	13,381
Activities	165,712	-	-	-	-	-	-	-	-	-	165,712
Factors	-	-	90,794	-	-	-	-	-	-	900	91,694
Households	-	-	-	44,249	-	8,939	1,502	-	-	692	55,382
Enterprises	-	-	-	37,996	-	-	-	-	-	-	37,996
Govt.	-	-	-	-	-	5,278	-	14,620	-	9,731	29,629
Taxes	5,817	-	1,211	-	1,072	6,520	-	-	-	-	14,620
Savings	-	-	-	7,352	10,124	8,975	9,467	-	1,948	28,420	66,286
Rest of the world (RoW)	62,089	-	-	2,097	1,535	8,285	-	-	-	-	74,006
Total	246,999	13,381	165,712	91,694	55,382	37,996	29,629	14,620	66,286	74,006	-

Source: Own compilation based on unbalanced prior 2012 macro-SAM.

The estimation of the balanced prior macro-SAM slightly alters the original data of macro aggregates as shown in Table B.6 below. GDP measured using the expenditure approach equals Nu. 99,771 million and deviates from the official estimates of GDP by 3.9%. There is only a deviation of 0.4% according to the production approach. The deviation between the expenditure and production approach based GDP estimates of the prior balanced macro-SAM is only 2.0%. In contrast, the estimates of the national accounts have a discrepancy of 6.6% (NSB, 2014).

Table B.6. GDP calculations based on macro-SAM

Expenditure approach			Production approach		
Item	**Unbalanced prior macro-SAM**	**Balanced prior macro-SAM**	**Item**	**Unbalanced prior macro-SAM**	**Balanced prior macro-SAM**
Consumption	42,690	42,650	Output of activities	165,538	165,712
Gov. expenditure	18,691	18,660	Intermediate Inputs	73,587	73,706
Net exports	-27,537	-27,825	Taxes on products less subsidies	5,813	5,817
Investments	66,253	66,286			
GDP, prior macro-SAM	**100,098**	**99,771**	**GDP, prior macro-SAM**	**97,765**	**97,823**
National Accounts 2012 estimate		**103,868**	**National accounts 2012 estimate**		**97,453**

Note: In Million Nu.
Following the expenditure approach, GDP equals the sum of final uses of goods and services, less the value of imported goods and services. Following the production approach, GDP equals the difference between output and intermediate consumptions plus taxes on products less subsidies (UN, 2009).

Bhutan's macroeconomic structure can be analysed by investigating the expenditure shares (column shares) and income shares (row shares) of the balanced prior macro SAM. Analysing the column shares in Table B.7, we see that the majority (67.1%) of the value of consumed commodities originates from domestic production, while imports account for 25.1%. Intermediate inputs comprise 44.5% of total output value and the average value added share accounts for 54.8%. The largest part of household expenditure is current expenditure (77.0%) and the savings rate equals 18.3%, which includes any capital expenditure of households.

Table B.7. Column shares of balanced prior 2012 macro-SAM

	Commodities	Margins	Activities	Factors	House-holds	Enter-prises	Govt.	Taxes	Invest-ments	Rest of the world	Total
Commodities		100.0%	44.5%		77.0%		63.0%		97.1%	46.3%	
Margins	5.4%										
Activities	67.1%										
Factors			54.8%							1.2%	
Households				48.3%		23.5%	5.1%			0.9%	
Enterprises				41.4%							
Govt.						13.9%		100.0%		13.1%	
Taxes	2.4%		0.7%		1.9%	17.2%					
Savings				8.0%	18.3%	23.6%	32.0%		2.9%	38.4%	
Rest of the world (RoW)	25.1%			2.3%	2.8%	21.8%					
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	

Source: Own compilation based on prior 2012 macro-SAM.

The row shares in Table B.8 show the sources of income of markets and institutions. 29.8% of commodities are used as intermediate inputs, while 17.3% and 7.6% is consumed by households and the government. Investment demand and exports make up 26.6% and 13.8%, respectively. Households receive the largest share of income directly from factors (79.9%), which mainly consists of labour returns and a small share of returns from unincorporated capital. Another 16.2% of income is derived from enterprises in form of dividends. Transfers from the government (2.7%) and rest of the world (1.3%) are small in comparison. Tax revenue makes up the largest share of government income (49.3%), while the government budget's dependency on external aid is still substantial (32.9%). Also, the capital account deficit is large, roughly making up 44.0% of total investments and 38.1% total expenditure of the rest of the world (see column shares).

Table B.8. Row shares of balanced prior 2012 macro-SAM

	Commodities	Margins	Activities	Factors	House-holds	Enter-prises	Govt.	Taxes	Invest-ments	Rest of the world	Total
Commodities		5.4%	29.8%		17.3%		7.6%		26.0%	13.9%	100.0%
Margins	100.0%										100.0%
Activities	100.0%										100.0%
Factors			99.0%							1.0%	100.0%
Households				79.9%		16.1%	2.7%			1.2%	100.0%
Enterprises				100.0%							100.0%
Govt.						17.8%		49.3%		32.8%	100.0%
Taxes	39.8%		8.3%		7.3%	44.6%					100.0%
Savings				11.1%	15.3%	13.5%	14.3%		2.9%	42.9%	100.0%
Rest of the world (RoW)	83.9%			2.8%	2.1%	11.2%					100.0%
Total											

Source: Own compilation based on prior 2012 macro-SAM.

B.3 Supply-Matrix

The supply matrix is a sub-matrix within a SAM that records the output *supplied* by activities valued at basic prices to the respective commodity account. Activities within the 2012 Bhutan SAM are either single- or multiple-product industries, i.e. they produce either one single or multiple outputs (a set of commodities). The output is an income for the activities account and at the same time an expenditure to the commodity accounts.

The presentation of the supply matrix is divided into three parts. First, the part of the supply matrix concerned with agriculture- and forestry-based activities and commodities is discussed. This part is discussed most extensively, given the SAM's focus on agriculture and rural livelihoods. Furthermore, a high share of this sector's output falls under home-produced home-consumed (HPHC) goods, which is taken into account by differentiating commodities accordingly. The second part describes mining, manufacturing and energy activities and commodities. Third, we discuss the part of the supply matrix dealing with services. Data sources, methods of computation and imputation as well as assumptions are carefully documented. Commodities are classified with reference to the Central Product Classification (CPC Ver. 2) codes (UN, 2008). Activities are classified using the International Standard Industrial Classification (ISIC 3.1 revised) code (UN, 2002). The respective correspondence tables are found in the appendices A and B.

B.3.1 Supply of Agriculture- and Forestry-based Commodities

B.3.1.1 Grouping of Agricultural Crops

Farmers in Bhutan, due to the high variety in agro-ecological zones, are growing a large range of agricultural crops. Still, there is an observable pattern and dominance of some cultivated crops that often serve as either staple food or cash crops. Data on agricultural output is derived from the various agricultural surveys (MoAF, 2013a, 2014) and the 2009 renewable natural resource (RNR) census (MoAF, 2009). Appendix C reports total production and area harvested per crop as well as farm-gate prices (using 2012 data) of all crops covered in the SAM. The last column shows to which specific SAM activity the respective crop is grouped in.

B.3.1.2 Structure of Agriculture- and Forestry-based Activities and Commodities

Most agriculture- and forestry-based activities represented in the 2012 SAM are multi-product activities, either because they produce a HPHC and a marketed commodity, or because they produce by-products (e.g. crop residues) or because they produce a range of products in certain ratios (e.g. milk and beef).

Table B.9 presents the underlying information used to compute the output value (i.e. supply measured in value) of each agriculture and forestry-based commodity. Data sources to compile the supply matrix for the agriculture- and forestry-based sectors predominantly consist of the agricultural sample surveys (ASS) 2012 (MoAF, 2013a); the livestock census (LC) 2012 (MoAF, 2013d); the renewable natural resource (RNR) census 2009 (MoAF, 2009); the national accounts (NA) for 2012 (NSB, 2014); as well as the cottage and small industry (CSI) 2013 dataset and data from corporate annual reports (referred to as *company data* in short) from agriculture and wood-based industries (MoEA, 2015a, 2015b). In a few cases, data is obtained through expert interviews (e.g. the animal feed production activity). If available, quantities measured in metric tons are reported in the second column. This allows to incorporate a quantity satellite account in a later CGE model in order to interpret model results in terms of quantity changes instead of value changes, which is otherwise only the case when prices are calibrated equal to one. Basic-prices are reported in the third column. Farm-gate prices for crops derived from the agricultural sample survey 2012 are used as a proxy for the basic price. This is reasonable, as farm-gate prices include no transportation and trade margins and as there are no production subsidies. Total national output in million Nu. is presented in the fourth column andcomments are provided in a separate column.

Unfortunately, the agricultural sample survey does not include questions related to livestock ownership and output.[48] Therefore, we had to resort to the RNR census 2009[49], which included questions on animal products sold and amount of revenue earned, from which the 2008 farm-gate prices are imputed. The imputed farm–gate price for livestock products is then adjusted for the difference in inflation between 2008 and 2012.

[48] Separate data collection on livestock and crop indicators is owned to the organizational structure of the Ministry of Agriculture and Forests (MoAF) in Bhutan. Conducting integrated surveys that include both crop and livestock indicators would greatly improve the data quality for agricultural research purposes.
[49] The renewable natural resource census 2009 was conducted in 2008, but is officially referred to as the RNR census 2009.

Table B.9. Computation of output value of agriculture and forestry based commodities

Commodity	Qty. produced (in metric tonnes)	Basic price (Farm gate price in Nu./kg)	Output (in million Nu.)	Data Source	Comment
Agriculture – crops					
Paddy	54,876	26.32	1,445	ASS 2012	Paddy basic price was derived from the final output value of milled rice accounting for the value of milling by-products and the milling charge.
Maize	59,993	14.86	891	Ibid.	
Other cereals and oilseeds	12,201	26.70	328	Ibid.	
Crop residues	168,680	1.00	169	Ibid.	Assumption: Price of crop residue is 1.00 Nu./kg.
Pulse	4,953	33.21	165	Ibid.	
Low-value vegetables	30,951	15.65	484	Ibid.	
High-value vegetables	9,814	60.68	596	Ibid.	
Potato	59,004	14.36	847	Ibid.	
Beverages and spices	4,569	129.78	593	Ibid.	
Agriculture – fruits and nuts					
Other nuts and fruit	16,888	21.31	360	Ibid.	
Apples	6,905	33.39	231	Ibid.	
Citrus fruits	41,809	19.93	833	Ibid.	
Agriculture – livestock					
Milk	29,625	30.68	909	LC 2012, RNR 2009	
Beef	620	121.13	75	Ibid.	
Manure	193,830	1.01	195	LC 2012, RNR 2009	Assuming a 68% dry matter content per ton. See sub-section on manure.
Live animals			187	RNR 2009	See sub-section on live animals.
Bullock draught power			281	LC 2012, RNR 2009	See sub-section on bullock draught power.
Chicken meat	909	159.48	145	Ibid.	
Eggs	2,901	136.24	395	Ibid.	
Other animal meat and products	1,337	120.85	162	Ibid.	

Commodity	Qty. produced (in metric tonnes)	Basic price (Farm gate price in Nu./kg)	Output (in million Nu.)	Data Source	Comment
Milled cereals					
Milled rice	31,230	51.37	1,604	ASS 2012; NSB (2015) SUT 2007	Basic price is estimated by taking the simple mean 2012 annual national price of the three main rice varieties and subtracting the SUT 2007 8.82% trade and transport margin for cereals.
Milled other cereals	2,789	48.29	135	ASS 2012	
Food manufacturing					
Dairy products	8,664	202.43	1,754	LC 2012 BLSS 2012; RNR 2009	Basic price estimated using BLSS 2012 data and SUT 2007 margins.
Processed rice	3,574	67.77	242	ASS 2012	
Processed maize	1,775	69.11	123	ASS 2012	
Other grain mill products			496	BLSS 2012; SUT 2007	Calculated as the residual of total output of grain mill production minus processed rice, maize, vegetable oils and animal feed.
Vegetable oils	674	77.16	52	BLSS 2012, SUT 2007	Basic price estimated using the unit price from the BLSS 2012 and subtracting the SUT 2007 transport margin for grain mill products of 15%: Consumed domestic quantity reported by BLSS as a proxy for total production.
Ara	15,913	34.67	552	BLSS 2012	Multiplying up-scaled household consumption of ara times average unit price as recorded by BLSS 2012 data.
Animal feed	19,462	20.59	401	MoEA, 2015a; SUT 2007	Imputed total animal feed production assuming that Karma Feed represents 90% of total domestic feed production. Total production is multiplied with mean sales price of 2013 after adjustment for inflation and trade and transport margin as reported by SUT 2007.
Processed fruits and vegetables			449	MoEA, 2015a, 2015b; CSI 2013	Revenue of the three largest agro-processing companies plus sales of processed fruits and vegetables of small and cottage industries.
Non-alcoholic beverages			457	MoEA, 2015b; CSI 2013	Revenue of the two largest bottling companies plus sales of beverages of small and cottage industries.
Alcoholic beverages and tobacco			913	Company data	Revenue of the only large-scale brewery and the state-owned distillery plus sales of alcoholic beverages of small and cottage industries excluding sales tax and excise duty.

Commodity	Qty. produced (in metric tonnes)	Basic price (Farm gate price in Nu./kg)	Output (in million Nu.)	Data Source	Comment
Forestry					
Logs (in m3)	216,784	4,781.58 (Nu/m3)	1,036	van Noord, 2010 and NRDCL, 2012	Production of logs (in m3) is estimated using average rural construction timber from 2005-07 (van Noord, 2010) and commercial logs extraction by NRDCL in 2012. Basic price is derived from NRDCL, 2012.
Firewood (in m3)	946,949	539.35 (Nu/m3)	511	BLSS 2012 and NRDCL, 2012	Quantity of firewood consumed is estimated from BLSS 2012 consumption data, wood chips consumption and estimated institutional demand (10% of household consumption). Price is a weighted average of firewood and wood chip prices.
Non-wood forest products			157	RNR 2009 Census; MoEA, 2013	Estimated using RNR 2009 production data of NWFP and export value of Cordyceps assuming a transport and trade margin of 25%.
Wood-based industries					
Products of wood and cork			772	Corporate annual reports 2012; CSI 2013	Revenue of the only large-scale wood-based industry (Bhutan Boards industry) plus sales of small and cottage industries such as sawmills.
Paper products			379	Corporate annual reports 2012; CSI 2013	Assuming that revenue of the largest media and print company (Kuensel) represents 50% of sector output.
Furniture			414	Corporate annual reports 2012; CSI 2013	Revenue of the largest wood-based industry (Wood Craft Centre) plus sales of small and cottage industries (e.g. furniture units).

Source: Own compilation.

B.3.1.3 Adjustment of Output for HPHC

In Bhutan, farmers consume a considerable share of their own production themselves, which is referred to as home-production-home-consumption (HPHC). HPHC also applies for raw materials which the farmers produced themselves and then use on their farm as intermediate inputs for milling, animal feeding or production of ara. In these cases, goods should not be valued at purchasing prices, as it is the case for goods consumed by non-farm households and enterprises. The significant difference is that the price of HPHC goods equals the basic price of output, while the purchasing price includes the mark-up for trade and transport margins as well as sales and VAT taxes. Depending on infrastructure and the value chain characteristics, differences in prices can be substantial. Hence, the consumption of HPHC goods by farm households would be significantly overstated if valued at purchasing prices. In order to avoid this misrepresentation, the 2012 SAM for Bhutan disaggregates the major HPHC goods into the two channels: HPHC goods (denoted by the prefix ch* e.g. chmaize) or marketed goods (denoted by the prefix cm* e.g. cmmaize). The BLSS 2012 included the question whether food consumption is from own source (i.e. HPHC) or bought on the market, here it is differentiated again whether the food is domestically produced or imported. Using this information, shares of HPHC are derived for a wide range of food commodities as presented in Table B.10.

Table B.10. Home-production home-consumption (HPHC) shares

Commodity	Total Domestic Supply	Total HPHC	% HPHC share	% intermediate demand	% final household demand
	(in Million Nu.)	(in Million Nu.)	of total domestic supply	of total HPHC	of total HPHC
Paddy	*See Milled domestic rice*				
Maize	891	708	79.5	50.2	49.8
Other cereals and oilseeds	328	258	78.6	80.3	19.7
Pulse	165	62	37.7	17.8	82.2
Low-value vegetables	484	155	32.1	21.1	78.9
High-value vegetables	596	147	24.8	10.7	89.3
Potato	847	235	27.8	57.6	42.4
Beverages and spices	593	42	7.0	76.1	23.9
Other nuts and fruits	374	68	18.3	5.3	94.7
Apple	231	26	11.1	5.8	94.2
Citrus	891	75	8.4	8.7	91.3
Milk	909	752	82.7	96.2	3.8
Beef	75	42	56.4	0.0	100.0
Chicken meat	145	22	15.1	0.0	100.0
Eggs	395	70	17.7	0.0	100.0
Other animal products and meat	162	29	18.1	0.0	100.0
Milled domestic rice	1,604	924	57.6	6.6	93.4
Milled Other Cereals	135	58	42.8	22.1	77.9
Dairy Products	1,754	671	38.2	0.0	100.0
Processed Rice	242	85	35.1	1.7	98.3
Processed Maize	123	52	42.2	0.0	100.0
Ara	552	384	69.7	0.0	100.0

Source: Own compilation.

The data is adjusted to reflect only HPHC of farm households. Non-farm households also report home consumption of home-produced goods in the BLSS 2012, which can have manifold explanations. It is known that through sharecropping non-farm households receive a share of the harvest which they might report as HPHC. Further, non-farm households produce agricultural goods for example from kitchen gardens, which is then largely a HPHC good. In general, the share HPHC of total consumption from non-farm households can be regarded as negligible and thus only the share of HPHC of total consumption of farm-households is considered. Further, also the farm output that is processed or consumed as an intermediate input on the farm, e.g. fed to animals, is considered as a HPHC good. This differentiation for intermediate input is also reflected within the use-matrix. On-farm and thus mostly small-scale processing activities use the HPHC good. In contrast, large-scale industrial processing activities consume the marketed commodity.

In Table B.11 below, a snapshot of the HPHC adjusted supply matrix including the first five agricultural commodities is presented.

Table B.11. Snapshot of the HPHC adjusted supply matrix

Output in million Nu.									
	chpaddy	**chmaize**	**cmmaize**	**chcereals**	**cmcereals**	**chpulse**	**cmpulse**	**cfodder**	**Total**
apaddy	1,445	-	-	-	-	-	-	-	1,445
amaize	-	654	183	-	-	-	-	54	891
aothcereals	-	-	-	238	70	-	-	19	328
apulse	-	-	-	-	-	62	102	-	165

Output shares in % of total output									
	chpaddy	**chmaize**	**cmmaize**	**chcereals**	**cmcereals**	**chpulse**	**cmpulse**	**cfodder**	**Total**
apaddy	100.0%								100.0%
amaize		68.6%	20.5%					10.9%	100.0%
aothcereals				74.9%	21.4%			3.7%	100.0%
apulse						37.7%	62.3%		100.0%

Source: Own compilation.

Table B.11 also shows that the share of crop output fed to animals is accounted within a separate fodder commodity (cfodder). That commodity is simply an aggregation of all crops fed to animals and also represents an HPHC commodity.

B.3.1.4 Supply of Agricultural Inputs

There is no agrochemical industry in Bhutan. Other agricultural inputs that are used as intermediate inputs are manure, live animals and bullock draught power. The estimation of the supply value of these inputs is described in the following.

Manure

The most recent statistic on the applied quantity of manure is from the RNR census 2009, according to which farmers use 1.47 tons of manure on average. This only relates to manually spread manure, not including manure droppings on cropland that originate from animals being tethered on cropland (i.e. in-situ manuring), which is a common practice in Bhutan. An average manure consumption of 1.47 tons translates to just 1.1 tons /hectare, which seem to be a very low estimate as more than 60% of farmers only rely on manure as their source of fertilizer. Assuming that in 2012 the average utilization of manure per farmer is identical, we arrive at a total estimated manure quantity of 93,529 tons for 2012. In the following, due to the reasons provided, we use this imputed quantity as a lower bound estimate.

An alternative approach of estimating the applied quantity of manure is a top-down approach using the livestock population data from the 2012 Livestock Census. Following this approach, we convert animal populations into livestock units (LU) using conversion factors from K. Wangchuk and Dorji (2008). LUs are multiplied with daily manure production and recovery rates derived from available literature. Doing so allows estimating the output of manure per livestock activity by computing the relative contribution of each livestock type.

As a first step, the dry matter manure production for each livestock type (cattle, poultry, goat, sheep and pigs) is estimated using values on animal size, daily manure production and water content from Moore and Gamroth (1982). Based on these values, cattle produce 3.2 kg of dry matter (DM) manure per day and livestock unit. DM manure production for other animals is in the range of 1.8 to 4.5 kg depending on the livestock type. As a second step, the share of total manure available as nutrients brought on cropland is determined for each livestock type. Samdup et al. (2010) found that improved and local cattle[50] spent 27% and 33% of the day on pasture land, resulting in the assumption that during the remaining time manure is deposited on the cropland. Hence, we assume an availability of 73% and 67% for improved and local cattle.

[50] An improved cattle breed in Bhutan is predominantly a Jersey cattle, but occasionally Brown Swiss cattle are found. The predominant local breeds are Nublang, Mithun and Jatsa, which is a cross between the two former ones.

For other animals we assume an availability of 50%, yet they play a minor role, as cattle represents the majority (94.8%) of total livestock units. This yields a total quantity of applied manure of 227,264 tons, which can serve as an upper boundary. The largest share of manure originates from cattle (95.8%), while 2.4% and 1.7% of manure comes from other animals and poultry, respectively.

The final estimated amount of manually applied manure is the average of both the lower and upper boundary estimate, which equals 160,396 tons. The tethered amount of manure is assumed to equal half of the difference of the upper boundary estimate and final estimate of manually applied manure, which equals 33,433 tons. Hence, total applied manure is estimated to equal 193,830 tons of manure.

The monetary value of manually applied manure can be approximated by determining its NPK content and multiplying the individual content by observable market prices of fertilizer. We have to account for the fact that farmers do not value the identical nutrient content in organic fertilizer the same as they do in case of chemical fertilizer due to reasons of storability, timing of nutrient release and handling amongst others. To account for this, we simply assume a 50% discount to impute the nutrient value of manure.

Long-term experiments on manure in Bhutan have determined a dry matter content of 68% and nutrient contents of 1.6% Nitrogen (N), 0.8% Phosphorus (P) and 2.9% Potassium (K) of dry matter manure (Chettri et al., 2003). These experiments have been conducted with a sample of farmers that used heap-storage methods. Adjusting for the DM content, one ton of manure thus contains 10.9 kg N, 5.4 kg P and 19.7 kg K. Using prices of commercially available fertilizer published by the MoAF for 2013, adjusting for inflation and converting prices for each chemical element of NPK, we arrive at market prices of 27.81 Nu./kg for N, 150.34 Nu./kg for P and 45.46 Nu./kg for K. Considering the previously justified discounts, the average price of one kg of manure is 1.01 Nu./kg and we arrive at a total value of Nu. 195 million of which manually applied manure and tethered manure comprise 83% and 17%, respectively.

Live animals

The RNR 2009 census includes information on live animals sold of each livestock type. For simplicity reasons, all live animals are grouped together into one commodity account. In total, live animals being worth Nu. 187 Million are sold, of which sold cattle made up 81.1%, other animals 16.6% and poultry 2.3%.

Bullock Draught Power

According to the RNR 2009 census, 78.9% of farmers relied on bullocks to plough their land. The value of bullock draught power can be decomposed into the capital cost of a bullock and the cost of feed, i.e. fodder (mainly crop residues) and compound feed. The initial cost of a bullock is Nu. 12,000 for a local breed and Nu. 10,000 for an improved breed. In the RNR 2009 census it is not differentiated which breed farmers use for ploughing. However, it is a well-known fact that predominantly local breeds are used for ploughing, as they are known to be more robust and powerful. Improved male cattle are rather needed for breeding purposes. Local male cattle account for 88% of the total male cattle population in Bhutan and since the difference in initial cost is small, we only use available data on the local breed to impute the cost of bullock draught power.

The economic life expectancy of a local breed is 10 years, but it is reasonable to assume that a bullock can only be used for ploughing over a span of 7 years. Using a 10% discount rate, we arrive at an estimated annualized capital cost of Nu. 1,953. It is further estimated that the annual cost of fodder per bullock corresponds to 2,460 Nu./yr. On days in which the bullock is used to plough, it is assumed that in addition to fodder compound feed is fed to bullocks. Usage levels of compound feed in Bhutan are very low and thus we assume that per bullock only 12 kg of compound feed per year is fed on average, resulting into an annual consumption value of Nu. 246 per bullock.

Adjusting the RNR 2009 census to 2012 levels, the number of bullocks used for ploughing in 2012 is estimated to be 54,252 animals. This yields a total capital cost of bullocks of Nu. 134 Million. After accounting for the cost of fodder (Nu. 133 million) and compound feed (Nu. 13 million), we arrive at a total value of bullock draught power of Nu. 280 Million.

B.3.1.5 Forestry

Forestry policies in Bhutan separate the timber markets strictly between rural and urban regions. Further, productive management of forests is separated into commercial management of forests (i.e. commercial forestry, which is discussed subsequently) and forests accessed or managed by rural communities (Arndt Feuerbacher et al., 2016).

Community Forestry

Generally, rural households are allowed to extract logs and firewood from the surrounding forests for their own needs. The annual consumption quota is regulated by the forest and nature conservation rules 2006 (RGoB, 2006), which allows households depending on whether they have access to electricity to harvest either 8 or 16m^3 of firewood annually. Logs used for own construction or renovation purposes can also be harvested from rural households directly on a standing-tree basis through forestry officers or supplied on a subsidized rate through the NRDCL. In case of forests explicitly designated as community forests, a management plan regulates the annual harvest limit. If the quantity harvested for the participants remains below the annual harvest limit, households are allowed to sell the remaining quantity of non-wood forest products and timber on the market. Community forests are an increasing forest governance scheme found in Bhutan, however the area under community forest regime still only accounted for 2.5% of total forest area in 2014 (MoAF, 2015). Data on total extracted rural timber for construction purposes (logs) is provided by van Noord (2010) for the years 2005 to 2007. More recent data is not available and thus the average of these three years, 147,095 m^3, is used as a proxy. Data on timber harvested by rural households is hardly available. The BLSS 2012 data set reports consumption of firewood in truck- and backloads, which are measures for 8 m^3 or 43 kg, respectively. The consumption reported in backloads of rural households serves as an estimate for the quantity of firewood collected and equals 638,403 m^3. Firewood consumption reported in terms of truckloads is assumed to be supplied by the commercial forestry sector.

Data on non-wood forest products (NWFP) is reported by the RNR 2009 census. Non-wood forest products collect by rural people include a large variety of products such as bamboo shoots, mushrooms, lemon grass and medicinal plants. The most important non-wood forest product, which in most cases is found on high-altitude land with little or no forest cover, is Cordyceps. Cordyceps are highly demanded in East-Asia and fetch export prices of 517,403 Nu./kg (9,689 USD/kg) (MoF, 2013b). In 2012, 196.35 kg of Cordyceps worth Nu. 102 million are exported (MoF, 2013b). It is assumed, that the farmgate price of Cordyceps makes up 75% of the FOB export price, with the remaining 25% accounting for trade and transport margin. Thus, total estimate output value of Cordyceps is estimated to be Nu. 76 Million in 2012. Value of the remaining non-wood forest products is estimated to be Nu. 81 Million in 2012, using the RNR 2009 census data and after having adjusted for inflation. Total estimated value of NWFPs sums to Nu. 157 Million in 2012.

Commercial Forestry

Commercial logs and firewood are extracted by the Natural Resource Development Corporation Limited (NRDCL), which is a state-owned enterprise that is in charge of sustainably utilizing and managing natural resources such as forests, stone and sand (NRDCL, 2013). They operate forest management units and annual production statistics is available from annual reports.

In 2012, NRDCL reported to have extracted 69,689 m3 of commercial logs being worth Nu. 294 Million. Besides the NRDCL, there are contractors that receive the mandate to extract logs and tops that are not suitable for prime timber and are instead used as firewood or wood chips.

No information on the quantity of firewood supplied by contractors is available, yet as both total quantity of firewood consumed and collected by rural households has been estimated previously, we compute total commercial extraction of firewood as a residual being equal to 201,182 m^3. This, however, would not include the consumption of firewood by other institutions than households, such as monasteries and government buildings as well as the consumption of firewood by industries. The NRDCL has supplied 23,406 m^3 wood chips to mostly ferro-alloy industries worth Nu. 37 million. We assume an additional institutional demand equal to 10% of total household demand, which amounts to 83,958 m^3 or a value of Nu. 43 million if valued at average firewood prices. The total firewood supply by commercial forestry thus amounts to 308,546 m^3. The NRDCL reported to have supplied only 4,478 truckloads of firewood equivalent to 35,824 m^3 (NRDCL, 2013) as well as the 23,406 m^3 of wood chips. Thus the remainder of 249,316 m^3 is estimated to be supplied by contractors only.

In Table B.12 the output of both NRDCL and contractors for timber, wood chips and firewood is presented. Wood chips are a component of the firewood commodity within the SAM and they are predominantly consumed by mineral industries in the South.

Table B.12. Supply of timber and firewood from commercial forestry

Supplier	Commodity	Supply in m^3	Supply in million Nu.	In % of total output
NRDCL	Timber	69,689	333	64.5%
NRDCL	Wood Chips	23,406	37	7.1%
NRDCL	Firewood	35,824	18	3.6%
Contractors	Firewood	249,316	128	24.8%
Total Timber		**69,689**	**333**	**64.5%**
Total Firewood (including woodchips)		**308,546**	**183**	**35.5%**
Total Output		**378,235**	**516**	**100.0%**

Source: Own compilation based on prior 2012 macro-SAM.

B.3.2 Mining, Manufacturing and Energy Commodities

Data sources to compile the supply matrix for the mining, manufacturing and energy outputs are largely based on aggregate gross output for activities reported in the national accounts 2012; the 2007 SUT (ADB & NSB, personal communication, November 2013); the medium and large industry (MLI) 2012 dataset (MoEA, 2015c) and information from various corporate annual reports provided by MoEA. Except for cottage and small industries such as textile manufacturing, industries in Bhutan are structured relatively simple, because they are dominated by few and large companies. Information contained in corporate annual reports is used to estimate total output for a large part of activities. In a few cases in which data from national accounts or corporate annual reports is insufficient, the respective sector's share in total output as reported in the 2007 is multiplied by the 2012 total output as reported by national account data. This approach of course implies that the sector's share in output in 2007 has not changed in relative terms over the years. The output value and the corresponding data sources of the mining, manufacturing and energy commodities is presented in Table B.13.

Table B.13. Output value of mining, manufacturing and energy commodities

Commodity	Output (in Million Nu.)	Data Source	Comment
Mining			
Coal	516	Corporate annual reports 2012;	Sale of coal as reported by the Eastern Bhutan Coal Corporation in their annual report.
Other minerals	2,159	National accounts 2012	Subtracting coal output of total mining gross output of mining sector as reported by NSB, 2014.
Manufacturing			
Clothing and wearing apparel	1,656	National Accounts 2012; SUT 2007	Estimated using the SUT 2007 output share (assuming constant shares over time) and total gross output of manufacturing from national accounts 2012
Basic chemicals	2,082	MLI 2013	
Rubber and plastics	1,182	MLI 2013	
Glass and glass products	3,117	National Accounts 2015;	Output by major sectors as provided by National Account department, NSB
Basic iron and steel	7,331	Corporate annual reports 2012	Total revenue of the major six ferro-alloy industries in Bhutan
Casted iron and steel, and non-ferrous metals	4,817	Corporate annual reports 2012	Total revenue of the major seven steel industries in Bhutan
Fabricated metal products, except machinery and equipment;	1,116	National Accounts 2012; SUT 2007	Estimated using the SUT 2007 output share (assuming constant shares over time) and total gross output of manufacturing from national accounts 2012
Electrical machinery and apparatus	1,075	National Accounts 2012; SUT 2007	Estimated using the SUT 2007 output share (assuming constant shares over time) and total gross output of manufacturing from national accounts 2012
Manufactured goods n.e.c.	257	Corporate annual reports 2012; CSI 2013; MLI 2012	
Energy and utilities			
Wholesale electricity	10,291	DGPC, 2013; BPC, 2013	Value of total electricity exports and electricity sold domestically by DGPC to BPC in 2012
Low-voltage (LV) electricity	563	Corporate annual reports 2012	Electricity sales to domestic LV customers valued at real average power tariffs (BPC, 2013)
High- and medium voltage electricity	2,533	Corporate annual reports 2012	Electricity sales to HV and MV customers valued at real average power tariffs (BPC, 2013)
Transmission of electricity	548	Corporate annual reports 2012	Revenue from export wheeling charges (BPC, 2013)
Water	39	National Accounts 2012; SUT 2007	Estimated using the SUT 2007 output share (assuming constant shares over time) and total gross output of manufacturing from national accounts 2012

Source: Own compilation.
Note: Output value in Million Nu.

B.3.3 Service Commodities

Output of services is largely dependent on gross output data reported by national accounts and shares of output derived from the 2007 SUT. We disaggregate the gross-output of the aggregated sector *transport, storage and communication* into the following four commodities: (1) land transport services; (2) air transport services; (3) Supporting and auxiliary transport services; and (4) Post and telecommunication services. As Bhutan has a very small air-transportation sector, output for this sector adjusted using the annual financial data of the state-owned airline Drukair (DHI, 2013, 2014). Output of land transport services and supporting and auxiliary transport services are estimated by multiplying the gross value added data from the national accounts 2012 with gross value added/output ratios derived from the 2007 SUT. Finally, the output of the post and telecommunication services is imputed as a residual. Output values of public administration, education and health are estimated using the output shares derived from the 2007 SUT in total gross output value as reported in the national account statistics 2012. Table B.14 presents the output value and the underlying data sources of all services.

Table B.14. Output value of services

Commodity	Output In Million Nu.	Data Source	Comment
Construction services	44,855	NA 2012	
Wholesale and retail trade services	9,421	NA 2012; SUT 2007	Estimated using the SUT 2007 output share (assuming constant shares over time) and total gross output of wholesale and retail trade from NA 2012
Lodging, food and beverages	2,413	NA 2012	
Land transport services	11,708	NA 2012; SUT 2007	Gross value added (GVA) for sector is reported in NA 2012; the sector's output is estimated using the SUT's gross value added/output ratio times the total GVA reported for 2012
Air transport services	2,761	Corporate annual reports 2012;	Revenue of Druk Air Corporation in 2012 (reported in DHI 2012 and 2012 annual reports);
Supporting and auxiliary transport services	1,373	NA 2012; SUT 2007	Gross value added (GVA) as in NA 2012; the sector's output is estimated using the SUT's gross value added/output ratio times the total GVA reported for 2012
Post and telecommunication services	3,142	NA 2012;	Residual of total gross output of transport, storage & communication as reported in NA 2012 minus output of transportation services (land + air) as well as supporting and auxiliary transport services.
Financial intermediation services	4,097	NA 2012; SUT 2007	
Insurance and pension services	1,922	NA 2012; SUT 2007	
Real estate services	2,068	NA 2012;	
Business services	382	NA 2012; SUT 2007	Estimated using the SUT 2007 output share of total gross output of wholesale and retail trade from NA 2012
Public administration services	11,954	NA 2012; SUT 2007	Estimated using the SUT 2007 output share of total gross output of community, social & personal services from NA 2012
Education services	3,483	NA 2012; SUT 2007	
Health and social services	2,793	NA 2012; SUT 2007	
Other services	651	NA 2012	

Source: Own compilation.
Note: Output value in Million Nu.

B.3.4 Import and Export of Goods

In 2012, Bhutan imported goods worth about Nu. 52,366 Million of which 20.7% and 79.3% originated from countries other than India (COTI) and India, respectively (MoF, 2013b). On the contrary, goods worth about Nu. 28,261 Million are exported, of which only 6.3% came from COTI and the remainder of 93.7% is exported to India. These numbers show, that India is Bhutan's most important trade partner by far. This is not only due to the geographic proximity, but also to the free-trade agreement between both countries. Bhutan has preferential trade agreements with many other countries, for instance Bangladesh. Also, Bhutan levies import duties on most imports from countries other than India. Data of exports and imports of goods conducted in 2012 is taken from the UN COMTRADE (UN, 2015a) database. This data is reported in HS 2007 classification code, which by using a HS 2007 – CPC v2 correspondence table can be mapped to the SAM's account structure. Imports and exports of goods as well as the import intensity and export share is presented in Table B.15 below. Import intensity is measured as the share of imports valued at purchaser prices of total domestic demand. The export share is the share of exports of total domestic output measured in purchaser prices. Please note that goods that are differentiated by HPHC are aggregated in the Table B.15 below.

Table B.15. Import and exports of goods in 2012

Commodity	Imports				Exports			
	COTI	India	Total	Import intensity	COTI	India	Total	Export share
Paddy	-	-	-	0.0%	-	-	-	0.0%
Maize	0	27	27	4.7%	-	-	-	0.0%
Other Cereals and Oilseeds	7	202	209	41.0%	0	1	1	0.3%
Pulse	2	198	200	55.9%	-	9	9	5.2%
Crop Residues	-	-	-	0.0%	-	-	-	0.0%
Low-value vegetables	0	102	102	22.2%	1	21	22	4.8%
High-value vegetables	0	71	72	11.6%	6	2	8	1.0%
Potato	-	61	61	10.0%	0	309	310	32.2%
Beverages and spices	2	81	84	22.8%	259	204	463	50.5%
Other Nuts and Fruits	120	56	175	39.0%	6	32	38	8.2%
Apple	-	4	4	2.0%	19	31	49	15.7%

Commodity	Imports				Exports			
	COTI	India	Total	Import intensity	COTI	India	Total	Export share
Citrus fruits	0	8	8	1.5%	420	33	453	31.6%
Milk	-	-	-	0.0%	-	-	-	0.0%
Beef	3	434	437	88.4%	-	-	-	0.0%
Live Animals	8	14	22	11.5%	-	0	0	0.0%
Chicken Meat	0	73	74	34.2%	-	-	-	0.0%
Eggs	-	-	-	0.0%	-	-	-	0.0%
Other animal meat and products	6	302	308	67.2%	0	-	0	0.0%
Fish	6	241	247	100.0%	-	-	-	No domestic prod.
Milled rice	0	1,254	1,254	46.4%	6	0	6	0.4%
Milled other cereals	1	365	366	78.8%	1	29	30	20.1%
Dairy Products	1	369	370	18.1%	0	-	0	0.0%
Processed milk	3	577	579	100.0%	-	-	-	No domestic prod.
Processed rice	-	-	-	0.0%	-	-	-	0.0%
Processed maize	-	-	-	0.0%	-	-	-	0.0%
Other grain mill products	90	1,210	1,301	82.3%	22	194	215	36.9%
Vegetable oils	18	907	925	95.6%	-	8	8	13.2%
Animal feed	0	50	50	11.3%	-	8	8	1.8%
Processed fruits and vegetables	70	164	233	38.4%	1	72	73	13.0%
Alcoholic beverages and tobacco	57	341	398	27.4%	-	80	80	3.9%
Ara	-	-	-	0.0%	-	-	-	0.0%
Non-alcoholic beverages	6	0	6	2.1%	15	106	121	20.2%
Wood Chips / Firewood	-	3	3	0.8%	-	1	1	0.1%
Logs	0	125	125	10.8%	0	0	0	0.0%
Non-wood forest products	0	7	7	12.5%	102	2	104	64.0%
Products of wood, cork, etc.	14	235	249	33.0%	1	250	250	29.3%
Paper products	39	707	747	68.4%	0	20	20	4.8%
Furniture	56	153	209	36.8%	1	14	15	3.0%
Coal and natural gas	16	788	804	72.7%	55	170	225	38.4%

Commodity	Imports				Exports			
	COTI	India	Total	Import intensity	COTI	India	Total	Export share
Other Minerals	120	596	716	49.0%	454	1,298	1,752	66.3%
Clothing and wearing apparel; leather and leather products	198	765	963	39.3%	0	26	27	1.3%
Other transportabe goods	57	92	150	100.0%	-	0	0	No domestic prod.
Basic chemicals	532	1,743	2,276	92.6%	3	1,658	1,662	74.1%
Fertilizer	-	60	60	100.0%	-	-	-	No domestic prod.
Pesticides	12	35	47	100.0%	-	-	-	No domestic prod.
Charcoal	0	895	895	100.0%	0	-	0	No domestic prod.
Rubber and plastics products	173	1,487	1,660	68.5%	0	316	316	24.6%
Glass and glass products and other non-metallic products n.e.c.	200	2,068	2,268	57.7%	0	1,556	1,556	44.8%
Basic iron and steel	-	80	80	6.1%	418	6,410	6,827	80.6%
Basic metal	6	3,696	3,702	100.0%	-	-	-	No domestic prod.
Casted iron and steel, and non-ferrous metals	2,117	3,291	5,409	83.3%	1	4,310	4,311	77.1%
Fabricated metal products, except machinery and equipment	774	2,165	2,939	72.9%	3	0	3	0.2%
Electrical machinery and apparatus	851	1,733	2,584	71.4%	-	-	-	0.0%
Office, accounting and computing machinery	317	173	490	100.0%	-	-	-	No domestic prod.
Radio, television and communication equipment	577	231	808	100.0%	-	-	-	No domestic prod.
Medical appliances, precision and optical instruments	170	223	393	100.0%	-	-	-	No domestic prod.
Transport equipment	687	1,734	2,422	100.0%	-	-	-	No domestic prod.
General and special purpose machinery	3,508	2,425	5,933	100.0%	-	-	-	No domestic prod.
Manufactured goods n.e.c.	18	750	768	77.7%	-	43	43	14.9%
Coke	-	941	941	100.0%	-	-	-	No domestic prod.
Fuel oil, natural gas, fuels n.e.c.	-	645	645	100.0%	-	-	-	No domestic prod.
Gasoline and kerosene	-	1,831	1,831	100.0%	-	-	-	No domestic prod.
Diesel	-	4,719	4,719	100.0%	-	-	-	No domestic prod.

Commodity	Imports				Exports			
	COTI	India	Total	Import intensity	COTI	India	Total	Export share
Wholesale electricity	-	13	13	1.1%	-	9,132	9,132	88.7%
LV electricity	-	-	-	0.0%	-	-	-	0.0%
HV electricity	-	-	-	0.0%	-	-	-	0.0%
Electricity transmission services	-	-	-	0.0%	-	-	-	0.0%
Water	-	-	-	0.0%	-	-	-	0.0%
TOTAL	**10,845**	**41,522**	**52,366**		**1,791**	**26,348**	**28,261**	

Source: Own compilation based on prior 2012 micro-SAM and UN, 2015a.
Note: In Million Nu.

B.3.5 Import and Export of Services

In 2012, Bhutan imported services worth Nu. 10,153 Million, of which 45% and 55% are imported from India and COTI, respectively (RMA, 2014b, 2017). In general, data on trade of services is of significant lower quality than trade of goods. The UN ServiceTrade database (UN, 2015b) compiles trade data on services using the Extended Balance of Payments Services (EBOPS) classification code (UN, 2010). Some of the reported EBOPS categories can be mapped to CPC v2 codes, which also is presented in Appendix D. However, the categories of business and personal travel cannot entirely be mapped to CPC. We argue that travellers consume a wide range of goods and services, most commonly comprising accommodation, food, beverages and transport as identified by the Manual on Statistics of International Trade in Services 2010 (UN, 2012). Purchases of gifts, souvenirs and other articles are also included, while valuables such as jewellery, consumer durable goods and any other items exceeding custom thresholds are not included (UN, 2012).

Table B.16 presents the import of services in 2012 according to SAM accounts. The data on import of personal travel services are reported in more detail, by differentiating them between health-related, education-related and other travel services. For the import of personal travel services, the health-related share is thus directly mapped to the health services account and the education-related share to the education service account. The remaining shares of personal and business travel services, for which no further details are provided, are distributed among the SAM commodity accounts in the following way: 15% to supporting and auxiliary transport services, 30% to the lodging, food and beverage serving account; 20% to the land transportation service account; 15% to the air transportation service account and 20% to the public administration services account. These assumptions do not consider expenditures on gifts, souvenirs and other articles which of course does not reflect reality but prevents us from making further assumptions of what kind of goods are actually purchased. Further, it is reasonable to assume that travel agency fees and margins, accommodation, food, transportation and public administration (for visa fees, permits, etc.) represent the largest expenditure items for travellers. The export of travel services, whether personal or business, is not differentiated in more detail. Both, exported business and personal travel services are distributed in the same way as proposed for the import of these service, described above.

Table B.16. Import of services in 2012 according to SAM accounts

	Import in million Nu.	**Import intensity**	**Export in million Nu.**	**Export share**
Construction services	2,806	5.9%	-	0.0%
Wholesale and retail trade services	172	1.9%	-	0.0%
Lodging; food and beverage serving services	462	29.1%	1391	53.3%
Land transport services	2325	17.7%	927	7.9%
Air transport services	454	64.6%	2512	91.0%
Supporting and auxiliary transport services	154	18.5%	695	50.6%
Post and telecommunication services	138	4.3%	49	1.6%
Financial intermediation services	18	0.4%	5	0.1%
Insurance and pension services	219	11.4%	214	11.1%
Real estate & dwellings	0	0.0%	0	0.0%
Business Services	786	63.6%	0	0.0%
Public administration services	308	2.7%	927	7.8%
Education services	1716	33.0%	-	0.0%
Health and social services	228	7.5%	-	0.0%
Other services, n.e.c	335	18.1%	116	7.1%
TOTAL Trade in 2012- WORLD	**10,121**		**6,836**	

Source: Own compilation based on UN, 2015b.
Note: In Million Nu.

B.4 Use-Matrix

The use-matrix contains the information on each activities' expenditure for intermediate inputs, recording the transactions between activity (column) and commodity (row) accounts. These transactions are either measured in purchaser prices if the purchased intermediate input originates from outside the production system or measured in basic prices (i.e. farmgate prices) if the origin lies within the production system. The latter is for example the case for retained seed, bullock draught power and manure for crop production and crop residues and fodder crops for livestock production. The following chapter describes the compilation of the use matrix in detail.

B.4.1 Agricultural Activities

There are sixteen agricultural production activities that can be differentiated into crop and livestock producing activities (Table B.17).

Table B.17. Classification of agricultural activities

Activity Name	Output:	ISIC (3.1. rev) activity
Paddy production	Paddy, crop residues	0111
Maize production	Maize, crop residues	0111
Other cereals and oilseeds prod.	Other cereals and oilseeds, crop residues	0111
Pulses prod.	Pulses, crop residues	0111
Low-value vegetables prod.	Low-value vegetables	0112
High-value vegetables	High-value vegetables	0112
Potato prod.	Potato	0112
Beverages and spices	Beverage and spices	0112, 0113
Other nuts and fruits	Other nuts and fruits	0113
Apple	Apples	0113
Citrus	Citrus fruits	0113
Cattle husbandry	Milk, beef, manure, bullock draught power	0140
Poultry husbandry	Chicken meat, eggs, manure	0140
Other animal husbandry	Other animal meat, manure	0140

The use matrix of agricultural activities is presented in Figure B.3. Crop producing activities are similar in their requirement for intermediate inputs such as seeds, manure, bullock draught power, pesticides and fertilizers. Some inputs for crop and livestock activities are directly available from the farm (i.e. "on farm inputs"). For crops, this includes seed, manure and draught animal services as highlighted with an "X" in quadrant I. For livestock this includes crop residues and fodder crops as recorded in quadrant II. Quadrant III records the expenditure of cropping activities on marketed inputs such as diesel (used for agricultural machinery), chemical fertilizer and pesticides. Quadrant IV comprises the marketed inputs of livestock activities such as compound animal feed and salt. The methods, data sources and necessary assumptions to derive the column shares for the agricultural activities' intermediate inputs are presented in the subsequent sections.

Figure B.3. Schematic representation of use matrix of agricultural activities

#	Commodity	Paddy prod.	..	Potato prod.	..	Bev. and spices prod.	..	Apple prod	..	Cattle	Poultry	Other animals
1	Paddy	X										
2	Maize											
3	Other cereals and oilseeds											
4	Pulses											
5	Crop residues									X	X	X
6	Crop fodder									X	X	X
7	Low-value vegetables											
8	High-value vegetables											
9	Potato			X								
10	Beverages and spices					X						
11	Other nuts and fruits											
12	Apple											
13	Citrus			Quadrant I						Quadrant		
14	Raw Milk											
15	Beef											
16	Manure	X		X		X		X				
17	Live animals											
18	Bullock draught power	X		X		X		X				
..												
..												
33	Animal feed									X	X	X
..	..											
49	Chemical fertilizer	X		Quadrant		X		X			Quadrant	
50	Pesticides	X		X		X		X				
..	..											
68	Diesel	X		X		X		X				

Source: Own compilation.

B.4.1.1 Intermediate Inputs of Crop Producing Activities

Seeds

The information on the quantity of output retained as seed is provided by experts from the MoAF (K. Dukpa, 2015). As with any other intermediate consumption, the information on seed consumption is recorded as the value of the quantity of output retained as seed (quantity multiplied times price). As the majority farmers use their own seed, we use the farmgate price of their respective output. This is a simplifying assumption, as in case of farmers using improved seeds the intermediate input of seeds is undervalued. Yet, there is not sufficient data available to determine the share of various seed inputs in crop producing activities. There are no cell entries for retained seed in case of permanent crops, as the plantation of a new orchard is not a current but a capital expenditure.

Manure

The question on manure application within the RNR census 2009 is on the farm level and not crop specific. Hence, it is not possible to directly assess the quantity of manure applied per crop. Instead, it is assumed that each respondent applies manure to all cultivated crops proportionally to the area harvested. This assumption, of course, simplifies reality – as farmers use more manure for some crops than others. Still using this approach allows estimating how much tons of manure each farmer applies per crop. Table B.18 presents the distribution of farm yard manure input across crops.

Table B.18. Distribution of farm yard manure application across crops

Crop	Paddy	Maize	Other cereals	Pulses	Low-value veg.	High-value veg	Potato	Spices	Other fruits and nuts	Apple	Citrus fruits
% share	18.7%	27.2%	10.9%	3.4%	9.0%	3.9%	9.6%	7.7%	5.2%	1.2%	3.1%

Source: 2012 Bhutan prior-micro SAM.

Diesel Consumption

Farmers using agricultural machinery such as powertillers and tractors also consume diesel. Based on expert opinions, we assume that powertillers and tractor are used 55 days per year (15% capacity factor) and that during one day the consume 5 and 15 litres of diesel per day, respectively (K. Thinley, 2015). The RNR 2009 census has surveyed the ownership of agricultural machinery. Aggregate ownership is scaled up by 40%, adjusting for the increased investments in agricultural machinery between 2008 and 2012. Diesel consumption is computed by multiplying aggregate ownership of machinery times capacity factor, fuel consumption and the price of diesel to arrive at annual estimated consumption of diesel. The price of diesel in 2012 is Nu. 43 per litre (NSB, 2015) and total consumption of diesel within agriculture thus amounts to Nu. 34 Million.

Chemical Fertilizer

There is no domestic fertilizer production in Bhutan and in 2012, chemical fertilizers worth Nu. 60 Million are imported (UN, 2015a). The agricultural sample survey 2012, asks farmers on what area of crop cultivated they use chemical fertilizer, however it does not include a question on fertilizing intensity, i.e. how much kg of chemical fertilizer a farmer uses per crop. According to the 2012 data, the average farmer applies chemical fertilizer on 0.28 hectares corresponding to 13,043 hectares (or 13% of total cultivated area) on which chemical fertilizer is applied. The RNR census 2009 includes detailed questions on what type and quantity of chemical fertilizer farmers use, differentiating between Super-Single-Phosphate, Suphala NPK (15-15-15), Urea and other chemical fertilizers. On average, farmers use 81 kg of chemical fertilizers and in total 4,381 tons are applied in 2008 (MoAF, 2009). However, as it is the case with manure, the census data does not allow to assess how the applied fertilizer is distributed among the cultivated crops.

We assume that farmers distribute fertilizer proportionately to their cultivated area. Consequently, an average fertilizing rate of the quantity of chemical fertilizer used in kg per crop and hectare is derived from the 2008 census data. As cash crop farmers cultivating potatoes have high application rates and the largest part of their land under potato cultivation we still obtain realistic fertilizing rates per crop, despite our simplifying assumption. The fertilizing rate is then multiplied with the fertilized area per crop derived from the ASS 2012 dataset to compute the distribution of chemical fertilizer across crops as shown in Table B.19 below. Most chemical fertilizer is thus used in potato cultivation, followed by paddy and maize. This is in line with field observations made in Bhutan.

Table B.19. Estimated distribution of applied chemical fertilizer across crops

Crop	Paddy	Maize	Other cereals	Pulses	Low-value veg.	High-value veg	Potato	Spices	Other fruits and nuts	Apple	Citrus fruits
% share	19.7%	22.1%	2.0%	0.5%	3.1%	2.2%	44.9%	0.0%	0.0%	4.9%	0.6%

Source: 2012 Bhutan prior-micro SAM.

Plant Protection chemicals

Similar to chemical fertilizer, there are no industries in Bhutan producing plant protection chemicals (PPCs). In 2012, Bhutan imported Nu. 47 Million of PPCs (UN, 2015a). The same method used to estimate the distribution of fertilizer across crops is applied, since the data sources available for the disaggregation are exactly the same. The RNR 2009 census included questions on the quantity of insecticides, fungicides, herbicides and other plant protection chemicals applied. According to the census data, the average farmer applied 11 kg and in total 608 tons of PPCs are applied. The ASS 2012 recorded the area per crop on which plant protection chemicals are applied. Most of plant protection chemicals are applied in paddy, potato and apple cultivation (Table B.20).

Table B.20. Estimated distribution of applied plant protection chemicals across crops

Crop	Paddy	Maize	Other cereals	Pulses	Low-value veg.	High-value veg	Potato	Spices	Other fruits and nuts	Apple	Citrus fruits
% share	47.5%	7.3%	1.4%	0.5%	3.6%	3.4%	22.8%	0.0%	0.1%	12.0%	1.5%

Source: 2012 Bhutan prior-micro SAM.

Bullock Draught Power

As with the ownership of agricultural machinery, the ownership of bullocks per farmer is only known from the RNR 2009 census. Further, the RNR 2009 census also includes a question on what ploughing technology farmers are using for their land preparation. Farmers could either respond that they use a) manual labour, b) bullocks, c) bullocks and other machineries or d) only other machineries (i.e. mostly powertillers). Total cost of bullock draught power is already estimated in the supply matrix chapter at Nu. 214 Million. The cost of bullock draught power is only distributed among those farmers that reported to rely on bullocks. Further, the cost of bullock draught power is distributed to each crop cultivated by the farmers in proportion of the farmer's total cultivated area. The distribution of the cost of bullock draught power is not linked to the ownership of bullocks, because bullock pairs are also hired and leased out between farmers.

B.4.1.2 Intermediate Inputs of Livestock Activities

Intermediate inputs of livestock activities consist mostly of fodder, feed, minerals (salt), medicine (vaccinations) and live animals (e.g. calves, chicks, piglets).[51] In the following, the expenditure for each of the intermediate input items are presented. Privately owned or leased pasture land on which livestock graze is not considered as an intermediate input but as a

[51] The 2012 SAM for Bhutan does not include information on the intermediate consumption of veterinary medicine, as no data is available.

production factor (pasture land). Feed, whether from crops or compound feed, as well as crop residues are treated as commodities and are thus intermediate inputs.

Salt

There is no information available how much salt farmers are feeding to their cattle in Bhutan. For the cattle activity, it is assumed that for each LU of cattle 30g of salt are fed daily, which equals a total salt consumption of 1,000 tons of salt. The price of salt in 2012 is equal to 10 Nu./kg (NSB, 2015), which results into a total consumption of salt worth Nu. 10 Million.

Feed and Fodder Sources

There is no information on the consumption of feed and fodder sources by each of the specific livestock activities in Bhutan. In 2015, J. Gurung et al. (2015) have assessed the various feed and fodder sources for Bhutan's overall livestock sector. They estimate total annual dry matter (DM) requirement at 760,225 tons, using an average DM requirement per livestock unit of 2.74 kg/day as determined by Samdup et al. (2010). Excluding forests, they estimate that pasture (improved and native), crop residues, fodder crops, plantations and trees cover 85.2% of total DM requirement. In Figure B.4 the individual share of each fodder source is presented.

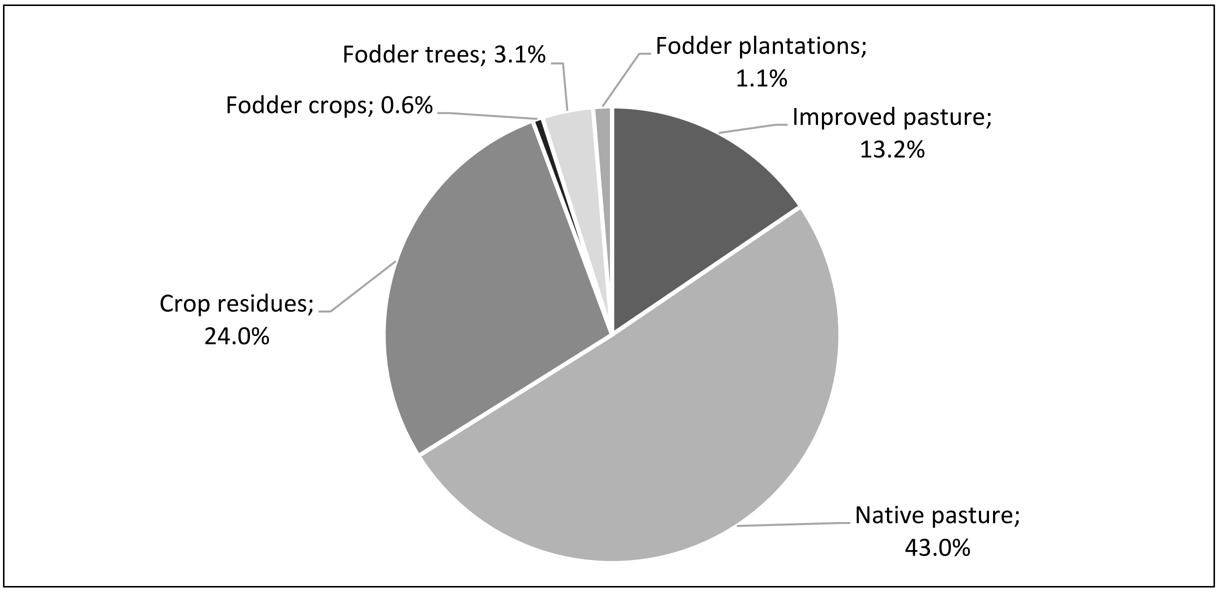


Figure B.4. Share of individual fodder resources

Source: J. Gurung et al. (2015).

Fodder Crops

The share of fodder crops, as assessed by J. Gurung et al. (2015) is very low (0.6%), corresponding to 4,718 tons. Analysing data from the ASS 2012 survey a total quantity of 12,174 tons of was crops fed to animals. Farmers reported to have fed any crop, except cardamom, to animals. Yet, for the SAM only low-value vegetables (mostly radish and turnips), maize, other cereals, other fruit and nuts and potato are considered as fodder-crops as they made up 97.5% of total quantity of crops fed to animals. The method and data sources used by J. Gurung et al. (2015) to estimate the quantity of fodder crops is not well documented, thus we prefer to use the estimate based on the ASS 2012 survey data. The implicit price of fodder-crops is estimated using farm-gate prices, yielding a weighted-average price of 16.3 Nu./kg.

Forest Land

The above composition of feed and fodder resources does not include fodder from forests. A large share of cattle grazes in forest land, predominantly local cattle breeds because they are more resistant towards parasites and diseases, Forest land is, by law, entirely owned by the government and according to W. Roder, Wangdi, Gyamtsho, and Dorji (2001), forests contribute between 20% and 24% of total dry matter requirement of Bhutan's livestock. There are legal grazing rights to be obtained for some forest areas, yet grazing in forests by livestock, especially cattle, is not limited to those areas (Walter Roder et al., 2002). The cost of DM provided by forest land is estimated to be zero, as farmers do not pay for grazing rights in the forest. It is assumed that 175,000 tons of DM are available from forest land. This translates to a contribution of about 22% to total DM requirement and is thus within the range reported by Roder *et al*. Based on total forest cover in Bhutan the assumed DM supply of forest land corresponds to an average extraction of about 60 kg of DM per hectare of forest land, which can be considered a realistic level.

Compound Feed

The country's only industrial-scale feed mill, Karma Feeds, produced 17,515 tons of compound feed in 2012 (Karma Feeds, 2015a), of which 72.6% is layer or broiler feed, 20.5% cattle feed and the remainder (6.9%) produced for other animals, mainly pigs. Karma Feeds is assumed to have a market share of 90% and total production is thus estimated to equal 19,462 tons.

Of total production, 1.6% are exported to India. The majority of exports, 83%, consisted of broiler feed. In 2012, 1,404 tons of compound feed are imported (UN, 2015a). Details on the composition of feed imports i.e. share of different type of feed is unknown. However, given the large share of broiler feed among exports, it is assumed that imported feed only consist of cattle and pig feed, with a similar ratio (75% to 25%) between both types as represented in domestic feed production. The purchaser price is estimated to be 23.38 Nu./kg after adjusting the base price for trade and transport margins.

Distribution of Fodder and Feed across Livestock Activities

Feed requirement per livestock type is calculated by multiplying the number of LUs per type of livestock times the daily DM requirement of 2.74 kg/day (Samdup et al., 2010). Table B.21 presents the total feed requirement per livestock type. The livestock population statistics and LU conversion ratios are used to arrive at the headcount in LU per livestock types well as the final quantity of DM requirement. The quantity of compound feed is deducted from the total DM requirement to arrive at the DM gap requirement to be met by feed and fodder resources.

Table B.21. Dry-matter (in tons) requirement per livestock unit and type

Livestock Type	Livestock population in 2012	LU conversion ratio[52]	Head-count in LU	Total DM req'ment	From compound feed	Gap in DM req'ment	% of total DM req'ment
Improved - milk	18,070	1.0	18,070	49,512	5,477.44	44,035	11.1%
Improved - adult dry female	11,515	1.0	11,515	31,551	-	31,551	0.0%
Improved - adult male	10,766	1.0	10,766	29,499	66.73	29,432	0.2%
Improved - young female	24,434	0.5	11,969	32,796	-	32,796	0.0%
Improved - young male	7,369	0.2	1,474	4,038	-	4,038	0.0%
Local - milk	53,476	1.0	53,476	146,524	720.00	145,804	0.5%
Local - adult dry female	45,531	1.0	45,531	124,755	-	124,755	0.0%
Local - adult male	83,330	1.0	83,330	228,324	489.38	227,835	0.2%
Local - young female	64,489	0.5	32,697	89,589	-	89,589	0.0%
Local - young male	23,954	0.2	4,791	13,127	-	13,127	0.0%
Total Cattle	**342,934**		**273,619**	**749,715**	**6,754**	**742,961**	**0.9%**
Poultry	**549,733**	**0.01**	**5,497**	**15,063**	**12,488**	**2,575**	**82.9%**
Goats	39,019	0.1	3,902	10,691	-	10,691	0.0%
Pigs	19,191	0.23	4,478	12,269	1,318	10,951	10.7%
Sheep	10,783	0.1	1,078	2,995	-	2,995	0.0%
Total other animals	**68,993**		**9,458**	**25,955**	**1,318**	**24,637**	**5.1%**
Total livestock	**961,660**		**288,574**	**790,733**	**20,382**	**771,458**	**2.6%**

Source: Own compilation.

There are only indications available in order to estimate the share of feed and fodder consumed by each livestock type. It is known that improved cattle consume more fodder crops and improved pasture than local cattle breeds. Also, male cattle are grazing in forest land to a larger extent than female cattle. The share of dry matter obtained from fodder plantation and trees is very low (below 5%) (J. Gurung et al., 2015) and is thus not considered within the SAM and the cost is assumed to be zero. The percentage of DM requirement met by a specific source of feed and fodder is estimated by the authors' best possible judgment. The resulting distribution among livestock types is presented in Table B.22.

[52] The LU conversion ratio for young female cattle is a weighted average of calves and heifers with LU conversion ratios of 0.2 and 0.7.

Table B.22. Distribution of tons of DM from feed and fodder across livestock types

Livestock Type	Compound feed	Fodder crops	Improved pasture	Native pasture	Crop residues	Forests	TOTAL
Improved - milk	5,300	1,376	22,019	9,175	8,945	2,520	**49,335**
Improved - adult dry female	-	631	14,198	6,310	6,152	4,260	**31,551**
Improved - adult male	67	147	10,030	5,900	6,490	6,865	**29,499**
Improved - young female	-	656	15,842	6,559	6,695	3,044	**32,796**
Improved - young male	-	40	1,535	808	588	1,068	**4,039**
Local - milk	720	3,645	17,497	71,444	29,161	24,057	**146,524**
Local - adult dry female	-	1,248	12,475	58,635	28,694	23,704	**124,756**
Local - adult male	489	1,140	18,113	77,506	47,871	83,205	**228,324**
Local - young female	-	1,165	8,959	42,107	20,785	16,574	**89,590**
Local - young male	-	66	1,050	5,907	2,494	3,611	**13,128**
Total Cattle	**6,576**	**10,114**	**121,718**	**284,351**	**157,875**	**168,908**	**749,542**
Poultry	**12,488**	**1068**	**-**	**-**	**1,107**	**313**	**14,976**
Goats		107	-	6,842	2,118	1,624	**10,691**
Pigs	1,318	552	-	-	7,178	3,220	**12,268**
Sheep		30	-	1,891	611	463	**2,995**
Total Other Animals	**1,318**	**689**	**0**	**8,733**	**9,907**	**5,307**	
Total Livestock	**20,382**	**11,871**	**121,718**	**293,084**	**168,889**	**174,528**	**790,472**
In % of total DM requirement	2.58%	1.50%	15.40%	37.08%	21.37%	22.08%	
Availability	21,915	11,871	121,975	326,895	169,000	175,000	**826,656**
Price	23.38*	16.30	0.67	0.20	1.00	-	
Value (in Million Nu.)	**476**	**193**	**82**	**59**	**169**	**-**	**987**
% of total value	42.40%	17.60%	12.30%	5.90%	17.10%	1.50%	

*Price for compound feed is purchasing price including trade and transport margins
Source: Own compilation.

Conservative assumptions are made about the price for one ton DM from improved pasture, native pasture and crop residues. As In total, the value of feed and fodder consumed by the livestock sector equals Nu. 987 Million, which is 42% of total livestock output. In Table B.23, the expenditure for intermediate inputs of each livestock activity is presented both in terms of absolute value as well as percentage of total output (column shares).

Table B.23. Intermediate inputs of livestock activities

Type of feed	Crop Fodder	Crop res.	Compound Feed	Minerals (Salt)	Improved pasture land	Native pasture land	Total output
Cattle	165	158	154	10	82	57	**1,615**
Poultry	17	1	292	0			**560**
Other animals	11	10	31	0		2	**199**

Source: Own compilation.
Note: Inputs in Million Nu.

Live Animals

Livestock purchased represents a capital expenditure as the expected average economic lifetime per animal is well above a year.

B.4.2 Food Manufacturing Activities

The 2012 SAM for Bhutan includes the following food-manufacturing or food-processing activities (Table B.24):

Table B.24. Food manufacturing activities

Activity Name	Output	ISIC (3.1. rev) activity
Paddy milling	Milled rice	1531
Other cereals milling	Milled Other cereals	1531
Dairy production	Dairy products	1512;1520
On-farm cereal processing	Processed rice; Processed maize	1531;1532;
Ara production	Ara; animal feed	1551
Grain mill and other food production	Other grain mill products; Vegetable oils	1541-1549
Animal feed production	Animal feed	1533
Fruits and vegetables processing, beverage and tobacco production	Processed fruits and vegetables; Non-alcoholic beverages; Alc. Beverages and tobacco	1513-1514; 1551-1554

The production activities paddy milling, other cereals milling, dairy products, on-farm cereal processing, and ara production are performed by farm households in Bhutan. Consequently, for these activities it is assumed that they consume intermediate inputs as HPHC goods, for example *chmilk* (home produced and home consumed milk) in case of dairy production.

There are also minor shares of these products produced by large scale industries. For example, ara is also produced by the only liquor distillery in Bhutan, the Army Welfare Project (AWP). In such a case, this commercial large-scale produced ara is aggregated under the account for alcoholic beverages, which is also subject to sales tax and excise duty. The remaining activities (Grain-mill and other food production; animal feed production; fruits and vegetable processing, beverage and tobacco production) are dominated by small- to large-scale industries with a negligible share produced by households. The intermediate consumption of these activities is estimated using available information from corporate annual reports and the SUT 2007 use-matrix.

Cereals and Paddy Milling

The largest share of cereal grains of paddy and other cereals are milled to rice or flour. In case of paddy, 95.6% or 52,137 tons of paddy are milled to rice at a recovery rate of 60% (Rinzin, 2015), while only 1.7 % or 2.7% of paddy production is either processed to ara or retained as seed. 65.5% or 6,925 tons of other cereals production are milled to flour with an weighted average recovery rate of 60.8% (K. Dukpa, 2015), while the remaining 34.5% is are either used for ara, seed or animal feed. We approximate intermediate-input use of the paddy and other cereal milling activity by using information on the cost of milling paddy provided by a rice production cost study conducted in 2012 (Rinzin, 2015).

Dairy Production

The use-matrix derived from the SUT 2007 does not contain any details on the intermediate consumption of dairy products. According to the livestock census (LC) 2012, 23,442 tons of milk, representing 79% of total milk production, are processed into dairy products. The value of processed milk at farm-gate prices (30.68 Nu) are Nu. 719 Million. In total, 4,251 tons of dairy products are produced (MoAF, 2013d), which corresponds to 5.56 litres of milk for every kg of dairy produce. This ratio is in the neighbourhood of other conversion rates. (Joshi & Gurung) (2009) reported that farmers processed 4.33 kg of milk into one kg of dairy, which consisted of 1/3 of butter and 2/3 of cheese. Besides milk, farmers mainly require firewood for dairy production. Other inputs are assumed to be negligible.

On-farm cereal processing

The two main cereals, rice and maize, are further processed into processed rice (referred to *Zaw,* a kind of puffed rice) or processed maize (referred to *Tengma*, similar to cornflakes). As farmers process their cereals on their farm, most intermediate inputs are HPHC commodities. The intermediate inputs are presented in Table B.25.

Table B.25. Intermediate inputs for cereal processing activities

	Quantity (in tons)	Price (Nu./kg)	Value in Million Nu.	% of output	Source
Inputs					
Maize (chmaize)	3,550	14.77	52	14.4%	based on assumed loss rate of 50%
Milled rice (chbhtrice)	3,971	51.37	204	55.9%	based on assumed loss rate of 10%
Milk (chmilk)	-	-	4	1.1%	Assumption based on SUT 2007 column shares for grain mill products
Dairy products (chdairy)	-	-	11	3.0%	
Vegetable oils (cmvegoil)	-	-	4	1.0%	
Firewood (cfirewood)	-	-	14	3.8%	
Electricity (clowelec)	-	-	2	0.6%	
Rubber and plastic product (crubber)	-	-	3	0.8%	
Land transport (clandtrans)	-	-	6	1.7%	
Total intermediate inputs		300		82.2%	
Output					
Processed maize	1,775	69.11	123	33.6%	
Processed rice	3,574	67.77	242	66.3%	
TOTAL Output			**365**		

Source: Own compilation.

Grain Mill and Other Food Production

The production activity of grain mill and other food products includes vegetables oils and any other grain mill products (e.g. bread) besides the previously described ones. Intermediate-input use is largely derived from the 2007 SUT (ADB, 2012). The major intermediate inputs are other agricultural goods (mostly oilseeds) and milled other cereals (mostly wheat flour). The input-output structure of grain mill production activity is summarized in Table B.26 below:

Table B.26. Intermediate inputs used for grain mill production

	Value in Million Nu.	% of output	Source
Inputs			
Other Agriculture	23	2.7%	Assumed 50% share of vegetable oils output value
Milled other cereals	165	30.1%	Assumed 33% share of grain mill product output value
Other grain mill products	23	4.2%	Assumption based on SUT 2007 column shares for grain mill products
Milk	6	1.1%	
Dairy products	4	0.7%	
Vegetable oils	6	1.0%	
Firewood	3	0.6%	
Electricity	27	4.9%	
Rubber and plastic products	4	0.8%	
Land transport	40	7.2%	
Financial intermediation services	14	1.6%	
Business service	13	2.3%	
Total intermediate inputs	316	57.6%	
Output			
Grain Mill products	496	90.4%	
Vegetable Oils	53	9.6%	
TOTAL Output	**548**		

Source: Own compilation.

Ara Production

Ara is a traditional alcoholic beverage made from mostly maize and other cereals with an alcoholic content of about 20%. Annual consumption of ara according to the BLSS 2012 survey can be estimated at 11,839 tons[53], of which 81.9% is consumed in Eastern Bhutan. Yet, actual ara consumption is probably significantly higher as respondents tend to underreport alcohol consumption for instance due to social stigma. In expert and field interviews it is both stated that farmers in Eastern Bhutan use more than half of their maize harvest to produce ara, which would be equivalent to at least 27% of total maize production in Bhutan or 16,552 tons.

Producing ara with an estimated alcohol by volume level of 20%, a medium yeast alcohol tolerance of 72% (medium attenution), an efficiency of 50% and a wort-batch ratio of 3:2, results in 1.27 kg of (flaked) corn required to brew one litre of ara.[54] Assuming that 50% of Maize in the East is used for ara production, 16,552 tons of maize would thus produce 13,033 tons of ara. If the relative consumption ratios between regions hold, i.e. underreporting between regions does not differ, total ara production can be estimated at 15,913 tons. The ara price as reported in the BLSS 2012 is 34.67 NU/litre which then corresponds into a total value of output equals Nu. 552 Million.

[53] For simplicity reasons one litre of Ara was set equal to one kg.
[54] Quantity of grains required for brewing are calculated with the tools available on www.brewersfriend.com.

A total of 20,210 tons of cereal input would be required, of which 80% or 16,552 tons is from maize and for the remainder it would be assumed that paddy and other cereals make up 3% (606 tons) and 17% (3,436 tons). Other inputs needed are water, yeast (part of grain mill products commodity) and firewood (C. Dukpa, 2015). Rural households are not charged water prices, thus it is not feasible to include it as an intermediate input. Two biscuits of yeast costing Nu. 10 and one backload of firewood (43 kg) to produce 10 litres of ara are required. Table B.27 gives an overview over the input-output structure of ara production.

Table B.27. Intermediate goods for Ara production

	Quantity (in tons)	Price (Nu./kg)	Value in Million Nu	% of output
Inputs				
Maize	16,168	14.77	238.8	43.3%
Other Cereals	3,436	22.70	78.0	14.1%
Paddy	606	26.10	15.8	2.9%
Yeast (Grain Milled Products)	1,591	30.00	47.7	8.7%
Firewood	68,426	0.55	37.5	6.8%
Total intermediate inputs			418	75.7%
Total Output	**15,913**	**34.67**	**552**	

Source: Own compilation.

Fruits and Vegetables Processing and Beverage Production Activity

The fruits and vegetable processing and beverage production activity produces three main outputs, of which alcoholic beverages makes up the largest share (66.8%), followed with almost equal shares of non-alcoholic beverages (16.8%) and processed fruits and vegetables (16.5%). The intermediate-inputs consumed are derived from the SUT 2007 SAM; from annual report information available for some of the sector's enterprises and from the 2007/08 SAM for India in order to approximate missing data.

The linkage between the fruits and vegetables processing and beverage production activity and the overall agricultural sector is fairly limited. Input of fruits and vegetables make up only 3.9% of the total output value of processed fruits and vegetables (Nu. 449 Million) and accordingly only 0.64% of the sector's overall output. In case of alcoholic beverage production (Nu. 1,821 Million), processed barley and other cereals are imported from India and there is no actual linkage between this sector and Bhutanese farmers. Output of the non-alcoholic beverages sector (total output of Nu. 457 Million) mainly consists of soft drinks produced by the two largest beverage companies in Bhutan, Tashi Beverages (Coca-Cola license) (63.9% of output) and Drangchu beverages (Pepsi license) (36.1% of output). This sector is also not known to demand significant quantities of raw materials from Bhutanese farmers.

Animal Feed Production

As previously mentioned, animal feed production in Bhutan is dominated by a single enterprise, Karma Feeds, which is situated in Phuentsholing - close to the border with India. Most of input-output data is obtained through personal communication with Karma Feeds (2015b). Further expenditure shares are estimated using the SUT 2007 shares. The largest share of raw material for animal feed production consists of grains (maize) and processed grains (grain mill products such as soya bean meal or distiller residues). According to Karma Feeds, about 5% of raw materials can be sourced from Bhutan currently while the remainder is imported from India.

B.4.3 Forestry-based Activities

Community Forestry

Intermediate inputs consumed for forestry activities by rural households are largely negligible. Some households utilize power chains and consume fuel, however detailed information is not available. Thus, we do not consider any intermediate inputs of forestry activities conducted by rural households. This is also supported by the fact that intermediate consumption of the overall forestry sector as presented in the 2007 SUT only makes up 3.1% of total output.

Commercial Forestry

The general forestry sector is included as a separate activity within the 2007 SUT. According to the column shares of the use-matrix based on the SUT 2007, intermediate consumption represents 3.1% of total sector output. For a commercial forestry operation, this share seems to be too low and also is not consistent with the share of intermediate inputs in total revenue reported by the NRDCL. We therefore use data from NRDCL 2012 annual report to derive intermediate input use for the commercial forestry sector. Doing so yields an intermediate input share of 22.6% of total output.

Manufacturing of Wood, Paper and Furniture Products

The intermediate-input consumption of manufacturing of wood, paper and furniture products is estimated based on the SUT 2007. The SUT 2007 has disaggregated this sector into three distinct activities: Manufacture of wood and of products of wood and cork; manufacture of paper and paper product; and manufacture of furniture. The sector's output (Nu. 1,564 Million) consists largely of 49.3% products of wood and cork, followed by furniture (26.4%) and paper products (24.2%). 65.0%% of total output are intermediate inputs, of which products of wood and cork (23.9%), textiles (8.4%), basic chemicals (7.5%), land transportation (7.9%) and logs (6%) are the items with the largest share.

B.4.4 Mining, Manufacturing and Energy Activities

Mining and Quarrying Activity

The mining and quarrying sector had an output of Nu. 2,674 Million of which 19.3% represents coal and 80.7% other minerals. The intermediate-input consumption of the mining and quarrying activity is entirely estimated based on the SUT 2007 and intermediate-inputs make up 32.6% of total output.

Manufacturing Activities

The SUT 2007 is used to estimate intermediate input consumption for the textile, rubber and plastics and fabricated metal manufacturing activity as well as the manufacturing n.e.c. sector. Intermediate input consumption for the remaining sectors listed in Table B.28, of which many are energy-intensive industries, is estimated primarily based on corporate annual report information and – in case of missing data – on SUT 2007 information.

Table B.28. Manufacturing activities

Activity Name	Output	ISIC (3.1. rev) activity
Textile manufacturing	Clothing and wearing	1711-1920
Basic chemicals manufacturing	Basic Chemicals	2411-2430
Rubber and plastics manufacturing	Rubber and plastics	2511-2520
Glass product manufacturing	Glass and glass products	2610-2699
Ferro-alloy manufacturing	Ferro-alloys	2710-2720
Casted iron, steel and non-ferrous manufacturing	Casted iron and steel, and non-ferrous metals	2731-2732
Fabricated metal manufacturing	Fabricated metal products, except machinery and equipment; Electrical machinery and apparatus	2811-3330
Manufacturing n.e.c.	Manufactured goods n.e.c.	3410;3599;3691;3720

Source: Own compilation.

Textile Manufacturing

The textile manufacturing activity has a total output of Nu. 1,656 Million (MLI 2013), of which 46.2% is comprised of intermediate inputs. Most important inputs are textile products (output share of 26.0%), followed by products of wood and cork (7.9%) and basic chemicals (7.2%).

Basic Chemicals Manufacturing

The basic chemical manufacturing sector in Bhutan is dominated by the Bhutan Calcium Carbide Limited company (BCCL), which produced output worth Nu. 1,133 Million Nu in 2012 or 60.4% of total sector output (Nu. 1,875 Million) (BCCL, 2014; MoEA, 2015c). Intermediate inputs made up 85.3% of total output. Production of basic chemicals in Bhutan is largely based on minerals and further requires various forms of energy. The commodity other minerals is the most important raw materials comprising 21.2% of output. Reducing agents are further important inputs with high input shares, including charcoal (11.6%), coke (6.2%) and coal (1.4%). Manufacturing of basic chemicals in Bhutan is also energy intensive, requiring high shares of electricity (17.2%) and fuel oil (4.4%).

Rubber and Plastics Manufacturing

The rubber and plastics manufacturing activity has a total output of Nu. 1,001 Million (MoEA, 2015c), of which 72.2% is comprised of intermediate inputs. Most important inputs are rubber and plastics products (output share of 32.6%), followed by insurance and pension services (9.6%) and business services (6.6%).

Glass and Glass Products Manufacturing

The glass and glass products manufacturing activity had a total output of Nu. 3,117 Million (MoEA, 2015c) and is dominated by cement producers. In 2012, the largest cement producer (Penden Cement Authority) produced an output worth of Nu. 1,982 Million, equal to 66% of total sector output (PCAL, 2014). Intermediate inputs make up 64.6% of total output. Other minerals represent the largest intermediate-input with an output-share of 17.2%, followed by coal (12.2%) and manufactured goods n.e.c. (6.0%). Electricity makes up only 3.6% of intermediate inputs.

Basic Iron and Steel Manufacturing

The basic metal sector as represented in the SUT 2007 is split into two activities for the 2012 SAM for Bhutan; in basic iron and steel manufacturing and casted iron and steel; and non-ferrous metals manufacturing. Basic iron and steel manufacturing is the largest manufacturing activity, producing an output of Nu. 7,331 Million in 2012. The sector consists mainly of ferro-silicon (i.e. a ferro-alloy) producers. Almost all ferro-silicon produced in Bhutan is exported and utilized in the upstream steel sector in India and other major steel producing countries. The largest producer is Bhutan Ferro Alloy Limited (BFAL), a public-listed company with an annual output of Nu. 2,084 Million in 2012 (BFAL, 2014). Detailed information on intermediate-inputs is taken from annual reports from BFAL and other ferro-alloy producers. 75.5% of output are intermediate-inputs and energy and reducing agents' inputs are the most important ones. Electricity makes up 21.3% of output and other carbon sources make up a combined 29.8% split up into charcoal (10.5%), coke (10.1%) and coal (9.2%). Further raw materials are other minerals (mostly quartzite) and basic iron and steel (sponge iron and iron scrap) comprising 5.3% and 7.4% of output and being mostly imported from India.

Casted Iron, Steel and Non-ferrous Manufacturing

The casted iron, steel and non-ferrous manufacturing activity produces steel bars and rods. Most companies are mini-steel mills using electric arc furnaces. Total output in 2012 is estimated at Nu. 4,792 Million and 80.3% of output is made up by intermediate inputs. Information of intermediate inputs is derived from various annual reports. Output shares are determined using the simple mean across companies. By far, imported basic iron and steel (sponge iron and iron scrap) make up the largest share of intermediate-inputs representing 65.5% of output value, followed by electricity with an output share of 4.7%.

Fabricated Metal Manufacturing

Information and data on intermediate-inputs by the fabricated metal manufacturing activity is solely based on the SUT 2007. nad There is no information available from annual reports or other sources. Total output is estimated to be Nu. 2,192 Million and 66.5% of output is made up by intermediate-inputs. Casted iron and steel, and non-ferrous metallic products have the largest output share of 32.6%, followed by land transport services with 20.5%.

Manufacturing n.e.c. (not elsewhere considered)

The manufacturing n.e.c. activity's intermediate-input structure is also estimated based on the SUT 2007. Intermediate-inputs make up 66.6%, of which other minerals contribute 23.1% and manufactured goods n.e.c. 6.6%.

B.4.4.1 Energy and Utilities

Within the SUT 2007, energy and utilities are represented by two activities: Electricity, gas, steam and hot water supply (electricity sector) as well as collection, purification and distribution of water (water sector). In the SAM, the electricity sector is, as previously mentioned, disaggregated into two separate activities: electricity generation and electricity transmission and distribution.

Electricity Generation

Hydropower generation is a very capital-intensive activity. Intermediate-inputs are derived from expenditure schedules as published within Druk Green Power Corporations' annual reports (2013, 2014) and comprised only 10.2% (Nu. 1,092 Million) of total sector output, of which wheeling charges (Nu. 548 Million) represented the largest share with an output share of 5.1%.

Electricity Transmission and Distribution

Intermediate-inputs for electricity transmission and distribution are derived from expenditure schedules reported within the annual report of Bhutan's national public utility, Bhutan Power Corporation (2013). The sector required Nu. 1,472 Million of intermediate-inputs representing 40.4% of total output. Naturally, purchase of electricity is the most important input with an output-share of 32.1%.

Collection, Purification and Distribution of Water (Water Sector)

The intermediate input structure of the water sector is estimated using the SUT 2007 shares. This activity is the smallest activity within the 2012 Bhutan SAM with an output of only Nu. 39 Million. Intermediate inputs make up 30% of output. Casted iron and steel; and non-ferrous metals is the largest intermediate-input with an output share of 13.5%. Electricity has the second largest share with 10.5%.

B.4.5 Service Activities

The SUT 2007 use matrix is used as the major data source to derive the intermediate input structure of service activities. However, for some service activities the SUT use-matrix reported an unrealistic intermediate-input structure, because activities have very low intermediate-input shares or only few or even single intermediate-input items. These activities are denoted with an asterisk in Table B.29 and are adjusted by considering input shares from the 2007/08 India SAM (Pradhan, Saluja, & Sharma, 2013).

Table B.29. Output of service activities and their most relevant inputs by share

Activity Name	Total output	Intermediate-input share (%)	Comment – most relevant inputs by share
Construction	44,855	52.3%	Glass and glass products (8.5%); Fabricated metal products (9.3%); Other minerals (5.6%)
Wholesale and retail trade, repair of motor vehicles and other goods	9,421	21.8%	Supporting and auxiliary transport services (4.6%); Financial services (3.4%); Telecommunication services (7.5%)
Hotels and restaurants	2,413	42.7%	Adjustments as in Table B.31; Beverages and spices (6.0%); imported rice (4.4%), domestic rice (3.9%)
Land transportation	11,708	49.3%	
Air transport	2,761	61.9%	
Supporting and auxiliary transport activities; activities of travel agencies	1,373	40.0%	
Post and telecommunications	3,142	18.9%	
Financial intermediation	4,097	10.3%	
Insurance and pension funding; Activities auxiliary to financial intermediation	1,922	2.3%	
Real estate activities*	2,071	5.0%	SUT 2007 reports only one intermediate input (Forestry an logging products)
Business services n.e.c.*	187	49.3%	SUT 2007 reports only one intermediate input (Telecommunication services)
Public administration	11,954	44.4%	
Education	3,483	37.6%	
Health and social work	2,793	40.5%	
Other services	651	40.3%	

Source: Own compilation.
Note: Output in Million Nu.

B.4.5.1 Adjustment of Use of Agricultural Commodities and Fossil Fuels

Another adjustment necessary for the use matrix of service activities concerns the SUT 2007's aggregation level of commodities that does not directly match the commodity structure of the 2012 Bhutan SAM. This particularly concerns agricultural commodities and petroleum fuels. Agricultural commodities are represented at a high aggregation level within the SUT 2007, for example all cereals are included in one commodity account while the 2012 Bhutan SAM differentiates between five cereal commodities. Assumptions had to be made for the hotel and restaurant sector for which agricultural commodities are important intermediate inputs. Table B.30 shows how the SUT 2007 input shares are disaggregated according to the 2012 Bhutan SAM structure for the hotel and restaurant activity.

Table B.30. Adjustment of agricultural intermediate inputs of hotel and restaurant activity

SUT 2007		2012 Bhutan SAM		
Intermediate input	**% output share**	**Intermediate input**	**Assumed distribution share %**	**% output share**
Cereals	10.99%	Maize	5%	0.6%
		Pulse	10%	1.1%
		Bhutanese Rice	35%	3.9%
		Milled other cereals	10%	1.1%
		Imported Rice	40%	4.4%
Vegetables	4.94%	High-value vegetables	50%	2.5%
		Low-value vegetables	20%	1.0%
		Potato	30%	1.5%
Other products of agriculture	7.5%	Other cereals and oilseeds	20%	1.5%
		Beverages and spices	80%	6.0%
Fruits and nuts	0.14%	Apple	40%	0.1%
		Citrus	40%	0.1%
		Other Nuts and Fruits	20%	0.0%
Live animals and other animal products	6.1%	Milk	40%	2.5%
		Eggs	60%	3.7%
Meat, fish, fruit, vegetables, oils and fats and dairy products	2.6%	Beef	15%	0.4%
		Chicken meat	25%	0.6%
		Other meat	10%	0.3%
		Processed fruits and vegetables	15%	0.4%
		Dairy products	25%	0.6%
		Vegetable oils	10%	0.3%
Beverages and Tobacco	1.8%	Non-alcoholic beverages	50%	0.9%
		Alcoholic beverages and tobacco	40%	0.7%
		Ara	10%	0.2%

Source: Own compilation.

Fuels are not explicitly recorded as a commodity within the SUT 2007, but aggregated under the *manufacturing n.e.c.* commodity. This commodity account included all fossil fuels such as coke, diesel, gasoline, kerosene, fuel oil and any other fuels. The 2012 Bhutan SAM disaggregates this commodity into five fuel accounts: 1) Coke, 2) Fuel oil and natural gas, 3) Gasoline and kerosene, 4) Diesel, and 5) Fuels not elsewhere considered. Assumptions are necessary in order to disaggregate the intermediate-input consumption from the SUT 2007 to the 2012 Bhutan SAM structure. Table B.31 shows the relative distribution of *manufacturing n.e.c.* as an intermediate-input across service activities and the assumed shares of the disaggregated fuel commodities.

Table B.31. Disaggregation of fossil fuel commodities across activities

	SUT 2007 Intermediate consumption of fossil fuels		Assumed distribution among 2012 Bhutan SAM commodities				
	% output shares	Consumption in Million Nu.	Coke	Fuel oil	Gasoline	Diesel	Fuels n.e.c
Construction	8.80%	3,948	5%	4%	3%	66%	22%
Wholesale and retail trade	0.35%	34	0%	5%	30%	65%	0%
Hotels and restaurants	1.11%	27	0%	5%	30%	65%	0%
Land transportation	17.81%	2,086	0%	5%	50%	45%	0%
Air transport	15.07%	416	0%	5%	75%	15%	5%
Supporting and auxiliary transport activities	1.64%	52	0%	5%	30%	65%	0%
Post and telecommunications	1.79%	25	0%	5%	30%	65%	0%
Financial intermediation	0.00%	-	0%	5%	30%	65%	0%
Insurance and pension funding	0.00%	-	0%	5%	30%	65%	0%
Real estate activities	0.00%	-	0%	5%	30%	65%	0%
Business services n.e.c.	0.00%	-	0%	5%	30%	65%	0%
Public administration	0.62%	74	0%	5%	30%	65%	0%
Education	1.05%	37	0%	5%	30%	65%	0%
Health and social work	0.46%	13	0%	5%	30%	65%	0%
Other services	6.05%	39	0%	5%	30%	65%	0%

Source: Own compilation.

B.5 Trade and Transport Margins

The 2012 Bhutan SAM includes two margin accounts, one for transportation margins and another for trade margins. Data on margins is derived from the SUT 2007, which in turn documents that trade margins “were calculated using the trade margin ratios of India” (ADB, 2012), because no trade and transport margin survey exists for Bhutan. The ADB used case studies to adjust trade margin data to the Bhutanese context. Regarding transportation margin data, information from corporate annual reports are used.

For the 2012 Bhutan SAM, some more detailed data on trade and transportation margins are obtained by expert interviews with traders and shop keepers during a field trip to Bhutan in early 2015. Further, since the SUT 2007 included only very aggregate data on agricultural commodities, additional data collection and analysis is required. Farm gate prices are estimated using the ASS 2012 data, while purchaser prices and export prices (in FOB terms) are available from the BLSS 2012 and BTS 2012. The sum of trade and transport margins could be estimated by subtracting mean farm gate prices from mean purchases prices. It needs to be noted, that this is of course only a crude method of estimating margins. Farm gate prices from the ASS 2012 data might be distorted as farmers might not only sell at their farm gate, but also by the roadside or at local markets. In the latter cases, reported farm gate prices would of course include margins for trade and transportation. Also, to further disaggregate margins into trade and transport margins, shares from the SUT 2007 are used. The SUT 2007 reports that 60.6% of total margins is comprised by trade margins, while the remainder (39.4%) accounts for transportation margins. This is certainly not realistic for all commodities. For example, some commodities have higher transportation shares as they are low-value crops with high water content (e.g. potatoes). Due to the lack of better data, this simplified method of estimating margins is used.

Margins are implemented as an expenditure of commodities to margin accounts. The sum of all trade margins is channelled to the wholesale and retail trade service account. The sum of transportation margins is likewise channelled to the land transportation service account. There are certainly transportation margins actually accruing to air transportation services, these are – however – not recorded by the SUT 2007.

B.6 Factor Returns (Value-added Components)

In addition to intermediate-inputs, activities also require factor inputs, have to pay taxes and might receive production subsidies. There are three factor account categories represented in the 2012 Bhutan SAM: labour, capital and land. These factor account categories are disaggregated into factor accounts by characteristics that describe the limited substitutability between them such as e.g. skill (for labour) or agroecological zone (for land).

B.6.1 Data Sources and Principle Approach to Disaggregate Factor Returns

Main data sources utilized to disaggregate factor returns per activity are the 2007 SUT, data from corporate annual reports and the BLSS 2012. The 2007 SUT for Bhutan distinguishes between three value added components: (1) taxes less subsidies on production; (2) compensation of employees; and (3) gross operating surplus. Taxes on production is discussed in the section on tax accounts. Compensation of employees is used as an approximation of labour returns even though it might include non-cash benefits such as subsidized transportation. Own-account workers or unpaid family labour are not part of this first component. These types of labour are often part of unincorporated businesses that earn mixed income. The third component – gross operating surplus – includes earnings before subtraction of interest or depreciation. In case of unincorporated businesses this component includes mixed income and thus also returns to labour. Mixed income requires special consideration and will be addressed in a separate section (OECD, 2001).

Given Bhutan's small size, certain industrial activities within the 2012 SAM consist of only few companies of which again some make up the majority of economic output. For instance, Karma Feeds is Bhutan's main animal feed producer representing an estimated 90% of total sector output. Another example is Bhutan Calcium Carbide Limited (BCCL), which is producing about 70% of total output of the basic chemical production activity. Consequently, if 2012 data from annual reports is available for a considerable share of an activity, then this data is preferred over value added data from the SUT 2007.

Returns to labour, land and capital are further disaggregated into sub-accounts, such as for example returns to skilled or unskilled labour, irrigated, rain-fed or permanent crop land or private or public capital. The data to disaggregate the value added components on the level of sub-accounts is taken from the BLSS 2012, ASS 2012 and information on ownership of companies.

B.6.2 Overview on Factor Accounts

Table B.32 provides an overview on all factor accounts included in the SAM. The detailed description of how factor returns are estimated is explained in the later sections of this chapter.

Table B.32. Return to factor accounts from activity categories

	Factor type	Agriculture and forestry	Manu-facturing	Energy and utilities	Construc-tion	Services	Rest of the World	Total	% share of total factors
Labour	Skilled Bhutanese labour	181	424	288	918	6,953	122	8,886	9.7%
	Semi-skilled Bhutanese labour	151	728	506	1,715	6,588	-	9,688	10.6%
	Low-skilled Bhutanese labour	180	539	285	1,189	5,585	-	7,778	8.5%
	Unskilled Bhutanese labour	75	289	67	210	3,019	-	3,659	4.0%
	Skilled Foreign labour	4	99	14	107	314	-	539	0.6%
	Semi-skilled foreign labour	4	88	6	225	50	-	375	0.4%
	Low-skilled foreign labour	2	250	4	2,897	46	-	3,198	3.5%
	Unskilled foreign labour	7	101	1	1,589	48	-	1,746	1.9%
	Family farm labour	5,031	307	-	-	-	-	5,338	5.9%
	Hired farm labour	320	52	-	-	-	-	372	0.4%
	Total labour	**5,955**	**2,877**	**1,170**	**8,851**	**22,604**	**122**	**41,579**	**45.6%**
Land	AEZ1 irrigated land	77	-	-	-	-	-	77	0.1%
	AEZ2 irrigated Land	123	-	-	-	-	-	123	0.1%
	AEZ3 irrigated Land	81	-	-	-	-	-	81	0.1%
	AEZ1 rain-fed land	146	-	-	-	-	-	146	0.2%
	AEZ rain-fed land	297	-	-	-	-	-	297	0.3%
	AEZ3 rain-fed land	814	-	-	-	-	-	814	0.9%
	AEZ1 permanent cropland	834	-	-	-	-	-	834	0.9%
	AEZ2 permanent cropland	496	-	-	-	-	-	496	0.5%
	AEZ3 permanent cropland	316	-	-	-	-	-	316	0.3%
	Improved pasture land	82	-	-	-	-	-	82	0.1%
	Native pasture land	59	-	-	-	-	-	59	0.1%
	Total land	**3,246**	-	-	-	-	-	**3,246**	**3.6%**
Capital	Powertiller	237	-	-	-	-	-	237	0.3%
	Unincorporated capital	127	-	-	-	-	-	127	0.1%
	Improved female cattle	234	-	-	-	-	-	234	0.3%
	Improved male cattle	25	-	-	-	-	-	25	0.0%
	Local female cattle	290	-	-	-	-	-	290	0.3%
	Local male cattle	172	-	-	-	-	-	172	0.2%
	Poultry	48	-	-	-	-	-	48	0.1%
	Other animals	76	-	-	-	-	-	76	0.1%
	Private owned incorporated capital	1,170	4,332	0	12,283	12,388	777	30,950	33.9%
	Public owned incorporated capital	142	290	10,253	-	3,528	-	14,213	15.6%
	Total capital	**2,521**	**4,621**	**10,253**	**12,283**	**15,916**	**777**	**46,371**	**50.8%**
Total	**Total Factors**	**11,722**	**7,498**	**11,423**	**21,134**	**38,520**	**900**	**91,196**	**100.0%**
	% of total factor	12.9%	8.2%	12.5%	23.2%	42.2%	1.0%	100.0%	

Source: Own compilation based on prior 2012 micro-SAM.

B.6.3 Treatment of Mixed Income

Mixed income consists of returns to labour, land and capital and concerns primarily agricultural activities and other sectors such as manufacturing of textiles, wholesale and retail-trade as well as other services. Mixed income is earned by unincorporated enterprises run by own-account workers and supported by unpaid family labour. As in such cases there is often no bookkeeping or accounting standards to comply with, disaggregating mixed income according to returns to labour, land and capital is challenging. In case of cropping activities, the labour requirement measured in person-days per hectare is obtained to estimate total labour input. Knowing the share of all production factor inputs except for land, this approach allows to estimate the share of cropland as the residual. In case of livestock activities, the share of pasture land and livestock is known, such that the share of labour is the residual.

The capital share in mixed income from manufacturing of textiles, wholesale and retail-trade and other services is assumed to be negligible. The textile industry in Bhutan, for instance, is dominated by cottage and small-scale industries, which are characterized by simple technologies and absence of large and capital-intensive machinery. Mixed income from these sectors, not including agricultural activities, is thus distributed among the labour accounts as it is done for labour return from all remaining sectors characterized by incorporated enterprises.

B.6.4 Factor Returns in Agricultural Activities

The return to all factors (value-added) of agricultural activities is computed as a residual of total output value minus total value of intermediate inputs. As previously mentioned, farmers earn mixed income without explicit distinction between the three factor categories labour, capital and land. The following two sections present how the shares of each factor category are estimated for cropping and livestock activities. In case of cropping activities, the following order applies: First, the return to agricultural capital is estimated; second, the return to labour and finally, the return to land is computed as a residual. For livestock activities, first the return to agricultural capital in form of livestock is estimated, then the return to pasture land and finally the return to labour is determined as a residual.

B.6.4.1 Factor Returns of Cropping Activities

Return to Agricultural Capital in Form of Machinery

Using data from the RNR census 2009, it is possible to estimate the return to agricultural capital. Agricultural capital is included in two different accounts: (1) Powertiller and tractors and (2) Unincorporated capital. The Agricultural Machinery Center (AMC) has published information on the acquisition cost of agricultural machinery. Table B.33 lists the machinery items included in the 2009 census and the cost as reported by (AMC, 2014). Some items are subsidized and in such cases the selling price is adjusted accordingly. Annualized cost of machinery is computed assuming a 10% discount rate and 10 year average economic lifetime.

Table B.33. Cost of agricultural machinery

Machinery item	Subsidy	Annualized cost	Capital account
Tractor	31.3%	164,065	Powertiller and tractors
Powertiller	50.0%	70,949	
Power Thresher		3,564	Unincorporated capital
Diesel Engine for Thresher		5,257	
Rice Mill Set		1,546	
Oil Mill Set		7,690	
Power Reaper		3,564	
Maize Sheller		2,143	
Paddy Transplanter		1,204	
Bullock Drawn Plow (Improved)		278	
Rotary Paddy Weeder		1,204	
Power Sprayer		2,000	
P.P. Equipment		20,000	
Water Pump	70.0%	41,065	
Power Chain Saw		10,000	
Hand Operated Winnower		1,000	
Cornflake (tengma) machine		6,043	
Veg.& fruit driers		10,000	
Silo		1,567	

Source: Own compilation based on AMC, 2014; MoAF, 2009.

Annualized cost per type of agricultural capital is allocated among different crop producing activities using the share of area harvested. This implicitly assumes that farmers owning agricultural machinery are using it for each crop proportionally to the share of area harvested.

In case of specialized machinery (e.g. rotary paddy weeder, vegetable and fruit driers, etc.), the cost is only allocated to the crops for which the machinery is exclusively used for. Total return to agricultural capital is scaled up by 40% to reflect the increasing level of investments made in agricultural machinery between 2008 and 2012. In total, returns to powertiller and tractors are estimated to be Nu. 237 Million, while return of other agricultural machinery summarized within the account of unincorporated capital is Nu. 67 Million.

Return to Agricultural Labour and Land in Crop Producing Activities

The return to family farm and hired farm labour per activity is estimated by multiplying the labour requirement measured in person-days per hectare with total area harvested and an estimated average wage. The rationale behind this approach is that agricultural wages are assumed to be independent of the actual productivity of a crop. Farmers that cultivates e.g. a high-value crop such as spices are assumed to either be able to perform all labour themselves or to hire the required labour at the spot market wage, which in return can be considered their shadow wage. This assumption simplifies reality, as it does not account for supervision cost and differences in skills, however, the benefit of this approach is to isolate the crop productivity and thus the return to land.

The labour requirement per hectare and crop has been estimated by Arndt Feuerbacher, Luckmann, Boysen, and Grethe (2017). The estimated average daily wage for an agricultural worker is 210 Nu./person-day. This may seem like a low estimate, as often (adjusted to 2012 levels) spot market wages of up to 350 Nu./person-day are reported. However, one needs to account for seasonal fluctuations and regional differences in wages. Hired-workers are often employed during peak labour seasons like transplanting and harvesting periods and thus wages reported during these periods cannot be used as an average.[55] Furthermore, wages are lower in Eastern and most parts of Southern Bhutan compared to West and Central-Western Bhutan.

There are three different types of cultivated land considered in the 2012 Bhutan SAM: irrigated land, rain-fed land and permanent cropland (orchards). Each land-type is disaggregated according to the three major agroecological zones (AEZ) in Bhutan, which are classified according to specific altitude ranges as listed in Table B.34. Hence, in total there are nine land accounts.

[55] Spot market wages as high as 350 Nu./person-day would also not be consistent with average monthly income of agricultural workers that are reported to range between 4,000 and 6,000 Nu/month.

Table B.34. Simplified classification of AEZs

Altitude range (meters above sea level)	AEZ 1 – Wet and humid subtropical	AEZ 2 – Dry subtropical	AEZ 3 – Temperate / alpine
Min	150	1,200	1,800
Max	1,200	1,800	4,600

Source: Own compilation based on Neuhoff et al., 2014.

The *humid* and *wet subtropical* AEZ is characterized by high rainfall and temperatures and provides suitable growing conditions for tropical fruit trees. The *dry subtropical* AEZ covers the medium altitude areas within Bhutan. Dependent on water availability, some crops such as maize and vegetables can be harvested two to three times a year in the subtropical zones. The climate in the *temperate / alpine* AEZ is cold and this is where the largest share of temperate crops such as apples, potatoes, wheat and barley are cultivated in Bhutan.

Crop land is classified according to these three AEZs based on Gewog level data. Gewogs are the lowest administrative unit within Bhutan and there are 205 gewogs in total. The predominant AEZ per gewog is determined using data on the altitude of gewog centres (C. Dukpa & Namgay, 2014), which serves as proxy for the overall altitude. As shown in Table B.35, using the procedure as described above total cropland is almost evenly distributed among the three AEZs. Most cropland (37%) is located in the wet and humid subtropical AEZ, where also more than half (56.6%) of permanent cropland is located. Most rain-fed land is found in the temperate / alpine AEZ, while most irrigated land is located in the dry subtropical AEZ.

Table B.35. Distribution of cropland (in hectares) across AEZs

	Total land		**Irrigated land**		**Rain-fed land**		**Permanent cropland**	
AEZ 1 – Wet and humid subtropical AEZ	39,726	37.0%	7,759	37.5%	19,772	34.2%	2,593	56.6%
AEZ 2 – Dry subtropical AEZ	33,004	30.7%	7,803	37.7%	17,170	29.7%	1,286	28.1%
AEZ 3 – Temperate / alpine AEZ	34,680	32.3%	5,131	24.8%	20,838	36.1%	701	15.3%
Total	107,410	100.0%	20,693	100.0%	57,781	100.0%	4,580	100.0%

Source: MoAF, 2013a.

The differentiation between the various types of land and the different agro-ecological climates is important to reflect constraints in agricultural production. If crop land is considered one type, it would be theoretically possible to shift rice production in irrigated land to rain-fed land or to shift orange production in subtropical permanent cropland to temperate irrigated land.

Table B.36 presents the estimation of labour and land return across all cropping activities. As mentioned previously, wages of agricultural workers are assumed to be constant across agricultural activities. About 6.4% of all agricultural workers are from landless farm households and are thus defined as hired farm workers. It is assumed that each cropping activity has the same share of hired farm labour, due to a lack of more detailed data.

Table B.36. Estimation of agricultural labour and land returns

Crops	Cultivated area	Labour days	Return to labour	Return to land	Land productivity in AEZ 1	Land productivity in AEZ 2	Land productivity in AEZ 3
	In hectares	Per hectare	In Million Nu.	In Million Nu.	In Million Nu. Per hectare	In Million Nu. Per hectare	In Million Nu. Per hectare
Paddy	16,678	265	927	281	13,677	17,871	19,367
Maize	23,866	145	727	64	2,708	2,297	3,360
Other Cereals and Oilseeds	9,204	102	196	78	5,962	7,381	12,069
Pulse	2,464	144	74	53	22,104	16,577	32,012
Low-value vegetables	5,078	139	148	271	32,812	37,818	75,340
High-value vegetables	2,770	180	105	444	95,133	130,877	213,904
Potato	6,181	207	269	347	12,550	16,876	72,411
Beverages and spices	2,652	145	81	459	192,607	181,627	100,392
Other Nuts and Fruits	2,319	122	59	248	74,406	189,589	232,424
Apple	703	174	26	177	295,549	272,898	252,070
Citrus fruits	3,265	144	99	761	195,164	262,454	204,830

Source: Own compilation based on Arndt Feuerbacher, Luckmann et al., 2017; MoAF, 2013a.

B.6.4.2 Factor Returns of Livestock Activities

Return to Agricultural Capital in Form of Livestock

Livestock itself is a form of capital, as in contrast to intermediate inputs it is not consumed within a single year. Instead it is considered a production factor that can be utilized over more than one period (i.e. year). To obtain the annual return from livestock capital, the asset value of livestock is capitalized using market prices of livestock, their economic lifetime and a discount rate of 10%. Prices and economic lifetime for cattle and poultry are obtained through personal communication with livestock experts from the MoAF for the year 2015 and adjusted for the year 2012. Livestock prices for goats, sheep and pigs (other animals) are obtained from the agricultural census 2009 and adjusted to 2012 price levels. The economic lifetime for other animals is based on the best knowledge of the authors. Table B.37 lists the different livestock capital accounts, their purchasing price, economic lifetime and capitalized annual value.

Table B.37. Livestock capital accounts

	Price (Nu./head)	Economic lifetime	Capitalized annual value (Nu./head)
Female improved cattle	30,000	8	5,623
Male improved cattle	10,000	7	2,054
Female local cattle	15,000	12	2,201
Male local cattle	12,000	10	1,953
Poultry	150	2	86
Goat	2,597	6	596
Sheep	3,060	6	703
Pig	5,862	3	2,357

Source: Own compilation.

Return to Pasture Land

Besides feeding livestock with fodder crops (e.g. maize) and compound feed, which is included within the intermediate inputs (use-matrix section), livestock is either grazing on native pasture, in forests or are fed with improved pasture. Fodder crops and fodder plantation are in total estimated to contribute below 5% of total dry matter (J. Gurung et al., 2015), therefore it is neglected within the following. The forest land in which livestock grazes is virtually all owned by the government. The share in return accruing to forest land is also assumed to be zero, since farmers let their livestock graze there for no cost.

In total, it is estimated that 480,000 hectares are used as pasture land. The majority is native pasture (98%), of which 59% is in private ownership and 26% and 16% is community or government pasture land, respectively (J. Gurung et al., 2015). Improved pasture makes up only 2% of pasture land, or 8,596 hectares, yet it has much higher yields of dry-matter per hectare (13.25 tons/hectare) compared to native pasture (0.75 tons/hectare). It is assumed that one kg dry-matter of improved and native pasture is worth 0.7 Nu./kg and 0.2 Nu./kg, respectively. In total, returns to improved and native pasture are Nu. 82 and Nu. 59 million, respectively.

Return to Labour in Livestock Activities

Return to labour in livestock activities is computed by subtracting return to livestock capital and pasture land from total value added.

B.6.4.3 Prior-estimates of Factor Returns in Agricultural Activities

Table B.38 on the following page presents the column shares of factors across all cropping and livestock activities. The value added share is overall high ranging from 41.9% in poultry husbandry to 99.1% in citrus cultivation. The value added share in poultry and the other livestock activities is lower than in all cropping activities due to the comparably high share of intermediate inputs. Agriculture in Bhutan is known to be labour intensive, which becomes evident by the high labour shares particularly in cereal production. However, as the column shares are calculated on value basis, high relative labour input measured in physical quantity might appear low in cases of high-yielding or high-priced activities such as potatoes and vegetables. Analysing Table B.38, it becomes also clear that capital in form of agricultural machinery has a very low input share in cropping activities, reflecting the low utilization levels of machinery. However, in livestock the capital share is substantial.

B.6.5 Factor Returns in Remaining Activities

The derivation of total value added as well as the respective shares of labour and capital of activities other than agriculture is predominantly done by using relative shares derived from the SUT 2007 or, if available, from corporate annual reports. For activities that are not incorporated (i.e. cottage and small industries), there is no information available from corporate annual reports as they don't have to file any. Furthermore, they are not represented in the SUT 2007. This concerns the production of milled cereals, dairy, ara (home-made alcohol) and goods from community forestry. In such cases, assumptions based on own expertise are made. Table B.39 below lists total output, intermediate inputs, production tax and value added in million Nu. as well as each sector's share of labour and capital.

Table B.38. Column shares of factors in cropping and livestock activities

	Cropping activities											Livestock activities		
	Paddy	Maize	Other cereals and oilseeds	Pulses	Low-value vegetables	High-value vegetables	Potato	Beverages and spices	Other nuts and fruits	Apple	Citrus fruits	Cattle	Poultry	Other animals
Intermediate Inputs	**16.5%**	**16.9%**	**16.0%**	**19.3%**	**11.5%**	**6.5%**	**24.6%**	**8.3%**	**3.7%**	**6.2%**	**1.8%**	**31.8%**	**58.1%**	**27.7%**
Family farm labour	57.1%	69.9%	53.7%	42.2%	28.6%	16.4%	29.7%	12.8%	14.8%	10.4%	10.4%	13.6%	31.0%	30.7%
Hired farm labour	4.0%	4.9%	3.7%	2.9%	2.0%	1.1%	2.1%	0.9%	1.0%	0.7%	0.7%	0.9%	2.2%	2.1%
Total labour	**61.0%**	**74.8%**	**57.4%**	**45.2%**	**30.6%**	**17.6%**	**31.8%**	**13.7%**	**15.9%**	**11.2%**	**11.1%**	**14.5%**	**33.2%**	**32.8%**
AEZ1 irrigated land	5.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
AEZ2 irrigated Land	8.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
AEZ3 irrigated Land	5.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
AEZ1 rain-fed land	0.0%	2.6%	4.9%	8.7%	7.7%	7.6%	0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
AEZ2 rain-fed land	0.0%	2.2%	7.2%	12.5%	13.2%	24.5%	2.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
AEZ3 rain-fed land	0.0%	1.8%	10.7%	11.2%	35.0%	42.4%	37.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
AEZ1 permanent cropland	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	47.2%	34.5%	0.3%	47.6%	0.0%	0.0%	0.0%
AEZ2 permanent cropland	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	22.2%	20.5%	0.7%	32.1%	0.0%	0.0%	0.0%
AEZ3 permanent cropland	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.0%	11.4%	75.9%	5.7%	0.0%	0.0%	0.0%
Improved pasture land	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.1%	0.0%	0.0%
Native pasture land	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.5%	0.0%	0.9%
Total land	**18.5%**	**6.6%**	**22.8%**	**32.4%**	**55.9%**	**74.5%**	**40.9%**	**77.4%**	**66.4%**	**76.9%**	**85.4%**	**8.6%**	**0.0%**	**0.9%**
Powertiller	6.8%	2.2%	2.8%	2.9%	3.1%	1.5%	4.1%	0.5%	2.2%	5.4%	1.9%	0.0%	0.0%	0.0%
Unincorporated capital	0.7%	0.6%	2.3%	1.7%	0.4%	0.7%	0.6%	0.6%	3.0%	3.1%	0.8%	0.0%	0.0%	0.0%
Improved female cattle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	14.6%	0.0%	0.0%
Improved male cattle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.6%	0.0%	0.0%
Local female cattle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	18.1%	0.0%	0.0%
Local male cattle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	10.7%	0.0%	0.0%
Poultry	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.7%	0.0%
Other animals	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	38.6%
Total capital	**7.4%**	**2.8%**	**5.1%**	**4.6%**	**3.5%**	**2.2%**	**4.7%**	**1.1%**	**5.2%**	**8.4%**	**2.6%**	**45.0%**	**8.7%**	**38.6%**
Total value added	**86.9%**	**84.2%**	**85.4%**	**82.2%**	**90.0%**	**94.2%**	**77.4%**	**92.1%**	**87.5%**	**96.5%**	**99.1%**	**68.2%**	**41.9%**	**72.3%**

Source: Own compilation based on prior 2012 micro-SA.

Table B.39. Total output, production tax and value added components

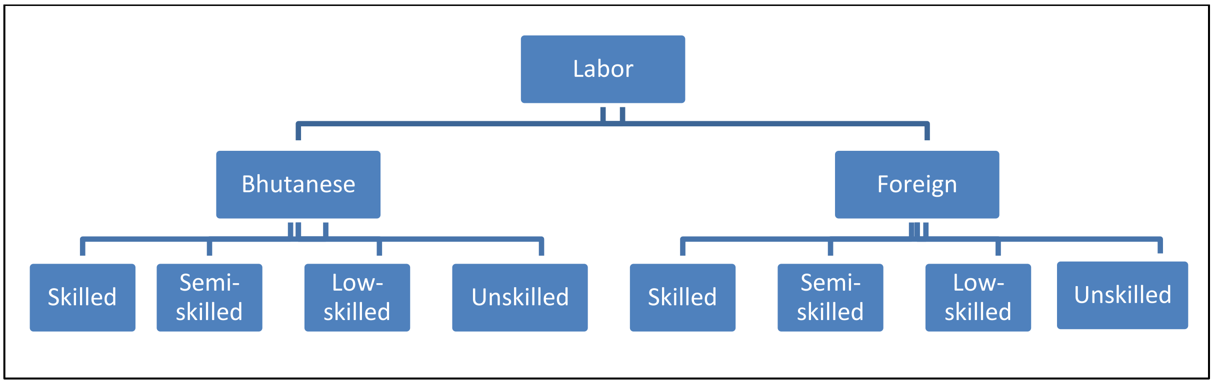
Economic activities	Output	Interm. Inputs	Prod. tax	Value Added	% Labour	% Capital	Data used
Paddy Milling	1,631	1,472	-	159	89.3%	10.7%	
Cereal milling	135	111	-	24	94.1%	5.9%	
Dairy production	1,755	1,070	-	685	95.9%	4.1%	
On-farm cereal processing	365	300	-	65	88.4%	11.6%	
Ara production	552	418	-	134	95.0%	5.0%	Assumed labour-capital shares
Grain mill and other food production	548	305	2	241	30.5%	69.5%	SUT 2007
Animal feed production	401	264	-	137	20.5%	79.5%	SUT 2007
Fruits and vegetables processing;	1,834	1,320	3	511	32.7%	67.3%	Company data
Community forestry	1,188	-	-	1,188	95.0%	5.0%	Assumed labour-capital shares
Commercial forestry	516	117	28	372	36.7%	63.3%	Company data
Manufacturing of wood,	1,564	1,016	7	541	64.4%	35.6%	Company data
Mining and quarrying	2,675	873	299	1,502	31.6%	68.4%	SUT 2007
Textile manufacturing	1,656	765	-	891	100.0%	0.0%	SUT 2007
Basic chemicals manufacturing	2,082	1,776	27	278	36.0%	64.0%	Company data
Rubber and plastics manufacturing	1,182	854	1	327	66.9%	33.1%	Company data
Glass product manufacturing	3,117	2,013	41	1,062	20.8%	79.2%	Company data
Basic iron and steel manufacturing	7,180	5,412	18	1,750	18.1%	81.9%	Company data
Casted iron and non-ferrous manufacturing	4,840	3,887	12	942	24.5%	75.5%	Company data
Fabricated metal manufacturing	2,192	1,457	46	689	59.1%	40.9%	Company data
Manufacturing n.e.c.	257	171	3	82	20.9%	79.1%	Company data
Electricity generation	10,291	1,052	12	9,226	5.9%	94.1%	Company data
Electricity transmission and retailing	3,643	1,473	0	2,170	27.8%	72.2%	Company data
Water	39	12	1	26	100.0%	0.0%	SUT 2007
Construction	44,894	23,476	285	21,134	41.9%	58.1%	SUT 2007
Wholesale and retail trade,	9,612	2,098	9	7,505	89.7%	10.3%	SUT 2007
Hotels and restaurants	2,397	1,017	2	1,378	55.0%	45.0%	SUT 2007
Land transportation	11,707	5,761	117	5,829	25.2%	74.8%	SUT 2007
Air transport	2,761	1,292	21	1,448	19.1%	80.9%	SUT 2007
Supporting and auxiliary transport activities;	1,373	549	5	819	21.1%	78.9%	SUT 2007
Post and telecommunications	3,142	595	2	2,545	14.6%	85.4%	SUT 2007
Financial intermediation	4,097	422	34	3,641	18.9%	81.1%	SUT 2007
Insurance and pension funding	1,922	76	3	1,844	12.1%	87.9%	SUT 2007
Real estate activities	2,071	254	18	1,799	11.0%	89.0%	SUT 2007
Business services n.e.c.	187	45	-	142	100.0%	0.0%	SUT 2007
Public administration	12,009	5,132	124	6,753	100.0%	0.0%	SUT 2007
Education	3,483	1,263	40	2,179	100.0%	0.0%	SUT 2007
Health and social work	2,793	1,080	31	1,682	100.0%	0.0%	SUT 2007
Other services	1,627	656	18	953	100.0%	0.0%	SUT 2007

Note: In million Nu.

B.6.5.1 Labour Accounts

Formally employed labour, i.e. labour outside agriculture, is disaggregated according to socio-economic characteristics as recorded by the BLSS 2012 survey. There is a high share of foreign labour in Bhutan, however labour policy does only allow for employment given certain criteria. Hence, nationality is the first criteria differentiating labour. Further, different levels of education are used as criteria to account for difference in skill levels among workers. The tree below (Figure B.5) shows the disaggregation structure of non-agricultural labour.

Figure B.5. Disaggregation structure of labour accounts



Source: Own compilation.

Data on the nationality of workers is provided by the BLSS 2012 data. However, foreign workers seem to be significantly underreported within the BLSS sampling framework, as already documented in Arndt C. Feuerbacher (2014). Still, the BLSS data is deemed to be adequate to determine the relative distribution of skill-levels among foreign and domestic workers. Adjustments to the absolute level of foreign workers per activity are documented in sub-section B.6.5.2. Table B.40 presents the classification of skill-levels used to disaggregate labour:

Table B.40. Classification of skill-levels

Skill-level	Characteristics
Skilled worker	Workers with tertiary education, i.e. holding an academic degree such as diploma, bachelor, masters or PhD, are classified as skilled workers.
Semi-skilled workers	Workers that have at least passed grade 10 in high-school, but who do not hold an academic degree.
Low-skilled workers	Workers that are literate, i.e. that can read or write in any of the official languages used in Bhutan
Unskilled workers	Illiterate workers

In addition to the above classification, an adjustment is done for workers employed within the occupation group of *Managers* or *Professionals.* These occupations are classified as skill level 3 and 4 by the International Standard Classification of Occupations (ISCO-08) (ILO, 2012). All workers, previously not classified with a skill-level of at least semi-skilled or skilled, are classified skilled if they work in one of these occupation groups. Analogously, workers employed within the occupation group *Technicians and Associate Professionals* or *Clerical Support Workers* are classified at least with a semi-skilled level, if they have not been classified as skilled previously.

The BLSS 2012 survey includes a question block on income sources per household, asking respondents how much income in cash or in kind they have received from salaries, agricultural activities, construction and own business amongst others. Even though, there is empirical evidence that households are likely to underreport their income when interviewed in surveys (Deaton, 1997), this data is nevertheless used to establish relative differences of income per labour account. Table B.41 reports median and mean monthly wage income per wage-earning household.

Table B.41. Income levels per labour account

Labour account	Median	Mean	Standard Deviation	Observations	% ratio of median wage to Bhutanese skilled wage
Bhutanese skilled	15,000	17,778	18,052	1,599	100.0%
Bhutanese semiskilled	10,000	12,856	13,162	2,726	66.7%
Bhutanese low-skilled	6,674	8,822	9,650	2,610	44.5%
Bhutanese unskilled	4,167	6,903	9,614	1,134	27.8%
Foreign skilled	20,000	25,506	22,039	61	133.3%
Foreign semiskilled	10,000	13,235	12,149	61	66.7%
Foreign low-skilled	6,140	6,122	3,557	133	40.9%
Foreign unskilled	6,000	6,865	3,619	27	40.0%
TOTAL	**9,000**	**11,698**	**12,393**	**8,351**	

Source: Own compilation.

Applying a one-way ANOVA Bonferroni mean-difference test shows that the difference of all mean wages of Bhutanese labour accounts is statistically significant at the 1% level. The number of observations of foreign labour is low, due to underrepresentation within the sampling framework. Differences of mean-wages of foreign labour are only statistically significant from each other for foreign skilled. Foreign semi-skilled is also statistically significant when compared to foreign skilled or low-skilled, but not when compared to foreign unskilled. The difference in mean wages of foreign low-skilled and unskilled is not statistically significant. However, especially in the case of unskilled foreign labour, the number of observations is low.

Despite lacking evidence that wages for foreign low-skilled and unskilled are significantly different, we utilize the same disaggregation structure for foreign labour as for Bhutanese labour due to consistency reasons.

B.6.5.2 Foreign Labour-Force

Within the BLSS 2012, foreign households make up only 1,555 households or 1.2% of all households (when statistical weights are not applied, 1.7% of households are foreign). Most foreign households have left family members in their home country, which is reflected by a lower mean household size (3.2) compared to Bhutanese households (4.6). Also, dependency ratios of foreign households (20%) are about one third of Bhutanese households (59%).

According to the labour market information system (LMIS) of Bhutan's Ministry of Labour and Human Resources (MoLHR), 55,142 foreign workers have been registered in Bhutan as per 6th of May, 2013 (MoLHR, 2013b). This number is substantially larger than the number of workers represented in the BLSS 2012 (3,082 workers), which corresponds to 1.3% of employed labour force. The labour force survey reports a similarly low share of foreign workers for the same year of 1.8% (MoLHR, 2013a). Hence, it seems that there is a systematic bias underrepresenting foreign labour in the sampling framework of both household and labour force surveys.

To adequately represent foreign workers in the 2012 Bhutan SAM, we apply the following procedure. We assume that the number of foreign workers (55,142) reported for May, 2013 is an appropriate estimate for 2012. Information of foreign worker's occupation provided by the LMIS is used to determine place of work (economic activity) of the largest share of registered workers (84.6%). For instance, there are 20,361 concrete workers and 9,984 masons registered in 2013. These workers can unequivocally be allocated to the construction sector.

Indirect allocation of occupations is applied when occupations indicate employment within the manufacturing sector, however without precisely specifying in which manufacturing activity. Additional information on employment of foreign workers per industry is used to determine the relative shares of foreign workers in overall employment. This information is obtained from the establishment census 2010 (MoLHR, 2010) and reported data for 2012 on selected medium and large industries provided by the Ministry of Economic Affairs (MoEA, 2015c). Registered occupations of workers employed within services are difficult to allocate to specific service activities, since the classification is too generalistic (e.g. "consultant" or "project manager"). In such cases, the BLSS 2012 relative shares of foreign worker employment within service activities are used for allocation.

Three out of four skill-levels (skilled, semiskilled and low-/unskilled) of foreign workers are determined based on occupations reported in the LMIS, using the ILO's correspondence of skill-levels and major occupation groups of the ISCO-08. The differentiation of low- and unskilled foreign workers is not feasible using the data on occupations. When possible, the relative share of low- and unskilled foreign workers per economic activity derived from the BLSS 2012 data is used. If not possible, the respective share of low- and unskilled domestic workers is used to approximate the distribution among foreign workers. The final estimated absolute number of foreign workers as well as their relative share of total employment per sector is presented in the following section.

B.6.5.3 Summary Data for Labour Accounts

The total labour return in Million Nu., average monthly wage as well as the satellite account data for all labour accounts is presented in Table B.42.

Table B.42. Satellite account data for labour force

Economic activity	Labour return (in Million Nu.)	Total employed	Number of employees per labour account and activity									
			Family farm labour	Hired farm labour	Skilled Bhutanese	Semi-skilled Bhutanese	Low-skilled Bhutanese	Unskilled Bhutanese	Skilled Foreign	Semi-skilled foreign	Low-skilled foreign	Unskilled foreign
Farm activities (Crop + Livestock)	3,191	95,511	89,492	6,018	-	-	-	-	-	-	-	-
Paddy Milling	142	4,248	4,063	184	-	-	-	-	-	-	-	-
Cereal milling	22	672	642	30								
Dairy production	657	19,666	18,837	828	-	-	-	-	-	-	-	-
On-farm cereal processing	58	1,726	1,726						-	-	-	-
Ara production	127	3,815	3,815		-	-	-	-	-	-	-	-
Grain mill and other food production	74	376			29	70	261	16				
Animal feed production	28	166			13	31	115	7	-	-	-	-
Fruits and vegetables processing	167	767			46	111	415	25	9	22	-	139
Community forestry	1,128	33,782	31,817	1,965	-	-	-	-	-	-	-	-
Commercial forestry	137	1,240			243	645	168	74	6	3	-	102
Manufacturing of wood,	348	2,291			429	508	735	463	10	17	47	82
Mining and quarrying	475	2,776			79	474	430	485	50	82	-	1,176
Textile manufacturing	891	13,024	9,210	1,499	22	247	892	1,051	28	26	49	-
Basic chemicals manufacturing	100	468			67	192	134	28	2	21	-	24
Rubber and plastics manufacturing	219	590			78	84	300	63	6	17	10	32
Glass product manufacturing	221	1,218			189	486	281	195	3	6	59	-
Basic iron and steel manufacturing	318	1,644			48	208	173	16	43	82	614	461
Casted iron and non-ferrous manufacturing	230	1,191			35	150	125	12	31	59	445	334
Fabricated metal manufacturing	407	1,930			76	201	39	25	57	100	1,432	-
Manufacturing n.e.c.	17	91			25	11	19	18	2	3	-	13
Electricity generation	540	2,982			342	1,344	1,075	177	12	6	-	26
Electricity transmission and retailing	603	3,266			538	1,377	837	321	47	54	92	-
Water	26	105			-	48	56	-	-	-	-	-

Table B.42. Continued

Economic activity	**Labour return** (in Million Nu.)	**Total employed**	**Number of employees per labour account and activity** Family farm labour	Hired farm labour	Skilled Bhutanese	Semi-skilled Bhutanese	Low-skilled Bhutanese	Unskilled Bhutanese	Skilled Foreign	Semi-skilled foreign	Low-skilled foreign	Unskilled foreign
Construction	8,851	52,302			935	3,166	2,785	521	155	687	24,634	19,419
Wholesale and retail trade,	6,733	17,626			1,761	5,271	5,636	4,854	6	14	67	17
Hotels and restaurants	758	5,636			460	1,875	1,794	1,275	13	18	141	61
Land transportation	1,471	8,486			97	1,159	3,987	1,744	64	130	473	832
Air transport	276	719			230	260	202	17	8	0	-	2
Supporting and auxiliary transport activities;	173	1,768			427	847	463	11	5	3	-	11
Post and telecommunications	372	1,400			310	586	155	34	19	54	-	242
Financial intermediation	687	2,502			1,192	982	257	52	7	2	-	9
Insurance and pension funding	223	738			446	246	45	-	-	-	-	-
Real estate activities	198	844			34	262	381	158	3	1	-	6
Business services n.e.c.	142	595			203	213	109	57	4	2	8	-
Public administration	6,753	28,623			5,102	8,085	10,514	4,921	-	-	-	-
Education	2,179	15,324			9,046	3,077	1,801	692	213	120	373	-
Health and social work	1,682	5,750			1,108	2,494	1,154	133	721	44	-	95
Other services	953	8,673			902	3,451	2,864	1,164	67	43	104	79
TOTAL	**41,577**	**344,529**	**159,603**	**10,525**	**24,514**	**38,161**	**38,200**	**18,610**	**1,592**	**1,616**	**28,547**	**23,162**

Source: Own compilation.

B.6.6 Capital

Rather than pooling all capital return in one account, the 2012 SAM for Bhutan disaggregates capital into three capital account types: private capital, public capital and unincorporated capital.

B.6.6.1 Private Capital

Private capital represents equity shares in incorporated companies owned by private households, whether these shares are privately hold or traded on the Royal Securities Exchange of Bhutan. Returns to private capital are channeled to the private enterprise account and returns to public capital to the public enterprise account, analogously. Details on the enterprise accounts are presented in section 7.4.

B.6.6.2 Public Capital

Public capital is defined as equity shares in incorporated companies either wholly or partially owned by the state. State-owned enterprises (SOE) as well as state controlled enterprises (more than 50% owned by the state) play a significant role in Bhutan. Dividends paid to SOEs are an important source of government budget and do not represent income to private households. The Royal Government of Bhutan (RGoB) either owns a company directly (i.e. direct state holding) or indirectly through its investment company, the Druk Holding and Investment (DHI) enterprise. The most relevant SOEs in Bhutan are listed in Table B.43. For a few enterprises, especially those that are not administered by DHI, no data is available on their annual revenue and their share of sector output. However, these companies are believed to be small and thus negligible as regards their role in paying dividends to the government.

B.6.6.3 Unincorporated Capital

Besides returns to incorporated capital, whether hold by private households or the public, there are returns to unincorporated capital, which is referred to informal capital in the following. Informal capital can be understood as a component of mixed income. It consists of returns to machinery used in crop, livestock and post-harvest activities. The procedure of estimating returns to informal capital used in agricultural activities (powertillers; other machinery; livestock types) is already documented in section B.6.4. Further activities with returns to informal capital are cereal milling; dairy production; cereal processing and Ara production. Returns on informal capital are directly channelled to farm-household accounts.

Table B.43. Overview of State-Owned Enterprises

Abbr.	Company name	Sector	Direct state holding	DHI holding	Revenue in (in million Nu.)
DGPC	Druk Green Power Corporation Ltd.	Electricity generation		100%	11,141
BPC	Bhutan Power Corporation Ltd.	Electricity distribution		100%	4,140
NRDCL	Natural Resources Development Corporation Ltd.	Forestry and mining		100%	485
BTL	Bhutan Telecom Ltd.	Telecommunications		100%	2,209
Drukair	Druk Air Ltd.	Air transportation		100%	2,761
BOBL	Bank of Bhutan Ltd.	Financial services		80%	2,136
BNBL	Bhutan National Bank Ltd.	Financial services		12%	2,175
RICBL	Royal Insurance Corporation of Bhutan Ltd.	Insurance services		18%	542
	DHI Infra Ltd.	Real Estate		100%	14
	Thimphu Tech Park Pvt. Ltd	Real Estate		31%	-
STCBL	State trading corporation Bhutan Ltd.	Trading		51%	1,010
DPL	Dungsam Polymers Ltd.	Manufacturing of rubber and plastics		100%	27
PCAL	Penden Cement Authority Ltd.	Manufacturing of glass products		40%	2,080
BFAL	Bhutan Ferro Alloys Ltd.	Manufacturing of basic iron		26%	2,143
BBPL	Bhutan Board Products Ltd.	Manufacturing of wood		48%	328
	Bhutan Postal Corporation	Telecommunications	100%	*	102
BDBL	Bhutan Development Bank Limited	Financial services	96%	*	725
	Bhutan Agro Industries	Food and beverage production	100%		92
KCL	Kuensel Corporation Limited	Manufacturing of wood	51%		184.3
FCB	Food Corporation of Bhutan	Wholesale and Trade	100%	*	982.96
	Wood Craft Center	Wood Manufacturing	100%	*	70
CDCL	Construction Development Corporation limited	Construction	100%	*	589.21
AWP	Army Welfare Project	Food and beverage production	100%		816.737
	National Pension and Provident Fund	Insurance services	100%	NA	NA
	National Housing and Development Corporation	Rental services	100%	NA	NA
BBS	Bhutan Broadcasting Services	Telecommunications	100%	NA	NA

*Ownership transferred to DHI in 2014
Source: Own compilation based on DHI, 2013, 2014; Kharka, 2015.
Note: Based on 2012 data

B.6.6.4 Disaggregation of Capital

Table B.44 reports the disaggregation of capital accounts across economic activities. Activities performed on the household level (cereal milling and processing, dairy and ara production) have solely returns to informal capital. Electricity generation and distribution are the only two sectors with a hundred percent share of public capital. Other sectors with significant shares of public capital are post and telecommunications; fruits and vegetable processing and financial intermediation.

Table B.44. Disaggregation of capital

Economic activity	Private capital % share	Public capital % share	Unincorporated capital % share
Paddy Milling	0.0	0.0	100.0
Cereal milling	0.0	0.0	100.0
Dairy production	0.0	0.0	100.0
On-farm cereal processing	0.0	0.0	100.0
Ara production	0.0	0.0	100.0
Grain mill and other food production	100.0	0.0	0.0
Animal feed production	100.0	0.0	0.0
Fruits and vegetables processing;	100.0	0.0	0.0
Community forestry	100.0	0.0	0.0
Commercial forestry	48.6	51.4	0.0
Manufacturing of wood,	91.6	8.4	0.0
Mining and quarrying	100.0	0.0	0.0
Textile manufacturing	0.0	0.0	0.0
Basic chemicals manufacturing	100.0	0.0	0.0
Rubber and plastics manufacturing	100.0	0.0	0.0
Glass product manufacturing	73.6	26.4	0.0
Basic iron and steel manufacturing	95.3	4.7	0.0
Casted iron and non-ferrous manufacturing	100.0	0.0	0.0
Fabricated metal manufacturing	100.0	0.0	0.0
Manufacturing n.e.c.	100.0	0.0	0.0
Electricity generation	0.0	100.0	0.0
Electricity transmission and retailing	0.0	100.0	0.0
Water	100.0	0.0	0.0
Construction	100.0	0.0	0.0
Wholesale and retail trade,	100.0	0.0	0.0
Hotels and restaurants	100.0	0.0	0.0
Land transportation	100.0	0.0	0.0
Air transport	0.0	100.0	0.0
Supporting and auxiliary transport activities;	100.0	0.0	0.0
Post and telecommunications	36.1	63.9	0.0
Financial intermediation	70.3	29.7	0.0
Insurance and pension funding	94.4	5.6	0.0
Real estate activities	100.0	0.0	0.0
Business services n.e.c.	0.0	0.0	0.0
Public administration	0.0	0.0	0.0
Education	0.0	0.0	0.0
Health and social work	0.0	0.0	0.0
Other services	0.0	0.0	0.0

Source: Own compilation.

B.7 Households and Enterprises

This chapter presents the classification and disaggregation of household accounts, the mapping of household factor income, of household consumption and households transfers as well as finally satellite account data. The primary data source used is the BLSS 2012. Two important adjustments had to be made concerning the actual size of population and the share of foreign households. According to the BLSS 2012, there are 127,942 households of which 98.8% are Bhutanese and 1.2% foreign households in 2012 (ADB & NSB, 2013).

The underlying sample framework of the BLSS 2007, in contrast, estimated that there are 125,491 households already in 2007 (NSB, 2007). Further, the average household size based on BLSS 2007 data is 5.0, which is significantly higher than the household size in 2012 of 4.6. Consequently, based on the statistical weights used in the BLSS 2012 the population of Bhutan would have declined from about 620,261 to 585,974 between 2007 and 2012; which results in an average negative population growth of 1.4% annually.

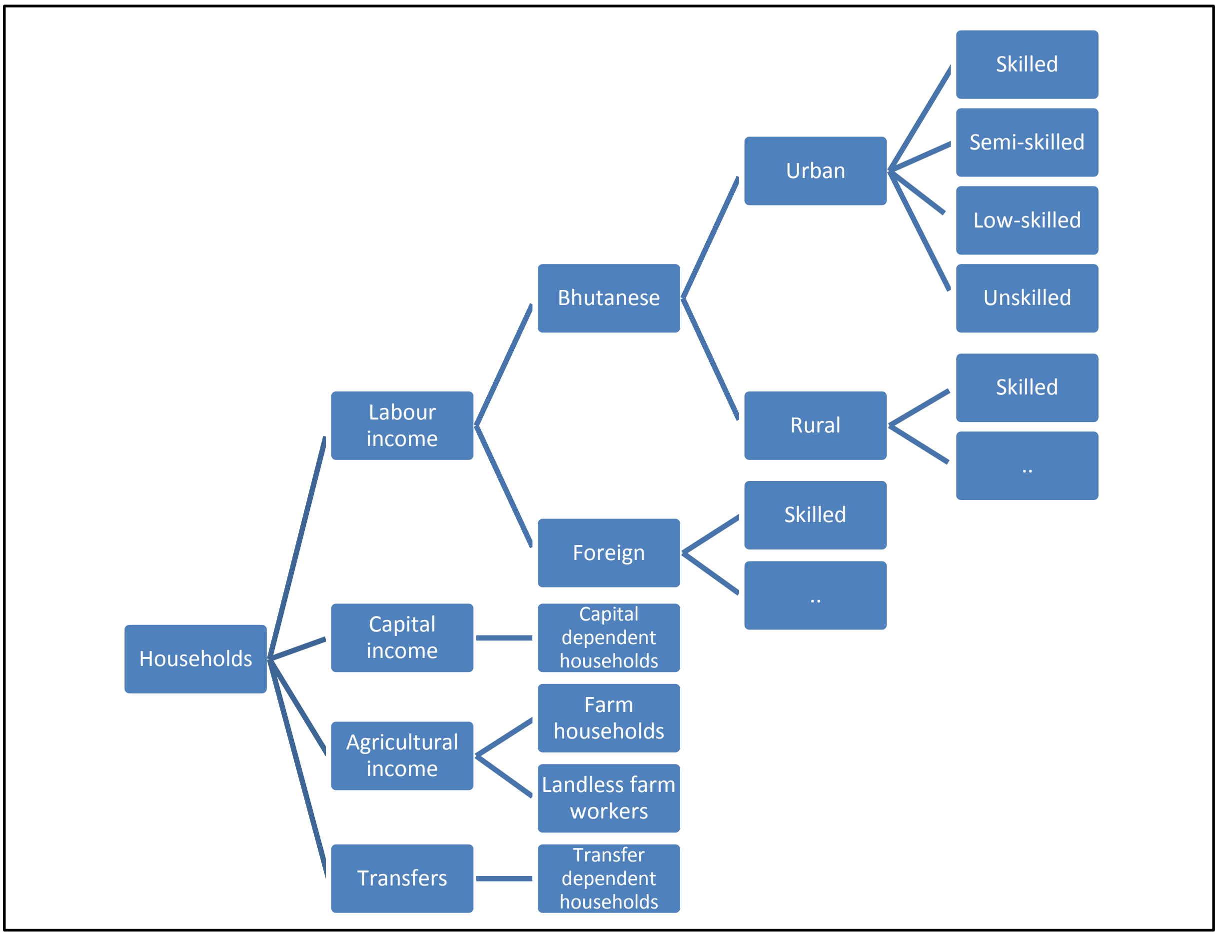
The last population census has been conducted in 2005, reporting that 634,982 people lived in Bhutan. Based on population projections from 2005 to 2015, the population of Bhutan is expected to reach 757,042 in 2015, growing at 1.77% annually (NSB, 2008). Following the projections, population in 2012 is estimated to be 720,680 people, which is substantially higher than represented in the BLSS 2012. While this number, being a projection, is still uncertain, it nevertheless seems to be more reliable. As a consequence, default statistical weights are scaled up to arrive at the projected population for 2012.

Another adjustment is made to the share of foreigners residing in Bhutan. Foreign households, as previously discussed, seem to be underrepresented within the BLSS sampling framework (the BLSS 2007 also reports a similarly low share of only 2.1% foreign households). The number of foreign households is scaled up matching the number of foreign workers as presented within the satellite account data of labour force. The two adjustments result in a population of 720,680 Bhutanese and 92,112 foreigners, summing up to an estimated total population of 812,792 people in 2012. Households within which at least half of members are foreigners are defined as foreign households. There are an estimated 26,453 foreign households with an average household size of 3.1 representing 82,592 foreigner or 89.7% of total foreigners in Bhutan. There are 160,321 Bhutanese households with an average household size of 4.6, representing the projected Bhutanese population of 720,680 plus the remaining 9,520 foreigners which live among Bhutanese households.

B.7.1 Classification of Household Accounts

There are different characteristics according to which household accounts can be separated, such as disaggregation according to income classes (e.g. disaggregation by income quantiles), ethnicity, geographic area and source of income. For the 2012 SAM, nationality (Bhutanese versus foreign), area (urban versus rural) and the source of income are characteristics used to separate households. Cicowiez et al. (2017) found that such a strategic disaggregation is more precise in simulating changes in income distribution and poverty levels compared to disaggregation by income deciles. There are four generic household account types, depending on whether households receive most of their income from (1) labour, (2) capital or (3) agriculture or (4) whether they are dependent on transfers such as pensions, intra-household transfers or remittances. The disaggregation structure is presented in Figure B.6 in more detail.

Figure B.6. Disaggregation structure of households



B.7.1.1 Labour Income Households

Households that receive majority of their income from labour are disaggregated into Bhutanese and foreign households. Bhutanese households are further disaggregated into rural and urban households. Rural and urban households as well as foreign households are then disaggregated according to which labour type households are most dependent on. If two or more labour-types are equally represented within households (e.g. one member works as a skilled and another as a semi-skilled worker) then the household is classified according to the labour-type representing the highest skill-level.

B.7.1.2 Capital Income Households

Households that receive the majority of their income from capital are grouped in a “capital dependent household” account. The criteria applied is that per adult equivalent households receive at least Nu. 300,000 from capital annually or capital income makes up at least 50% of household income, while the annual per adult equivalent income from capital exceeds 150,000 NU. In total, capital dependent households represents of 3,120 households or 12,700 people, respectively.

B.7.1.3 Agricultural Income Households

If there is at least one household member reporting to work in agriculture, then the household may be considered a household dependent on agricultural income. If the household owns less than 0.1 hectare, following the definition of Jayne et al. (2003), it is defined as landless, thus belonging to the landless farmer household. The remaining households are defined as farming households. About 6,416 households or 8.4% of total agricultural households in 2012 are classified as landless farmers and 69,858 households (91.6%) are farming households. Further disaggregation of the remaining agricultural households by farming system, market orientation, etc. is possible, yet not pursued within this SAM development procedure.

B.7.1.4 Transfer-dependent Households

Households that neither fall into one of the above categories, i.e. they do not have household members receiving a wage, they do not classify as capital dependent or agricultural income households, then they are classified as transfer-dependent households. Transfer-dependent households receive their income from pensions, domestic and foreign remittances.

B.7.1.5 Satellite Account Data on Households

Table B.45 presents summary data including satellite account data on the household accounts. Please note that the estimated total population exceeds the official population projections for 2012. This is due to the apparent underestimation of foreigners residing in Bhutan, which we estimate at 92,112 people.

Table B.45. Summary data on household accounts

Household (HH) type	Mean HH-size	# of HHs	% of total HHs	Population	% of pop.
Urban skilled	4.1	12,319	6.6	51,022	6.3
Urban semiskilled	4.2	18,507	9.9	76,990	9.5
Urban low-skilled	4.4	15,122	8.1	65,823	8.1
Urban unskilled	4.5	6,014	3.2	26,886	3.3
Foreigners skilled	2.8	1,264	0.7	3,547	0.4
Foreigners semiskilled	3.3	964	0.5	3,188	0.4
Foreigners low-skilled	3.8	12,578	6.7	47,600	5.9
Foreigners unskilled	2.4	11,647	6.2	28,257	3.5
Capital dependent	4.1	3,119	1.7	12,700	1.6
Rural skilled	3.7	4,931	2.6	18,284	2.2
Rural semiskilled	4.2	5,575	3.0	23,450	2.9
Rural low-skilled	4.4	6,499	3.5	28,590	3.5
Rural unskilled	4.4	2,770	1.5	12,053	1.5
Farm households	3.4	9,190	4.9	31,306	3.9
Landless-farmer	5.1	69,858	37.4	355,836	43.8
Transfer dependents	4.2	6,416	3.4	27,259	3.4
TOTAL households	**4.4**	**186,775**	**100.0%**	**812,792**	**100.0%**

Source: Own compilation

B.7.2 Mapping of Household Income

B.7.2.1 Factor Income

Households receive factor income from returns of labour, capital and land. The mapping of factor income to households is prepared using data on income per source and household reported by the BLSS 2012 data. The BLSS 2012 dataset includes a separate block of questions asking households on their annual income from various sources, ranging from wages, agricultural activities, own business over to remittances and pensions.

Mapping labour returns to households, we compute the relative distribution of workers within each labour account type across household accounts. Thus the share of e.g. how much skilled workers belong to urban skilled households is determined and labour return can be distributed among the various household accounts.

Capital returns to households are mapped in a similar way. Returns to incorporated capital, both private and public capital, are first channelled to enterprise accounts (see section 7.4 on enterprises for more details). While public enterprises (i.e. SOEs) pay dividends to the government, dividends paid by private enterprises represent income to households. As each households reports its annual income from capital (own business), we can estimate the relative distribution of capital return across households. Given the nature of its classification, the largest share of capital income (47%) is channelled to the capital dependent household account

Returns from agricultural land are distributed among households according to the reported landownership in the BLSS 2012. A substantial amount of agricultural land in Bhutan is owned by the members of the clerical and monarch community. However, no data is available to what extent this land is leased out to farmers and at what land lease rate.

B.7.2.2 Household Transfers

Besides income from factors, household receive transfers through domestic remittances (intra-household transfers), inward remittances (received from abroad) and the government (e.g. pensions). The distribution of these transfers is estimated using BLSS 2012 data, which includes questions on income received from remittances and pensions. There is, however, no differentiation whether remittances received or sent originate from abroad or from within Bhutan.

Remittances Sent by Households

BLSS 2012 data is used to derive the distribution of both remittances sent abroad and to domestic households. Remittances sent abroad are assumed to originate from all households except farm and landless farmer households. According to the BoP, Nu. 1,535 Million is sent in remittances abroad. For domestic remittances sent, the BLSS 2012 shares are used for all household accounts. While the RMA uses information from bank transfers to estimate remittances send or received from abroad (RMA, 2014b), there are no official statistics on domestic remittances. It is assumed that domestic remittances make up 3% of GDP (about Nu. 2,923 Million).

Remittances Received by Households

The BLSS also does not differentiate between remittances received from abroad and from domestic households. In 2012, according to the BoP 2012, about Nu. 692 Million in outward remittances are received from abroad, which are distributed using relative shares derived from BLSS 2012 data. To obtain an estimate for domestic remittances received, the above estimate (3% of GDP) is applied. As there is no data available on estimating which household type sends remittances to another household account, we distribute the amount of domestic remittances sent by each household with equal shares among all households. The shares used to distribute remittances received is also obtained from the BLSS 2012.

Government Transfers Received by Households

Government transfers consist largely of pensions. Income from pensions is also included within the BLSS 2012. In total, about Nu. 1,502 Million of government transfers are paid out to households (MoF, 2013a). These transfers are distributed among households using relative shares derived from BLSS 2012 data.

B.7.2.3 Household Income Shares

The previous sections have documented the various income sources of households. Table B.46 below presents the share of income sources in total household income across all household types.

Table B.46. Income sources of households

Household Type	Factors				Transfers			TOTAL
	Labour	Incorp. capital	Unincorp. capital	Land	Domestic remittances received	Pensions	Remittances from abroad	
Urban skilled	81.4%	15.4%	0.0%	0.1%	0.9%	1.6%	0.7%	100.0%
Urban semiskilled	85.4%	10.3%	0.0%	0.1%	0.2%	3.1%	0.9%	100.0%
Urban low-skilled	84.2%	11.1%	0.0%	0.1%	0.7%	3.8%	0.1%	100.0%
Urban unskilled	80.7%	15.3%	0.0%	0.1%	2.6%	1.0%	0.3%	100.0%
Foreigners skilled	84.2%	13.8%	0.0%	0.0%	0.0%	2.0%	0.0%	100.0%
Foreigners semiskilled	82.6%	13.4%	0.0%	0.0%	0.0%	4.0%	0.0%	100.0%
Foreigners low-skilled	98.5%	1.1%	0.0%	0.0%	0.0%	0.4%	0.0%	100.0%
Foreigners unskilled	99.3%	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	100.0%
Capital dependent	23.6%	74.6%	0.0%	0.0%	0.1%	1.3%	0.4%	100.0%
Rural skilled	95.0%	2.2%	0.0%	0.1%	0.5%	0.4%	1.8%	100.0%
Rural semiskilled	86.5%	7.9%	0.0%	0.2%	2.8%	0.4%	2.2%	100.0%
Rural low-skilled	85.8%	10.1%	0.0%	0.3%	2.6%	1.0%	0.3%	100.0%
Rural unskilled	86.5%	11.6%	0.0%	0.2%	0.4%	1.2%	0.0%	100.0%
Farm households	0.0%	10.0%	0.0%	0.5%	56.1%	19.1%	14.3%	100.0%
Landless-farmer	52.5%	6.9%	7.2%	20.9%	9.1%	2.4%	0.9%	100.0%
Transfer dependents	73.6%	11.6%	6.3%	0.0%	5.6%	2.4%	0.6%	100.0%

Source: Own compilation based on prior 2012 micro SAM.

B.7.3 Mapping of Household Consumption

As previously described in the supply-matrix chapter, this SAM differentiates between HPHC commodities valued at basic prices and commodities purchased via markets valued at purchasing prices. The BLSS 2012 survey includes a large block of questions asking households on their expenditure on both food and non-food items. Determining the relative share of each household account's expenditure in total household expenditure per commodity can be done using the BLSS 2012 data. However, the challenge lies in estimating total household expenditure per commodity as there are no official estimates that approximately match the SAM's level of disaggregation. Hence, total household consumption per commodity needs to be estimated. This can be done either by using BLSS 2012 data or computing it as a residual.

While the first option comprises a bottom-up approach based on empirical data, it also faces various limitations. Determining the household's absolute expenditure on all commodities, one would need an almost comprehensive coverage of expenditure items. As mentioned, the BLSS 2012 covers questions on the consumption of a wide range of food items. However, in case of some commodities (e.g. glass products), there are only one or two items included in the BLSS 2012, which certainly leads to underestimation of consumption in absolute terms of these specific commodities. This problem does not affect most food items. For these items, the BLSS

2012 includes very detailed questions, e.g. asking for a wide range of vegetables and fruits. However, estimating absolute expenditure on agricultural goods and food is problematic due to seasonal effects. The BLSS 2012 has been conducted between March and May 2012. Consequently, household expenditure for off-season goods, e.g. citrus or apples, is underrepresented. Last but not least, households have to recall their expenditure over three recall periods (7 days, 30 days and annually). The longer the recall period, the more uncertain household responses are.

Alternatively to using a bottom-up approach in estimating household consumption per commodity, it is possible to compute the residual of expenditures on commodities. This is done by considering the sum of commodity output and imports valued at purchaser prices (sum of commodity columns) and subtracting intermediate consumption of commodities, government consumption, capital expenditure and exports. This approach also bears the risk, that if total demand of industries, government or export markets is over- or understated, then household consumption in turn is under- or overstated. Even if the demand per commodity of other institutions and markets is deemed to be reliable, one still needs to take into account stock changes. For the 2012 SAM estimation, no detailed data on stock changes is available, which needs to be taken into account when applying the top-down approach of estimating household consumption per commodity.

In the national accounts 2013, private final consumption per item category is reported (NSB, 2013). This information is not sufficient to estimate total private final consumption for each commodity account represented in the SAM, however it is useful to compare it to final expenditure per item category estimates computed using BLSS 2012 data and by applying the residual method. As Table B.47 shows, the residual estimate of total private final consumption is very close to the national account 2012 figure. Total private final consumption using the BLSS 2012 data is however significantly lower.

Table B.47. Private final consumption per item category

Consumption items	BLSS 2012	Residual	National account 2012
Food and non-alcoholic beverages	13,200	17,401	16,454
Alcoholic Beverages, Tobacco & Narcotics	413	2,652	1,216
Clothing and Footwear	518	2,601	2,868
Housing, water, electricity, gas	5,312	5,344	9,516
Furnishing, Household equipment & Routine Household Maintenance	706	1,526	1,592
Restaurants & Hotel	511	578	1,325
Transport	720	3,109	1,993
Communication	795	1,184	600
Health	256	NA*	1,138
Education	468	NA*	1,267
Recreation & Culture	937	1,942	479
Miscellaneous Goods and Services	1,547	6,365	4,243
Final private expenditure	**25,383**	**42,702**	**42,690**

* It is not possible to calculate a residual for health and education expenditure as the actual share of government expenditure is not explicitly reported.
Source: Based on authors own analysis and NSB (2013).
Note: In Million Nu.

Even though both approaches have their shortcomings, the second approach (residual computation) is believed to be more appropriate and is thus applied. For health and education, total household expenditure is assumed to be equal to the NA 2012 figures. Further challenges arise for specific items for which the residual approach results in unrealistic budget shares (i.e. column shares) in total household expenditure. This is particularly the case for the food budget shares of potatoes, spices, apples and citrus fruits. All four are major export agricultural crops traded in large volumes. Thus, possible explanations could be underestimation of exports, but also stock changes. This is considered later on in the estimation of the stock changes account as well in configuring error bounds of exports within the SAM estimation process.

As previously mentioned, BLSS 2012 data is used to compute relative shares of household consumption. This is not necessary for HPHC goods, which are only consumed by farm households, i.e. their relative share is 100%. A small number of commodities is not represented in the BLSS questionnaire, for example non-wood forest products. In such cases, the relative shares of similar commodities is used as a proxy. Absolute consumption on commodities per household is simply computed by multiplying the relative shares times the estimated total household consumption per commodity.

B.7.4 Enterprises

All returns to capital, except unincorporated capital, are channelled as income to either the private enterprise or SOE account. Returns from informal capital are directly transferred to the household accounts. Enterprises are defined as commercial legal entities that are registered or incorporated. In the context of Bhutan, these enterprises can also be simply distinguished from unincorporated businesses since the former has to file tax declarations for business or corporate taxes. The distinction between private and SOEs as well as private and public capital is documented in section 6.6.

The 2012 SAM includes one private enterprise and one SOE account. Income to the enterprise account is equal to the sum of either private or public capital returns. Enterprise accounts record no consumption of intermediate inputs, as this is already captured in the use-matrix of activities. The after-tax income from returns of capital is either paid out as dividends to the respective shareholders, paid as interest expenses or saved as retained earnings. Depreciation of capital is already captured as a transaction of capital accounts to the savings account.

The dividend ratio, calculated as the share of dividends in net profit, is used to obtain the share of retained earnings and dividends paid to capital owners. For both private enterprise and SOE account, the dividend ratio is derived from available annual corporate reports and from DHI (DHI, 2014; RMA, 2014b). Income taxes paid, whether corporate or business taxes, is first calculated for the SOE account, as most information is available. Afterwards, tax payments of private enterprises is derived as a residual by subtracting tax payments of SOEs from total corporate and business tax income to the government as recorded in the macro SAM. Using the same procedure, the transfer of capital returns to the rest of the world account is computed.

B.8 Government, Capital and Rest of the World Accounts

B.8.1 Government

B.8.1.1 Government Expenditure and Savings

Government expenditure on public administration, education and health

There is only one government account in the 2012 SAM, thus the transactions of the government account are mostly identical to the transfers recorded in the macro-SAM. Government expenditure consists of only three commodities (or rather services): public administration, education and health. Information on total current and capital expenditure for 2012 by the RGoB is reported within the financial statements for the fiscal years 2011-12 and 2012-13 (MoF, 2012b, 2013a). However, there is no explicit data on government expenditure on public administration, education and health. Instead, we calculate government expenditure for these items as a residual after subtracting activity and household expenditure (which is based on the NA estimates) from the total output value. Doing so, we arrive at Nu. 15,150 million, which is a significantly lower prior estimate for total government consumption as the official estimate (Nu. 18,691 million).

Our lower estimate for government expenditure is in line with levels of total current expenditure reported in the financial statements which are Nu. 13,901 million. The potential discrepancy with the national accounts statistics might derive from the SUT 2007 structure, which assumes that the government consumes all public administration, education and health services. This would explain why the reported output of these services in the national accounts 2012 of Nu. 18,229 million are almost as high as the official estimate of aggregate government consumption. However, there are good reasons to justify to use a lower level of government expenditure as reflected by the residual. First, as mentioned, the disaggregated schedule of the government's current expenditure only amounts to Nu. 13,901 million. Second, the 2012 national accounts also report household consumption of health and education services, which in sum amount to 2,405 million Nu and need to be subtracted from the total output.

Government transfers

There are no public safety net programs in Bhutan and the only component within Bhutan's social protection system in 2012 Bhutan is a civil service pension system (RMA, 2014a, 2017; World Bank, 2010). As also reported in the macro-SAM, there is a total transfer between the government and households of Nu. 1,502 Million. Data from the BLSS 2012 is used to determine the relative distribution of government-households transfer among household accounts.

Government savings

We impute government savings by subtracting total government expenditure from government income.

B.8.1.2 Government Income

Government income is derived from various channels. Tax revenue makes up about 42% of government income and from a policy analysis perspective, information on taxes is of special interest. In the following, it is briefly described on how the transactions between tax accounts and respective tax payers (commodities, activities, etc.) is derived.

Customs Duty

There is no explicit information available on how much custom duties are received per commodity. Bhutan and India have a free trade agreement, so custom duties are only levied on imports from countries other than India (COTI). The tariff rates for commodities classified by six-digit HS code have been made available by the Ministry of Finance (MoF, 2012c). As the import value in 2012 from COTI reported by HS six-digit codes is also available (UN, 2015a), custom duty levied per reported import item is estimated and aggregated according to the commodity account structure of the 2012 SAM. One factor complicating this procedure is, that during the global financial crisis a fiscal incentive policy has been passed that included various sales tax and custom duty exemption for the manufacturing and service sector (MoF, 2010b). Therefore, adjustments are necessary to scale down the estimated custom duty of Nu. 1,535 Million to the officially reported 372 Million Nu. A similar procedure is also necessary for the estimation of sales tax.

Excise Duty

There are two types of excise duties that are levied on goods consumed in Bhutan: Excise duty levied on alcoholic beverages produced in Bhutan and excise duty levied on goods produced in India and exported to Bhutan. The former is regulated by Bhutanese laws, while the latter is subject to legislation in India. Instead of refunding the Indian excise duty to Bhutanese importers, there are annual bilateral meetings between the government of India and Bhutan in which the refund of excise duty paid by Bhutanese importers is negotiated. This excise duty refund is then refunded by the Indian government to the Bhutanese government. Hence, in practice the excise duty can be considered a tax on imports from India, which is not regulated by Bhutan, but which nevertheless is a source of government revenue to the Bhutanese government. Within the 2012 SAM, both excise duties are represented as separate tax accounts.

The Bhutanese excise duty on alcoholic beverages ranges between 30% and 75% (MoF, 2016) and directly corresponds to the Alcohol and Tobacco products commodity account. According to the government revenue report, the excise duty on alcoholic products is Nu. 482 Million in 2012 (MoF, 2013a).

There is no data on refunded Indian excise duty on the commodity level, instead there is only information on the annual excise duty refund, which is Nu. 2,673 Million for 2012 (MoF, 2013a). Breaking the Indian excise duty down on the commodity level is estimated using the excise duty rates levied in India and multiplying them with Bhutanese import data. Further, there are various exceptions in which no Indian excise duty is levied since products are declared as goods exported to Bhutan. For instance, goods imported from India used for the construction of hydropower projects are net of Indian excise duty. These exceptions had to be taken into account when estimating the excise duty on the commodity level. Due to a lack of data, assumptions are made on the share of imports relating to hydropower projects.

Sales Tax

Sales tax are levied either on the time of import regardless of country of origin or are levied at the point of sale if the good is produced domestically. In 2012, revenue from sales tax is Nu. 2,281 Million. Sales tax rates are published for each good classified by the HS six-digit code (MoF, 2012c), however, again no disaggregated data on sales tax revenue per commodity is available. Further, the fiscal incentive policy also included sales tax exemptions, for example for raw materials and packaging used by manufacturing industries. A simple mean sales tax is computed for each account category, as no detailed data on domestic production based on the HS six-digit level is available. The sales tax base sales per commodity is approximated by the value of domestic supply measured in basic prices plus value of imports (in CIF terms) minus the export value. The tax base is then multiplied by the simple mean tax rate to arrive at the estimated sales tax revenue per commodity. For some specific commodities or group of commodities sales tax revenue is reported, in this case the officially reported tax revenue is used. For all remaining commodities, the estimated sales tax revenue is adjusted tax exemptions and uniformly downscaled to match the reported total sales tax.

Direct Tax

Direct taxes include corporate income tax, business income tax and personal income tax. Also, while not technically a direct tax, 25% of motor vehicle tax revenue is included within the 2012 SAM direct tax account. This is based on the assumption, that 25% of motor vehicle tax is paid by private households. In total, direct tax revenue equals Nu. 7,592 million in 2012 according to the financial statement figures reported for 2011-12 and 2012-13 (MoF, 2012a, 2013a). Of this, households paid Nu. 1,072 million, direct taxes paid by private enterprises and SOEs amounted to Nu. 3,021 and Nu. 3,499 million. BLSS 2012 data is used to determine the relative distribution of direct tax payment by the various household accounts.

Production Tax

Taxes on production include various taxes, lump sum fees (e.g. license fees) and royalties paid by activities. It also includes the remaining 75% of the motor vehicle tax. In total, Nu. 1,211 million of production tax has been collected in 2012 (MoF, 2013c). Of this, a considerable share (28%) is made up by royalties paid by commercial forestry, mining and hydropower generation activities. The remaining share of production tax revenue is allocated among activities using relative shares derived from the SUT 2007.

B.8.2 Capital Accounts

The capital account captures savings on the income side (row) and investments on the expenditure side. Savings originate from enterprises, households, government, stock changes and rest of the world. Enterprise savings are retained earnings computed as a residual by subtracting tax and dividend payments from total enterprise income. Household and government savings are also computed as a residual. Stock changes records positive entries if a good or service imported or produced in the current year is used in following year. Analogously, it records negative entries if goods or services imported or produced in an earlier year are used within the current year (ADB, 2012, p. 7). There is no explicit information on stock changes available and stock changes are therefore determined within the cross-entropy balancing procedure providing prior-estimates. Savings from rest of the world can be interpreted as the capital account deficit (or surplus, if negative) which ensures that all components of the balance of payment (BOP) sum to zero.

Investments are capital expenditure on commodities which are not entirely consumed within the same accounting period. This concerns commodities such as machinery, vehicles and construction service, but also seedlings used by permanent cropping activities or live animals demanded by livestock activities. The largest share of investment is made up by construction services (67%) and in total investments amount to Nu. 65,563 million.

B.8.3 Rest of the World

Transactions with the rest of the world account consist of import and export of goods and services, factor payments, household transfers, government transfers and the balance with the rest of the world. Imports and exports have already been described in detail in sections 3.4 and 3.5. The factor payments account consists of factor payments to abroad through foreign day labour and capital. For capital, private and public enterprises pay capital returns in form of dividends and interest to foreign capital owners. Return to foreign capital owners from public enterprises is approximated by the interest paid by DGPC (Nu. 1,274 Million). Private enterprises pay Nu. 7,017 Million, which is the remaining payment to abroad capital as presented in the macro-SAM. Return to capital invested abroad is Nu. 777 million in 2012 (RMA, 2014b, p. 92) and accrues to the private capital account.

Total payment to foreign labour, i.e. payments to workers that do not reside in Bhutan, is equal to Nu. 2,098 million (RMA, 2014b). As most foreign day labour is employed in manufacturing sectors located along the Southern border to India, the relative shares of foreign labour accounts in these sectors is used to break up the payment of foreign labour accounts to the rest of the world account. Returns from labour abroad are only Nu. 122 million in 2012 (RMA, 2014b) and are assumed to accrue only to the skilled labour account. Household transfers to the rest of the world consist of remittances received and sent, which are discussed in the household section. Government transfers are adopted from the macro-SAM and consist of development aid in form of budget grants. Finally, the balance with the rest of the world account is used to balance the surplus resulting from investments, trade of goods and factor payments and the deficit resulting from trade of services, government and household transfers.

B.9 Estimation of Final Micro-SAM

Naturally, the prior SAM's underlying different data sources do not result into a consistent framework in which recorded expenditure of agents equals recorded income. Due to measurement errors, data gaps and other challenges, the prior SAM is thus unbalanced, i.e. the sum of columns (expenditure) does not equal the sum of the corresponding row. As a remedy, there are various estimation methodologies that allow to arrive at an estimated final Micro-SAM, with balanced row and column totals. Like the balanced prior macro-SAM, the final micro-SAM is estimated using the *SAM Estimation Program, Version 3.3* developed by Scott McDonald and Sherman Robinson (2006).

B.9.1 Treatment of Stock Changes

The aggregate stock changes recorded in national accounts 2012 are known to be Nu. -72 million, but not data is reported for individual commodity accounts (NSB, 2013). In the SUT 2007, changes in inventory made up Nu. 1,959 million, or 4% of GDP. For the compilation of the prior SAM we assumed that total stock changes make up 2% of total GDP. Due to missing data, a random number between 0 and 1 million Nu. is generated for stock changes of each commodity (except services). This allows the consideration of stock changes within the estimation procedure, as the SAM estimation program can only work with prior information (zero cell entries do not enter the estimation procedure), The random generated prior values for stock changes are either forced to be negative or positive depending on the deviation of column and row totals.[56] As the column total exceeds the row total, the randomly produced cell entry for the stock changes cell is positive. 50% of the column and row total difference is added to the randomly generated stock change cell entry.

[56] For example, in case of paddy production the prior micro-SAM records a difference of 0.9 million Nu. (0.1% of the column total).

B.9.2 Final 2012 Bhutan SAM

The final micro 2012 SAM cannot be displayed due to its size, instead we present the final 2012 macro SAM in Table B.48.

Table B.48. Final 2012 macro-SAM for Bhutan

		A	B	C	D	E	F	G	H	I	J	
		Commodities	Margins	Activities	Factors	House-holds	Enter-prises	Govt.	Taxes	Invest-ments	Rest of the world	Total
1	Commodities		14,501	71,613		42,562		15,396		65,158	35,675	244,906
2	Margins	14,501										14,501
3	Activities	162,936										162,936
4	Factors			90,232							900	91,132
5	Households				44,168		9,179	1,502			692	55,541
6	Enterprises				37,877							37,877
7	Govt.						5,278		14,518		9,733	29,528
8	Taxes	5,834		1,091		1,072	6,520					14,518
9	Savings				7,037	10,371	8,579	12,630		2,152	26,542	67,310
10	Rest of the world (RoW)	61,634			2,050	1,535	8,322					73,542
11	Total	244,906	14,501	162,936	91,132	55,541	37,877	29,528	14,518	67,310	73,542	-

Source: Own compilation based on final 2012 micro SAM.

Deriving Bhutan's GDP from the final 2012 macro SAM amounts to Nu. 99,309 million or Nu. 97,157 million depending on whether the expenditure or production approach is applied (Table B.49). The deviation between both approaches is 2.2%. Based on the expenditure approach, the deviation from the official GDP estimates is 4.4%, but only 0.3% if the production approach is used. The deviation between both approaches and between the official estimates are defendable, as the official estimates have an even higher discrepancy of 6.6%.

Table B.49. Comparison of GDP estimates of prior and final 2012 macro SAM

Item	Expenditure approach		Item	Production approach	
	Balanced prior-macro SAM	Final macro SAM		Balanced prior-macro SAM	Final macro SAM
Consumption	42,650	42,562	Output of activities	165,712	162,936
Gov. expenditure	18,660	15,396	Intermediate Inputs	73,706	71,613
Net exports	-27,825	-25,960	Taxes on products less	5,817	5,834
Investments	66,286	67,310	subsidies		5,834
GDP	**99,771**	**99,309**	**GDP**	**97,823**	**97,157**
National Accounts 2012 estimate		**103,868**	**National accounts 2012 estimate**		**97,453**

Source: Own compilation based on prior macro SAM and final 2012 macro SAM.
Note: In Million Nu.

There are some notable deviations between the prior and final 2012 macro SAM reported in Table B.50. Applying the bottom-up approach, we estimate total government consumption to be about 17.5% lower as reported in the national accounts. The issue of using a lower estimated government expenditure is already addressed in section 8.1.1. We use the national account 2012 estimates for household consumption of health and education services, which in turn results in a lower residual value of government consumption. This discrepancy explains 74% of the reported deviation of government consumption.

Total exports are 4.1% higher than in the prior SAM, which is largely due to potential underreporting of exports of cash crops (predominantly spices and citrus fruits) and ferro-alloys. The higher estimate of exports results in a decrease of foreign savings (6.6%). Due to lower expenditure, government savings decrease by 33.4%. The remaining deviations are rather of lower magnitude.

Table B.50. Percentage deviations between final and balanced prior 2012 macro SAM

		A	B	C	D	E	F	G	H	I	J	
		Commodities	Margins	Activities	Factors	House-holds	Enter-prises	Govt.	Taxes	Invest-ments	Rest of the world	Total
1	Commodities		8.4%	-2.8%		-0.2%		-17.5%		1.3%	4.1%	-0.8%
2	Margins	8.4%										8.4%
3	Activities	-1.7%										-1.7%
4	Factors			-0.6%							0.0%	-0.6%
5	Households				-0.2%		2.7%	0.0%			0.0%	0.3%
6	Enterprises				-0.3%							-0.3%
7	Govt.						0.0%		-0.7%		0.0%	-0.3%
8	Taxes	0.3%		-9.9%		0.0%	0.0%					-0.7%
9	Savings				-4.3%	2.4%	-4.4%	33.4%		10.5%	-6.6%	1.5%
10	Rest of the world (RoW)	-0.7%			-2.3%	0.0%	0.4%					-0.6%
11	Total	-0.8%	8.4%	-1.7%	-0.6%	0.3%	-0.3%	-0.3%	-0.7%	1.5%	-0.6%	

Appendix C CGE Model extensions

In the following the various extensions of the comparative-static CGE model framework STAGE2, which were made for the CGE model applications in Chapter 3, Chapter 4 and Chapter 6 are documented. STAGE2 was developed by Scott McDonald and Karen Thierfelder, who also have published a detailed model documentation (see Scott McDonald & Thierfelder, 2015). Consequently, the technical appendix will only focus on those model parts, which were substantially modified for the purpose of this thesis. First, the sets, parameters and variables are described, which are used in the behavioural specifications and equations of the documented model extensions. Generally, parameters are printed in lower case and variables in upper case. Second, the model extensions are graphically illustrated and the underlying equations are listed.

C.1 Model Sets, Parameters and Variable

C.1.1 Sets

STAGE2 includes the following basic sets:

$$
\begin{aligned}
sac &= \{\text{all SAM accounts}\} \\
cc &= \{\text{commodities and aggregates}\} \\
a &= \{\text{activities}\} \\
ff &= \{\text{factors and aggregates}\} \\
ins &= \{\text{domestic institutions and rest of the world}\} \\
h &= \{\text{households}\} \\
g &= \{\text{government}\} \\
e &= \{\text{enterprises}\} \\
i &= \{\text{investment}\} \\
w &= \{\text{rest of the world}\}
\end{aligned}
$$

To include commodities in the production structure, we define an additional basic set that identifies both factors, ff (e.g. labour), and commodities, cc (e.g. chemical fertilizer):

$$cf(sac) = \{\text{Production factors}\}.$$

Sets cc, a, ff ,and cf have various subsets, of which the most relevant ones are introduced below.

Subsets of *cc*:

$$c(cc) = \{\text{Commodities }\}$$
$$c1(cc) = \{\text{Leisure/consumption aggregate}\}$$
$$c2(cc) = \{\text{Leisure or consumption aggregate}\}$$
$$ccons(cc) = \{\text{Consumption aggregate}\}$$
$$c1eis(cc) = \{\text{Leisure aggregate}\}$$
$$c3(cc) = \{\text{Commodity groups}\}$$
$$ccf(c) = \{\text{Commercial fuelwood}\}$$
$$ccharc(c) = \{\text{Charcoal}\}$$

Subsets of *a*:

$$aqx(a) = \{\text{Activities with CES at top level}\}$$
$$aqx(a) = \{\text{Activities with Leontief at top level}\}$$
$$aleon2(a) = \{\text{Activities with Leontief at the second level}\}$$
.. analogous notation until..
$$aleon6(a) = \{\text{Activities with Leontief at the second level}\}$$
$$acet(a) = \{\text{Activities with flexible multi-product output shares}\}$$
$$acetn(a) = \{\text{Activities with fixed multi-product output shares}\}$$
$$aprod(a) = \{\text{Activity within production boundary}\}$$
$$arf(a) = \{\text{Household specific fuelwood extraction activity}\}$$

Subsets of *ff:*

$$f(ff) = \{\text{Factors}\}$$
$$f2(ff) = \{\text{Factors demanded at level 2}\}$$
.. analogous notation until..
$$f6(ff) = \{\text{Factors demanded at level 6}\}$$
$$n(f) = \{\text{Agricultural land factors}\}$$
$$on(n) = \{\text{Organic agricultural land}\}$$
$$rf(f) = \{\text{Forest land}\}$$

Subsets of *cf:*

$cf2(cc) = \{\text{Aggregate commodity/factor production input at level 2}\}$
.. analogous notation until..
$cf6(cc) = \{\text{Aggregate commodity/factor production input at level 6}\}$

There are also mapping (or cross-sets) that are used to match specific members of one set with members of another one.

$map\_h\_alei(h,a) = \{\text{Mapping of households with household specific leisure activities}\}$
$IARF(arf,h) = \{\text{Mapping of fuelwood extraction activities and households}\}$

C.1.2 Parameters

A complete list of parameters used in STAGE2 is provided in (Scott McDonald & Thierfelder, 2015)

Table C.1. Parameters

Parameter Name	Parameter Description
$ad^{DS}(c1,h)$	Shift parameter for CES aggregation of leisure and consumption aggregates
$adf^{L*}(cf,a)$	CES production function shift parameter (≥L3)
$adfield^{L*}(cf,a)$	CES production function shift parameter (used in field operations nest) (≥L3)
$alim(n)$	Asymptote for asymptotic land supply curve
$ati^{MO}(a)$	Parameter for CET supply of multi-product output
$at^{CET}(n)$	Parameter for CET land mobility function
$\beta(c3,h)$	Marginal budget shares for commodity groups in LES
$chagconst(c3,h)$	Share parameters for subsistence consumption of commodity groups in LES
$\delta^{X}(a)$	Share parameter for CES aggregation (L1)
$\delta^{va}(cf,a)$	Share parameter for CES aggregation of value added (L2)
$\delta^{L*}(cf,cf,a)$	Share parameter for CES production function starting at levels (≥L3)
$\delta^{DS}(c1,c2,h)$	Share parameter for CES aggregation of composite leisure and consumption
$elafs(n)$	Land supply elasticity
$\varepsilon^{AL}(n)$	Asymptotic land supply elasticity
$\varepsilon(t)$	Real wage elasticity for seasonal labour (t)

$\gamma(a,c)$	Share parameter for CET supply of multi-product output
$\gamma^{CET}(n,a)$	Share parameter for CET land mobility function
$\gamma(t)$	Scale parameter used in the seasonal labour wage curve equation
$ioleon(cf,a)$	Leontief share parameter (≥L3)
$ioqvaqx(a)$	Leontief share parameter for the value added aggregate (L1)
$ioqintqx(a)$	Leontief share parameter for the intermediate aggregate (L1)
$ioqtdqd(c,a)$	Leontief share parameter for intermediate inputs (L2)
$\omega(n)$	Asymptotic land supply curve parameter
$rhoc(a)$	Substitution elasticity for CES aggregation of total output (L1)
$\rho^{VA}(a)$	Substitution elasticity for CES aggregation of value added (L2)
$\rho^{L*}(cf,a)$	Substitution elasticity for CES aggregation of production factors (cf) (≥L3)
$\rho^{DS}(c1,h)$	Substitution elasticity for CES aggregation of composite consumption and leisure
$\rho^{MO}(a)$	Transformation elasticity for CET supply of multi-product output
$\rho^{CET}(n)$	Transformation elasticity for CET land mobility function
$shfs(n)$	Share parameter in the land supply elasticity
$\theta(n)$	Calibration parameter for asymptotic land supply curve
$ushr(ins,f)$	Institutions' share in unemployed factor quantity

C.1.3 Variables

Table C.2. Variable list

Variable Name	Variable Description
AD_a^x	CES shift variable (set exogenous) at output aggregation level (L1)
$ADFD(cf,a)$	Efficiency shifter for production factor inputs
$CQ(arf,ccf)$	Commercial quota for commercial fuelwood by household specific fuelwood extraction activities
$CQR(arf,ccf)$	Commercial quota rent
CPI	Consumer price index
$CVI(n)$	Idle converted land
$EQ(ins,rf)$	Extraction quota (transformed in forest land equivalents)
$EQRADJ(ins,rf)$	Extraction quota rent adjuster
$EQR(rf,arf)$	Extraction quota rent
$FD(ff,a)$	Factor demand by activities
$FS(ff)$	Factor supply
$FSI(ins,f)$	Factor supply by institutions
$FSIL(h,f)$	Factor supply by households to leisure activities
$FSISH(ins,f)$	Institutional share in factor income
$FSIW(ins,f)$	Factor supply by households to production activities
$FW(n)$	Fallow land
$H(arf)$	Households involved in fuelwood extraction activities
$HCONS(h)$	Household expenditure on consumption (excl. leisure)
$HEXP(h)$	Household expenditure
$HOHO(hp,h)$	Household transfers
$INSVA(ins,f)$	Institutional factor income
$IOQXACQX(a,c)$	Multi-product output share variable
$PFDIST(cf,a)$	Activity specific productivity adjuster for commodities entering CES production nest
$PFIELD(cf)$	Price for field operations input
$PQD(cc)$	Purchaser price
$PQDDIST(cc,h)$	Composite price adjuster

$PINT(a)$	Composite price of intermediate inputs
PPI	Producer Price Index
$PVA(a)$	Composite price of value added
$PX(a)$	Activity output price
$PXAC(a,c)$	Activity specific output price
$PXC(c)$	Producer price
$QCD(cc,h)$	Household consumption of commodity aggregates and single commodities
$QCF(cf,a)$	Demand for commodities within production factor nests (e.g. field operations or chemical fertilizer)
$QFIELD(cf,a)$	Demand for commodities within production factor nests (e.g. field operations or chemical fertilizer)
$QINT(a)$	Composite intermediate inputs
$QD(c)$	Domestic demand
$QM(c)$	Imports
$QQ(c)$	Supply
QVA_a	Composite value added
$QX(a)$	Activity output
$QXAC(a,c)$	Activity specific commodity output
$SHH(h)$	Households savings rate
$TF(ff)$	Factor tax
$TV(c)$	Value-added tax
$TX(a)$	Production tax
$TYH(h)$	Household direct (income) tax rate
$UNEMP(f)$	Unemployed factor quantity
$WF(f)$	Factor price
$WFDIST(f,a)$	Activity specific factor productivity
$YFDISP(f)$	Disposable factor income
$YH(h)$	Household income

C.1.4 Extension of the Production Structure

The production structure in STAGE2 was extended in order to either incorporate seasonal labour, as done in Chapter 3, or field operations, as done in Chapter 4. Both production structures are graphically illustrated in the figures below. The nest levels L3.1, L4.1 and L4.2 of the seasonal production structure are similar to the field operations production structure. However, instead of including field operations, the structure only incorporates the real commodity inputs for the land-saving nest a L3.1 (i.e., the commodities chemical fertilizer and manure, which are aggregated in L4.1). Hence, the labour input required for manuring is not explicitly taken into account.

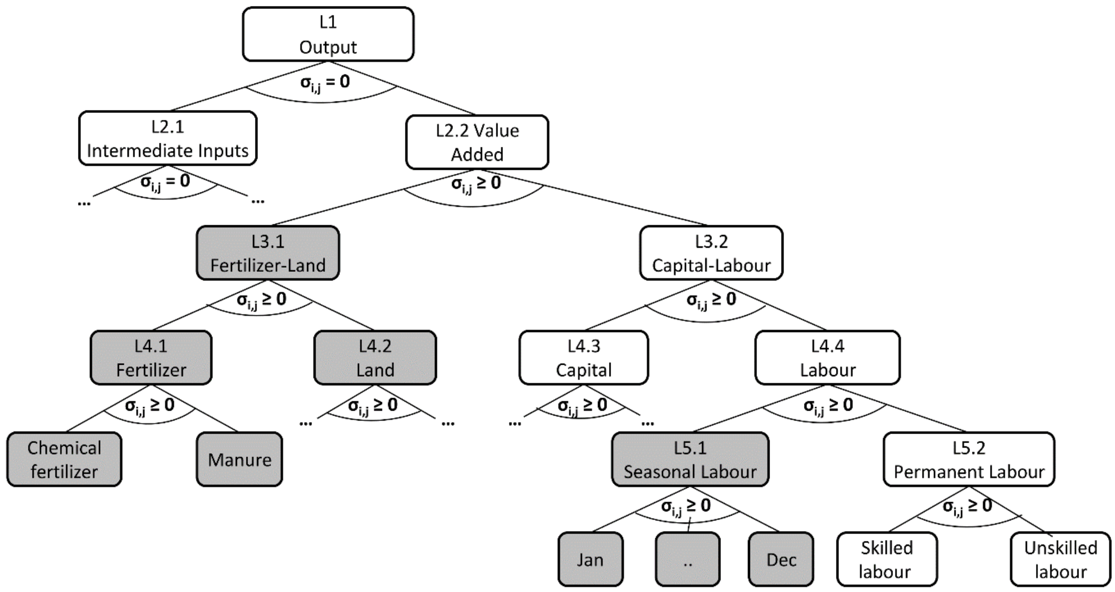


Figure C.1. Production structure incorporating seasonal labour demand

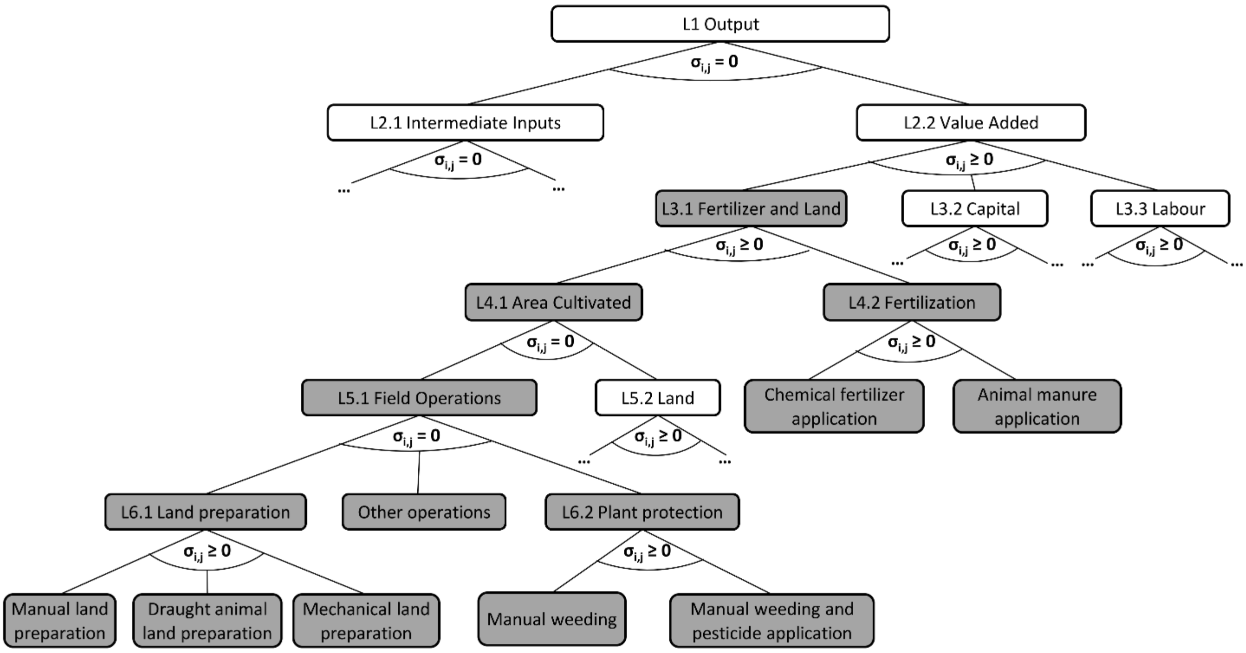


Figure C.2. Extended production structure of economic activities

Note: Sigmas denote substitution elasticities. Light shaded nests represent the standard three level structure and dark shaded nests represent the extended structure including field operations

C.1.4.1 Production structure levels 1-2 as in STAGE2

Generally, the first two levels of the production nest are structurally unchanged from STAGE2 and the respective equations are presented below.

Name	Equation	Level
$PVADEF_a$	$PX_a * (1-TX_a) * QX_a = (PVA_a * QVA_a) + (PINT_a * QINT_a)$	L1
$PXDEF_a$	$PX_a = \sum_c IOQXACQX_{a,c} * PXC_c$	L1
	CES Level 1	
$QXPRODFN_a$	$QX_a = AD_a^x \left(\delta_a^x QVA_a^{-rhoc_a^x} + \left(1-\delta_a^x\right) QINT_a^{-rhoc_a^x}\right)^{-\frac{1}{rhoc_a^x}}$ $\forall aqx_a$	L1
$QXFOC_a$	$\frac{QVA_a}{QINT_a} = \left[\frac{PINT_a}{PVA_a} * \frac{\delta_a^x}{\left(1-\delta_a^x\right)}\right]^{\frac{1}{\left(1+rhoc_a^x\right)}}$ $\forall aqx_a$	L1
	Leontief Level 1	
$QVADEF_a$	$QVA_a = ioqvaqx_a * QX_a \quad \forall aqxn_a$	L1
$QINTDEF_a$	$QINT_a = ioqintqx_a * QX_a \quad \forall aqxn_a$	L1
	Intermediate demand – Leontief Level 2.1	
$PINTDEF_a$	$PINT_a = \sum_c \left(ioqtdqd_{c,a} * PQD_c\right)$	L2.1
$QINTDEQ_c$	$QINTD_c = \sum_a ioqtdqd_{c,a} * QINT_a + \sum_a QCF_{c,a}$	L2.1
	Value added – CES Level 2.2	
$QVAPRODFN_a$	$QVA_a = AD_a^{va} * \left[\sum_{f2\$\delta_{f2,a}^{va}} \delta_{f2,a}^{va} * ADFD_{f2,a} * FD_{f2,a}^{-\rho_a^{va}} + \sum_{cf2\$\delta_{cf2,a}^{va}} \delta_{cf2,a}^{va} * ADFD_{cf2,a} * QCF_{cf2,a}^{-\rho_a^{va}}\right]^{-1/\rho_a^{va}}$	L2.2
$QVAFOC1_{f2,a}$	$WF_{f2} * WFDIST_{f2,a} * \left(1+TF_{f2,a}\right) = PVA_a * QVA_a$ $* \left[\sum_{f2\$\delta_{f2,a}^{va}} \delta_{f2,a}^{va} * ADFD_{f2,a} * FD_{f2,a}^{-\rho_a^{va}} + \sum_{cf2\$\delta_{cf2,a}^{va}} \delta_{cf2,a}^{va} * ADFD_{cf2,a} * QCF_{cf2,a}^{-\rho_a^{va}}\right]^{-1}$ $* \delta_{f2,a}^{va} * ADFD_{f2,a}^{-\rho_a^{va}} * FD_{f2,a}^{\left(-\rho_a^{va}-1\right)}$	L2.2
$QVAFOC2_{cf2,a}$	$PQD_{cf2} * PFDIST_{cf2,a} = PVA_a * QVA_a$ $* \left[\sum_{f2\$\delta_{f2,a}^{va}} \delta_{f2,a}^{va} * ADFD_{f2,a} * FD_{f2,a}^{-\rho_a^{va}} + \sum_{cf2\$\delta_{cf2,a}^{va}} \delta_{cf2,a}^{va} * ADFD_{cf2,a} * QCF_{cf2,a}^{-\rho_a^{va}}\right]^{-1}$ $* \delta_{cf2,a}^{va} * ADFD_{cf2,a}^{-\rho_a^{va}} * QCF_{cf2,a}^{\left(-\rho_a^{va}-1\right)}$	L2.2

C.1.4.2 Equations for Seasonal Production Structure (Chapter 3)

Name	Equation	Level
	Leontief Value Added Level 2.1	
$QVALEON1_{cf2,a}$	$QCF_{cf2,a} = ioleon^{va}_{cf2,a} * QVA_a$	L2.2
$QVALEON2_{f2,a}$	$FD_{f2,a} = ioleon^{va}_{f2,a} * QVA_a$	L2.2
$PVALEON_a$	$PVA_a = \sum_{cf2} PQD_{cf2} * PFDIST_{cf2,a} * ioleon^{va}_{f2,a}, QCF_{cf2,a} + \sum_{f2} WF_{f2} * WFDIST_{f2,a} * (1+TF_{f2,a}) * ioleon^{va}_{f2,a}$	L2.2
	Level 3.1 – CES aggregation of Fertilizer and Cultivated Land	
$CFD31PFN_{cf2,a}$	$QCF_{cf2,a} = adf^{L31}_{cf2,a} * \left[\sum_{cf3\$\delta^{L31}_{cf2,cf3,a}} \delta^{L31}_{cf2,cf3,a} * QCF_{cf3,a}^{-\rho^{L31}_{cf2,a}} + \sum_{f3\$\delta^{L31}_{cf2,f3,a}} \delta^{L31}_{cf2,f3,a} * ADFD_{f3,a} * FD_{f3,a}^{-\rho^{L31}_{cf2,a}} \right]^{-1/-\rho^{L31}_{cf2,a}}$	L3.1
$CFD31FOC1_{cf2,cf3,a}$	$PQD_{cf3} * PFDIST_{cf3,a} = PQD_{cf2} * PFDIST_{cf2,a} * QCF_{cf2,a} * \left[\sum_{cf3\$\delta^{L3}_{cf2,cf3,a}} \delta^{L31}_{cf2,cf3,a} * QCF_{cf3,a}^{-\rho^{L31}_{cf2,a}} + \sum_{f3\$\delta^{L3}_{cf2,f3,a}} \delta^{L31}_{cf2,f3,a} * ADFD_{f3,a} * FD_{f3,a}^{-\rho^{L31}_{cf2,a}} \right]^{-1} * \delta^{L31}_{cf2,cf3,a} * QCF_{cf3,a}^{(-\rho^{L31}_{cf2,a}-1)}$	L3.1
$CFD31FOC1_{cf2,f3,a}$	$WF_{f3} * WFDIST_{cf3,a} * (1+TF_{f3,a}) = PQD_{cf2} * PFDIST_{cf2,a} * QCF_{cf2,a} * \left[\sum_{cf3\$\delta^{L31}_{cf2,cf3,a}} \delta^{L31}_{cf2,cf3,a} * QCF_{cf3,a}^{-\rho^{L31}_{cf2,a}} + \sum_{f3\$\delta^{L31}_{cf2,f3,a}} \delta^{L31}_{cf2,f3,a} * ADFD_{f3,a} * FD_{f3,a}^{-\rho^{L31}_{cf2,a}} \right]^{-1} * \delta^{L31}_{cf2,f3,a} * ADFD_{f3,a}^{-\rho^{L31}_{cf2,a}} * FD_{f3,a}^{(-\rho^{L31}_{cf2,a}-1)}$	L3.1

Level 3.2 – CES aggregation of capital/labour

$FD32PFN_{f2,a}$

$$FD_{f2,a} = adf^{L32}_{f2,a} * \left[\sum_{f3\$\delta^{L32}_{f2,f3,a}} \delta^{L32}_{f2,f3,a} * ADFD_{f3,a} * FD_{f3,a}{}^{-\rho^{L32}_{f2,a}} \right]^{-1/-\rho^{L32}_{f2,a}} \quad \text{L3.1}$$

$FD32FOC_{f2,f3,a}$

$$WF_{f3} * WFDIST_{f3,a} * (1 + TF_{f3,a}) = WF_{f2} * WFDIST_{f2,a} * (1 + TF_{f2,a}) * FD_{f2,a} * \left[\sum_{f3\$\delta^{L32}_{f2,f3,a}} \delta^{L32}_{f2,f3,a} * ADFD_{f3,a} * FD_{f3,a}{}^{-\rho^{L32}_{f2,a}} \right]^{-1} * \delta^{L32}_{f2,f3,a} * ADFD_{f3,a}{}^{-\rho^{L32}_{f2,a}} * FD_{f3,a}{}^{(-\rho^{L32}_{f2,a}-1)} \quad \text{L3.1}$$

Level 4.1 – CES aggregation of manure and chemical fertilizer into fertilizer

$CFD41PFN_{cf3,a}$

$$QCF_{cf3,a} = adf^{L41}_{cf3,a} * \left[\sum_{cf4\$\delta^{L41}_{cf3,cf4,a}} \delta^{L41}_{cf3,cf4,a} * QCF_{cf4,a}{}^{-\rho^{L41}_{cf3,a}} \right]^{-1/-\rho^{L41}_{cf3,a}} \quad \text{L4.1}$$

$CFD41FOC_{cf3,cf4,a}$

$$PQD_{cf4} * PFDIST_{cf4,a} = PQD_{cf3} * PFDIST_{cf3,a} * QCF_{cf3,a} * \left[\sum_{cf4\$\delta^{L41}_{cf3,cf4,a}} \delta^{L41}_{cf3,cf4,a} * QCF_{cf4,a}{}^{-\rho^{L41}_{cf3,a}} \right]^{-1} * \delta^{L41}_{cf3,cf4,a} * QCF_{cf4,a}{}^{(-\rho^{L41}_{cf3,a}-1)} \quad \text{L4.1}$$

Level 4.2 – CES aggregation of land types

$FD42PFN_{f3,a}$

$$FD_{f3,a} = adf^{L42}_{f3,a} * \left[\sum_{n\$\delta^{L42}_{f3,n,a}} \delta^{L42}_{f3,n,a} * FD_{n,a}{}^{-\rho^{L42}_{f3,a}} \right]^{-1/-\rho^{L42}_{f3,a}} \quad \text{L4.2}$$

$FD42FOC_{f3,n,a}$

$$WF_{n} * WFDIST_{n,a} = WF_{f3} * WFDIST_{f3,a} * FD_{f3,a} * \left[\sum_{n\$\delta^{L42}_{f3,n,a}} \delta^{L42}_{f3,n,a} * FD_{n,a}{}^{-\rho^{L42}_{f3,a}} \right]^{-1} * \delta^{L42}_{f3,n,a} * FD_{n,a}{}^{(-\rho^{L42}_{f3,a}-1)} \quad \text{L4.2}$$

Level 4.3/4.4 – CES aggregation of capital and labour aggregates

$FD43PFN_{f3,a}$	$FD_{f3,a} = adf_{f3,a}^{L43} * \left[\sum_{f4\$\delta_{f3,f4,a}^{L43}} \delta_{f3,f4,a}^{L43} * FD_{f4,a}^{-\rho_{f3,a}^{L43}} \right]^{-1/-\rho_{f3,a}^{L43}}$
$FD43FOC_{f3,f4,a}$	$WF_{f4} * WFDIST_{f4,a} = WF_{f3} * WFDIST_{f3,a} * FD_{f3,a} * \left[\sum_{f4\$\delta_{f3,f4,a}^{L43}} \delta_{f3,f4,a}^{L43} * FD_{f4,a}^{-\rho_{f3,a}^{L43}} \right]^{-1} * \delta_{f3,f4,a}^{L43} * FD_{f4,a}^{(-\rho_{f3,a}^{L43}-1)}$

Level 5.1 – Leontief aggregation of seasonal labour

$FD51LEON1_{f4,f5,a}$	$FD_{f5,a} = ioleon_{f4,f5,a}^{51} * FD_{f4,a}$	$\forall aleon5_a$
$FD51LEON2_{f4,a}$	$WF_{f4} * WFDIST_{f4,a} = \sum_{f5} ioleon_{f4,f5,a}^{51} * WF_{f5} * WFDIST_{f5,a}$	$\forall aleon5_a$

Level 5.1/5.2 – CES aggregation of seasonal or permanent labour

$FD5PFN_{f4,a}$	$FD_{f4,a} = adf_{f4,a}^{L5} * \left[\sum_{f5\$\delta_{f4,f5,a}^{L5}} \delta_{f4,f5,a}^{L5} * FD_{f5,a}^{-\rho_{f4,a}^{L5}} \right]^{-1/-\rho_{f4,a}^{L5}}$
$FD5FOC_{f4,f5,a}$	$WF_{f5} * WFDIST_{f5,a} = WF_{f4} * WFDIST_{f4,a} * FD_{f4,a} * \left[\sum_{f5\$\delta_{f4,f5,a}^{L5}} \delta_{f4,f5,a}^{L5} * FD_{f5,a}^{-\rho_{f4,a}^{L5}} \right]^{-1} * \delta_{f4,f5,a}^{L5} * FD_{f5,a}^{(-\rho_{f4,a}^{L5}-1)}$

In principal, any of the above presented CES aggregation nests can also be represented as a Leontief nest.

C.1.4.3 Equations for Field Operations Production Structure (Chapter 4)

Name	Equation	Level
	CES Field Operations Level 3.1	
$FLD3PFN_{cf2,a}$	$QFIELD_{cf2,a} = adfield^{L31}_{cf2,a} * \left[\sum_{cf3\$\delta^{L31}_{cf2,cf3,a}} \delta^{L31}_{cf2,cf3,a} * QFIELD_{cf3,a}^{-\rho^{L31}_{cf2,a}} \right]^{-1/-\rho^{L31}_{cf2,a}}$	L3.1
$FLD3FOC1_{cf2,cf3,a}$	$PFIELD_{cf3} * PFDIST_{cf3,a} = PFIELD_{cf2} * PFDIST_{cf2,a} * QFIELD_{cf2,a} * \left[\sum_{cf3\$\delta^{L31}_{cf2,cf3,a}} \delta^{L31}_{cf2,cf3,a} * QFIELD_{cf3,a}^{-\rho^{L31}_{cf2,a}} \right]^{-1} * \delta^{L31}_{cf2,cf3,a} * QFIELD_{cf3,a}^{(-\rho^{L31}_{cf2,a}-1)}$	L3.1
	Leontief Field Operations Level 3.1	
$QFLDLEO31_{cf2,cf3,a}$	$QFIELD_{cf3,a} = iofield^{L31}_{cf2,cf3,a} * QFIELD_{cf2,a} \quad \forall aleon3_a$	L3.1
$PFLDLEO31_{cf2,cf3,a}$	$PFIELD_{cf2} * PFDIST_{cf2,a} = \sum_{cf3} PFIELD_{cf3} * PFDIST_{cf3,a} * iofield^{L31}_{cf2,cf3,a} \quad \forall aleon3_a$	L3.1
	CES Field Operations Level 4	
$FLD4PFN_{cf3,a}$	$QFIELD_{cf3,a} = adfield^{L4}_{cf3,a} * \left[\sum_{cf4\$\delta^{L4}_{cf3,cf4,a}} \delta^{L4}_{cf3,cf4,a} * QFIELD_{cf4,a}^{-\rho^{L4}_{cf3,a}} \right]^{-1/-\rho^{L4}_{cf3,a}}$	L4
$PFLD4FOC1_{cf3,cf4,a}$	$PFIELD_{cf4} * PFDIST_{cf4,a} = PFIELD_{cf3} * PFDIST_{cf3,a} * QFIELD_{cf3,a} * \left[\sum_{cf4\$\delta^{L4}_{cf3,cf4,a}} \delta^{L4}_{cf3,cf4,a} * QFIELD_{cf4,a}^{-\rho^{L4}_{cf3,a}} \right]^{-1} * \delta^{L4}_{cf3,cf4,a} * QFIELD_{cf4,a}^{(-\rho^{L4}_{cf3,a}-1)}$	L4

Name	Equation	Level
	CES Level 5	
$FLD5PFN_{cf4,a}$	$QFIELD_{cf4,a} = adfield^{L5}_{cf4,a} * \left[\sum_{cf5\$\delta^{L5}_{cf4,cf5,a}} \delta^{L5}_{cf4,cf5,a} * QFIELD_{cf5,a}^{-\rho^{L5}_{cf4,a}} + \sum_{n\$\delta^{L5}_{n,a}} \delta^{L5}_{n,a} * FD_{n,a}^{-\rho^{L5}_{cf4,a}} \right]^{-1/-\rho^{L5}_{cf4,a}}$	L5
$PFLD5FOC1_{cf4,cf5,a}$	$PFIELD_{cf5} * PFDIST_{cf5,a} = PFIELD_{cf4} * PFDIST_{cf4,a} * QFIELD_{cf4,a} * \left[\sum_{cf5\$\delta^{L5}_{cf4,cf5,a}} \delta^{L5}_{cf4,cf5,a} * QFIELD_{cf5,a}^{-\rho^{L5}_{cf4,a}} + \sum_{n\$\delta^{L5}_{cf4,n,a}} \delta^{L5}_{cf4,n,a} * FD_{n,a}^{-\rho^{L5}_{cf4,a}} \right]^{-1} * \delta^{L5}_{cf4,cf5,a} * QFIELD_{cf5,a}^{(-\rho^{L5}_{cf4,a}-1)}$	L5
$PFLD5FOC2_{cf4,n,a}$	$WF_n * WFDIST_{n,a} = PFIELD_{cf4} * PFDIST_{cf4,a} * QFIELD_{cf4,a} * \left[\sum_{cf5\$\delta^{L5}_{cf4,cf5,a}} \delta^{L5}_{cf4,cf5,a} * QFIELD_{cf5,a}^{-\rho^{L5}_{cf4,a}} + \sum_{n\$\delta^{L5}_{cf4,n,a}} \delta^{L5}_{cf4,n,a} * FD_{n,a}^{-\rho^{L5}_{cf4,a}} \right]^{-1} * \delta^{L5}_{cf4,n,a} * FD_{n,a}^{(-\rho^{L5}_{cf4,a}-1)}$	L5
	CES Level 6	
$FLD6PFN_{cf5,a}$	$QFIELD_{cf5,a} = adfield^{L6}_{cf5,a} * \left[\sum_{cf6\$\delta^{L6}_{cf5,cf6,a}} \delta^{L6}_{cf5,cf6,a} * QFIELD_{cf6,a}^{-\rho^{L6}_{cf5,a}} \right]^{-1/-\rho^{L6}_{cf5,a}}$	L6
$PFLD6FOC1_{cf5,cf6,a}$	$PFIELD_{cf6} * PFDIST_{cf6,a} = PFIELD_{cf5} * PFDIST_{cf5,a} * QFIELD_{cf5,a} * \left[\sum_{cf6\$\delta^{L6}_{cf5,cf6,a}} \delta^{L6}_{cf5,cf6,a} * QFIELD_{cf6,a}^{-\rho^{L6}_{cf5,a}} + \sum_{n\$\delta^{cf5}_{cf5,n,a}} \delta^{L6}_{cf5,n,a} * FD_{n,a}^{-\rho^{L6}_{cf5,a}} \right]^{-1} * \delta^{L6}_{cf5,cf6,a} * QFIELD_{cf6,a}^{(-\rho^{L6}_{cf5,a}-1)}$	L6

C.1.5 CES-LES-CES Demand System

The seasonal model developed in Chapter 3 contains a CES-LES-CES demand system. Modelling household demand using such a behavioural specification is rather rare, if not novel, within the CGE modelling literature. The system is illustrated in Figure C.3 below. At the bottom level, households' trade-off labour with leisure. In the middle level, leisure is aggregated from permanent and seasonal labour using a CES aggregation. Aggregation of real consumption follows a LES, wherein subsistence and discretionary spending is broken down on commodity groups. At the bottom level, a CES nest aggregates the single commodities (as reflected in the SAM) into the commodity groups.

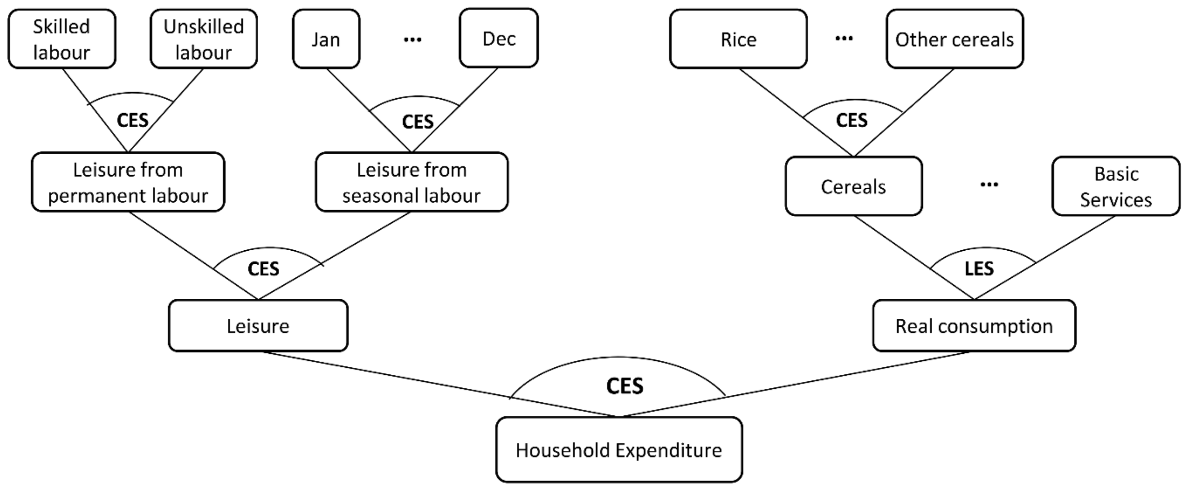


Figure C.3. Illustration of CES-LES-CES Demand System

The equations of the CES-LES-CES system are documented in the table below.

CES-LES-CES Household Demand System

Household expenditure and budget constraints

$HEXPEQ_h$	$HEXP_h = \left(YH_h - \left(1 - TYH_h\right)\right) * \left(1 - SHH_h\right) - \sum_{hp} HOHO_{hp,h}$
$HBUDGETEQ1_{c1,h}$	$HEXP_h = QCD_{c1,h} * PQDDIST_{c1,h} * PQD_{c1}$
$HBUDGETEQ2_h$	$QCD_{'consag'} = \sum_{c3} QCD_{c3,h}$
$HCONSEQ_h$	$HCONS_h = QCD_{'consag',h} * PQD_{'consag',h} * PQDDIST_{'consag',h}$

Bottom level – Labour-leisure trade-off

$UTILEQ_{c1,h}$	$QCD_{c1,h} = ad^{DS}_{c1,h} * \left(\sum_{c2\$\delta^{DS}_{c1,c2,h}} \delta^{DS}_{c1,c2,h} * QCD_{c2,h}^{-\rho^{DS}_{c1,h}} \right)^{-1/\rho^{DS}_{c1,h}}$
$UTILFOC1_{c2,c1,h}$	$PQD_{c2} * PQDDIST_{c2,h} = \left(QCD_{c1,h} * PQD_{c1} * PQDDIST_{c1,h}\right) * \left(\sum_{c2p\$\delta^{DS}_{c1,c2p,h}} \delta^{DS}_{c1,c2p,h} * QCD_{c2p,h}^{-\rho^{DS}_{c1,h}} \right)^{-1} * \delta^{DS}_{c1,c2,h} * QCD_{c2,h}^{\left(-\rho^{DS}_{c1,h}-1\right)}$

Middle level – CES aggregation of leisure

$QCDleisEQ_{'cleis',h}$	$QCD_{'cleis',h} = ad^{DS}_{'cleis',h} * \left(\sum_{c\$\delta^{DS}_{'cleis',c,h}} \delta^{DS}_{'cleis',c,h} * QCD_{c,h}^{-\rho^{DS}_{'cleis',h}} \right)^{-1/\rho^{DS}_{'cleis',h}}$
$QCDleisFOC_{'cleis',c,h}$	$PQD_c * \left(1 + TV_c\right) = \left(QCD_{'cleis',h} * PQD_{'cleis'} * PQDDIST_{'cleis',h}\right) * \left(\sum_{cp\$\delta^{DS}_{'cleis',cp,h}} \delta^{DS}_{'cleis',cp,h} * QCD_{cp,h}^{-\rho^{DS}_{'cleis',h}} \right)^{-1} * \delta^{DS}_{'cleis',c,h} * QCD_{c,h}^{\left(-\rho^{DS}_{'cleis',h}-1\right)}$

Middle level – LES demand system for real commodity groups

$QCDLESEQ_{c3,h}$	$PQD_{c3} * PQDDIST_{c3,h} * QCD_{c3,h} = PQD_{c3} * PQDDIST_{c3,h} * chagconst_{c3,h} + \beta_{c3,h} * \left(HCONS_h - \sum_{c3p} PQD_{c3p} * PQDDIST_{c3p,h} * chagconst_{c3p,h} \right)$

Top level – CES aggregation of real commodities

$QCD3EQ_{c3,h}$	$QCD_{c3,h} = ad^{DS}_{c3,h} * \left(\sum_{c\$\delta^{DS}_{c3,cp,h}} \delta^{DS}_{c3,c,h} * QCD_{c,h}^{-\rho^{DS}_{c3,h}} \right)^{-1/\rho^{DS}_{c3,h}}$
$QCD3FOC_{c3,h}$	$PQD_c * \left(1 + TV_c\right) = \left(QCD_{c3,h} * PQD_{c3} * PQDDIST_{c3,h}\right) * \left(\sum_{cp\$\delta^{DS}_{3,cp,h}} \delta^{DS}_{c3,cp,h} * QCD_{cp,h}^{-\rho^{DS}_{c3,h}} \right)^{-1} * \delta^{DS}_{c3,c,h} * QCD_{c,h}^{\left(-\rho^{DS}_{c3,h}-1\right)}$

C.2 Multi-product Industry Output

Following Punt (2013), the model was extended to allow for flexible multi-product output, for those sectors which belong to the subset *acet(a)*. The composition of multi-product output is governed by a CET specification and requires that the share of an industry's product output in total output, $IOQXACQXV_{a,c}$, is endogenized for those industries with flexible multi-product output.

Name	Equation	
	Output for industries with fixed multi-product output	
$ACTIVOUT_{a,c}$	$QXAC_{a,c} = IOQXACQXV_{a,c} * QX_a$	$\forall acetn_a$
$ACTIVOUT1_a$	$QX_a = ati_a * \left[\sum_c \gamma_{a,c} * QXAC_{a,c}^{\rho_a^{MO}} \right]^{\left(1/\rho_a^{MO} \right)}$	$\forall acet_a$
$ACTIVOUT2_{a,c}$	$QXAC_{a,c} = QX_a * \left(PXAC_{a,c} \Big/ \left(PX_a * \gamma_{a,c} * ati_a^{\rho_a^{MO}} \right) \right)^{\left(1/\left(\rho_a^{MO}-1\right) \right)}$	$\forall acet_a$
$PRODEQUIL_{a,c}$	$QXAC_{a,c} = IOQXACQXV_{a,c} * QX_a$	$\forall acet_a$
$PXDEF_a$	$PX_a = \sum_c IOQXACQXV_{a,c} * PXAC_{a,c}$	

C.3 Land Market Extensions

C.3.1 Two-phase land supply regime to model organic conversion policies

The land market in STAGE2 was extended to incorporate two phases of land supply changes in order to model the 100% organic agriculture conversion policy in Chapter 4.

The first phase is the exogenous conversion from conventional to organic land and the second phase is land expansion along an upward sloping land supply curve. Any converted land is captured by the parameter $CVT0_n$. The final quantity of converted land is equal to the difference in $CVT0_n$ and the variable CVI_n, which captures the idle convertible land (i.e., the part of the converted land which is not brought back under cultivation). The land rent remains fixed at base levels ($WF0_n = WF_n$) as long as land supply increases due to available converted land (i.e., $CVI_n \geq 0$). If all convertible land is cultivated (i.e., $CVI_n = 0$), then the regime switches to the second phase, which is governed by land supply curve. The land rent is again endogenously determined in this phase. In the specific context of Bhutan, the land supply curve expands arable land at the expense of existing fallow land. The increase in arable land resulting from the land supply curve is equal to the difference of the quantity of fallow land in the base, $FW0_n$, and the variable of remaining fallow land, FW_n. The equations of this two-phase land supply regime are presented below.

Name	**Equation**	
	Land market clearing condition	
$FSNCLEAR_n$	$FS0_n + CVT0_n + FW0_n - CVI_n - FW_n = FS_n$	$\forall on$
	Land supply curve	
$FSNCURVE_n$	$FW_n = FW0_n + FS0_n - \left(shfs_n * \left({WF_n}/{CPI} \right)^{elafs_n} \right)$	$\forall on$
	Binary wage regime	
$WFNEQ_n$	$\frac{WF_n}{CPI} = \begin{cases} \frac{WF0_n}{CPI}, \text{ if } FW_n \geq FW0_n \text{ or } CVI_n > 0 \\ \left(\frac{FS0_n + \left(FW0_n - FW_{on} \right)}{shfs_n} \right)^{\frac{1}{elafs_n}}, \text{if } FW_n \leq FW0_n \text{ and } CVI_n = 0 \end{cases}$	

The two phase land supply regime also requires the following restrictions:

Restriction for fallow land:

(0.1) $FW0_n \geq FW_n \qquad \forall on$

Restriction for converted land:

$CVI_n \geq 0 \qquad \forall on$

Restriction for land rent:

$WF0_n \leq WF_n \leq +\infty \qquad \forall on$

C.3.2 Land allocation via CET function

Agricultural land allocation in Chapter 6 is modelled using a Constant Elasticity of Transformation (CET) specification, which allows for a sluggish allocation of land governed by a CET (transformation) parameter ρ_n^{CET}.

Name	Equation
	CET land allocation
$LANDOUT1_n$	$FS_n = at_n^{CET} * \left[\sum_a \gamma_{n,a}^{CET} * FD_{n,ap}^{\rho_n^{CET}} \right]^{1/\rho_n^{CET}}$
$LANDOUT2_{n,a}$	$FD_{n,a} = FS_n * \left[WFDIST_{n,a} * \left(\gamma_{n,a}^{CET} * at_n^{CET\,\rho_n^{CET}} \right)^{-1} \right]^{\left(1/\rho_n^{CET} - 1 \right)}$

C.3.3 Land supply via an asymptotic supply curve

An asymptotic land supply curve (Eickhout et al., 2009) was implemented for the model analysis in Chapter 3 and 6. The asymptote, $alim_n$, is equal to the sum of all cultivated land, $FS0_n$, and all presently observed fallow land, $FLW0_n$. The calibration of the curve's two parameters, ω_n and θ_n is based on the inherent land supply elasticity, ε_n^{AL}. The asymptotic land supply curve calibration and final equation is documented below.

Calibration of ω_n and θ_n:

$$\omega_n = \varepsilon_n^{AL} * \frac{\left(alim_n - FLW0_n \right)}{FLW0_n}$$

$$\theta_n = FLW0_n * \frac{WF0_n}{PPI0}^{\omega_n}$$

Name	Equation
	Asymptotic land supply curve
$FSNCURVE2_n$	$FS_n = alim_n - \omega_n * \left(\frac{WF_n}{PPI} \right)^{-\omega_n}$

C.4 Factor Market Extensions

C.4.1 Factor market clearing by institutions

The clearing of the factor market is modified in Chapter 3 and 6 taking into account institutions' factor endowment. All institutions (i.e., households, enterprises, the government and the rest of the world) are members of the set ins . The SAM is extended with a satellite account recording factor ownership by institutions, $FSI_{ins,f}$. Factor supply to the production boundary is defined as the variable $FSIW_{ins,f}$ and factor supply to household specific leisure and reproduction activities is defined as $FSIL_{ins,f}$. Accounting for institutional factor ownership endogenises the functional share in factor income, captured by the variable $FSISH_{ins,f}$. Institution's income from factors is defined as $INSVA_{ins,f}$. Institutions share in factor income requires either a change in total factor endowment (e.g., because of unemployment) or because of a change in structure of factor endowment (e.g., because of labour mobility across sectors or labour segments). Labour mobility is not reflected in this thesis, but various settings of unemployment by using institutions' share, $ushr_{ins,f}$, in the quantity of unemployed factors $UNEMP_f$. The equations of the factor market clearing and income distribution by institutions are presented below:

Name	**Equation**
	Factor market clearing by institutions
$FSIEQ_{ins,f}$	$FSI_{ins,f} = FSIW_{ins,f} + FSIL_{ins,f} + ushr_{ins,f} * UNEMP_f$
$FSIWEQ_f$	$\sum_{ins} FSIW_{ins,f} = \sum_{a\$aprod_a} FD_{f,a}$
$FSILEQ_{h,f}$	$FSIL_{h,f} = \sum_{a\$map\_h\_alei_{h,a}} FD_{f,a}$
$FSISHEQ_{ins,f}$	$FSISH_{ins,f} = \frac{\left(FSIW_{ins,f} + FISL_{ins,f}\right)}{\sum_{insp} FSIW_{insp,f} + FSIL_{insp,f}}$
$INSVAEQ_{ins,f}$	$INSVA_{ins,f} = FSISH_{ins,f} * YFDISP_f$

C.4.2 Wage Curve for seasonal underemployment

A wage curve following (Blanchflower & Oswald, 1995) is implemented in Chapter 6 to account for seasonal underemployment using the subset *t(f)* for the different periods of seasonal labour. The real wage elasticity is assumed to be equal $\varepsilon_t = -0.1$. The scale parameter γ_t is calibrated by rearranging the wage curve specified in the equation presented below.

Name	Equation
	Wage curve for seasonal underemployment
$WCURVEEQ_t$	$\log\left(\frac{WF_t}{PPI}\right) = \gamma_t + \varepsilon_t * \log\left(UNEMP_t\right)$

C.5 Forest Land, Fuelwood Quotas and Aggregation of Fuelwood and Charcoal Commodities

For the analysis of forest policy scenarios in Chapter 6, two forms of quotas are introduced. A extraction quota, $EQ_{ins,rf}$, denotes the total extraction quota for commercial and subsistence fuelwood converted into forest area. The extraction quota is the upper limit of how much forest land, rf, the household specific fuelwood extraction activity, arf, can use. This forest land demand is captured by variable $FD_{rf,arf}$.

The extraction quota is enforced by the extraction quota rent adjuster $EQRADJ_{ins,rf}$. For reasons of consistency of physical output, households' extraction of commercial and subsistence fuelwood is treated in separate activities, leading to a mismatch of the number of extraction quotas and the activities constrained by them. Each households faces one extraction quota, which restricts the combined output of two activities. Equation $EQRMATCHEQ_{rf,arf}$ matches the quota constraint by mapping $EQRADJ_{ins,rf}$ with the activity specific quota rent, $EQR_{rf,arf}$, via the mapping $IARF(arf, ins)$.

The commercial fuelwood quota, $CQ_{arf.ccf}$, regulates the quantity of commercial fuelwood extraction by households' rural forestry activities, $QXAC_{arf,ccf}$. The commercial quota is enforced by the quota rent $CQR_{arf,ccf}$ and no additional equation is needed, since both are identified by the same sets.

Commercial fuelwood from the different household extraction activities, *arf*, is aggregated using the same equation used for the aggregation of homogenous commodities in STAGE2. Normally, imports and domestic production are aggregated using a CES function, but in case of charcoal the model is extended to allow for perfect substitution between imports and domestic production.

Name	**Equation**
	Extraction Quota
$EQUOTAEQ_{ins,rf}$	$EQ_{ins,rf} \geq \sum_{arf \forall IARF_{arf,ins}} FD_{rf,arf}$
$EQRMATCHEQ_{rf,arf}$	$EQR_{rf,arf} = \sum_{ins \forall IARF_{arf,ins}} EQRADJ_{ins,rf}$
	Commercial Quota
$CQUOTAEQ_{arf,ccf}$	$CQ_{arf,ccf} \geq \frac{QXAC_{arf,ccf}}{H_{arf}}$
$EQUOTARENTEQ_{h}$	$EQUOTARENT_{h} = \sum_{a,rfor \forall IARF_{a,h}} EQR_{rfor,a} * WF_{rfor} * WFDIST_{rfor,a} * FD_{rf,a}$
$CQUOTARENTEQ_{h}$	$CQUOTARENT_{h} = \sum_{arf,rfor \forall IARF_{arf,h}} QX_{arf} * PX_{arf} * CQR_{arf}$
	Aggregation of. commercial fuelwood
$COMOUT2_{c}$	$QXC_{ccf} = \sum_{a} QXAC_{a,ccf}$
	Aggregation of domestic and imported charcoal
$QCHARCQQ_{c}$	$QQ_{c} - QD_{c} \geq QM_{c} \qquad \forall cchar_{c}$

Bibliography

Acs, S., Berentsen, P. B.M., & Huirne, R. B.M. (2007). Conversion to organic arable farming in The Netherlands: A dynamic linear programming analysis. *Agricultural Systems*, *94*(2), 405–415. Retrieved from http://www.sciencedirect.com/science/article/pii/S0308521X06001697

Adam, J. C. (2009). Improved and more environmentally friendly charcoal production system using a low-cost retort–kiln (Eco-charcoal). *Renewable Energy*, *34*(8), 1923–1925. https://doi.org/10.1016/j.renene.2008.12.009

Adamtey, N., Musyoka, M. W., Zundel, C., Cobo, J. G., Karanja, E., Fiaboe, K. K.M., . . . Foster, D. (2016). Productivity, profitability and partial nutrient balance in maize-based conventional and organic farming systems in Kenya. *Agriculture, Ecosystems & Environment*, *235*, 61–79. https://doi.org/10.1016/j.agee.2016.10.001

ADB. (2012). *Supply and use tables for selected economies in Asia and the Pacific: A research study*. Mandaluyonng City, Philippines. Retrieved from Asian Development Bank website: http://www.adb.org/publications/supply-and-use-tables-selected-economies-asia-and-pacific-research-study

ADB, & NSB. (2013). *Bhutan Living Standard Survey (BLSS) 2012*. Thimphu, Bhutan.

Aeschbach-Hertig, W., & Gleeson, T. (2012). Regional strategies for the accelerating global problem of groundwater depletion. *Nature Geoscience*, *5*(12), 853–861. https://doi.org/10.1038/ngeo1617

Ahamad, M. G., Khondker, R. K., Ahmed, Z. U., & Tanin, F. (2011). Seasonal Unemployment and Voluntary Out-Migration from Northern Bangladesh. *Modern Economy*, *02*(02), 174–179. https://doi.org/10.4236/me.2011.22023

Ali, F., & Parikh, A. (1992). Relationships among labor, bullock, and tractor inputs in Pakistan agriculture. *American Journal of Agricultural Economics*, *74*(2), 371–377. Retrieved from http://ajae.oxfordjournals.org/content/74/2/371.short

Alkire, S., & Foster, J. (2011). Counting and multidimensional poverty measurement. *Journal of Public Economics*, *95*(7), 476–487. https://doi.org/10.1016/j.jpubeco.2010.11.006

AMC. (2014). *Machinery Price List*. Paro, Bhutan. Retrieved from Agriculture Machinery Centre (AMC) Paro website: http://www.amc.gov.bt/index.php?r=product/index

Anand, S., & Sen, Amartya. (1994). *Human Development Index: Methodology and Measurement* (Human Development Report Office Occasional Papers No. 12). New York, USA.

Antal, M. J., & Grønli, M. (2003). The art, science, and technology of charcoal production. *Industrial & Engineering Chemistry Research*, *42*(8), 1619–1640.

Aragie, E., Dudu, H., Ferrari, E., Mainar Causapé, A., McDonald, Scott, & Thierfelder, K. (2017). *STAGE_DEV: A variant of the STAGE model to analyse developing countries*. Brussels: Publications Office of the European Union. Retrieved from http://publications.jrc.ec.europa.eu/repository/bitstream/JRC104686/kj-na-28627-en-n_.pdf

Armington, P. S. (1969). A Theory of Demand for Products Distinguished by Place of Production. *IMF Staff Papers*, *16*(1), 159–178.

Arndt, C., Benfica, R., Maximiano, N., Nucifora, A. M. D., & Thurlow, James T. (2008). Higher fuel and food prices: impacts and responses for Mozambique. *Agricultural Economics*, *39*(August), 497–511. https://doi.org/10.1111/j.1574-0862.2008.00355.x

Arndt, H. (1981). Economic Development: A Semantic History. *Economic Development and Cultural Change*, *29*(3), 457–466. https://doi.org/10.1086/451266

Arrow, K. J., & Debreu, G. (1954). Existence of an equilibrium for a competitive economy. *Econometrica: Journal of the Econometric Society*, 265–290. Retrieved from http://www.jstor.org/stable/1907353

Atwood, S., Nagpal, S., Mbuya, N., & Laviolette, L. (2014). *Nutrition in Bhutan: Situational Analysis and Policy Recommendations*. Washington DC, USA.

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M. J., Aviles-Vazquez, K., . . . Perfecto, I. (2007). Organic agriculture and the global food supply. *Renewable Agriculture and Food Systems*, *22*(2), 86–108.

Bailis, R., Rujanavech, C., Dwivedi, P., Oliveira Vilela, A. de, Chang, H., & Miranda, R. C. de. (2013). Innovation in charcoal production: A comparative life-cycle assessment of two kiln technologies in Brazil. *Energy for Sustainable Development*, *17*(2), 189–200. https://doi.org/10.1016/j.esd.2012.10.008

Bajgai, R., & Tshering, S. (2012). *Rural-urban migration: A challenge in preserving socio-cultural practices and values: Case of Barapangthang village* (Proc. of the 2nd Int. Seminar on Population and Development). Kanglung, Bhutan.

Ballard, C. (2000). How many hours are in a simulated day? The effects of time endowment on the results of tax-policy simulation models. *Unpublished Paper, Michigan State University*. Retrieved from https://pdfs.semanticscholar.org/59b3/4cbb9cc1c02f2c0735dec3e3bcb9ad632507.pdf

Banerjee, A., & Bandopadhyay, R. (2016). Biodiversity Hotspot of Bhutan and its Sustainability. *Current Science*, *110*(4), 521. https://doi.org/10.18520/cs/v110/i4/521-528

Banse, M., van Meijl, H., Tabeau, A., & Woltjer, G. (2008). Will EU biofuel policies affect global agricultural markets? *European Review of Agricultural Economics*, *35*(2), 117–141. https://doi.org/10.1093/erae/jbn023

Barbier, Edward B. (2010). Poverty, development, and environment. *Environment and Development Economics*, *15*(06), 635–660. https://doi.org/10.1017/S1355770X1000032X

Barbier, Edward B. (2012). Sustainability. The green economy post Rio+20. *Science (New York, N.Y.)*, *338*(6109), 887–888. https://doi.org/10.1126/science.1227360

Barbieri, P., Pellerin, S., & Nesme, T. Comparing crop rotations between organic and conventional farming. *Scientific Reports*, *7*(1), 13761. https://doi.org/10.1038/s41598-017-14271-6

Bardhan, P. K. (1984). Determinants of supply and demand for labor in a poor agrarian economy: an analysis of household survey data from rural West Bengal. In H. Binswanger & M. Rosenzweig (Eds.), *Contractual Arrangements, Employment and Wages in Rural Labor Markets: A Critical Review.* New Haven, CT: Yale University Press.

Basu, A. K. (2013). Impact of rural employment guarantee schemes on seasonal labor markets: Optimum compensation and workers' welfare. *The Journal of Economic Inequality*, *11*(1), 1–34. https://doi.org/10.1007/s10888-011-9179-y

BBS (2012, March 18). Businesses affected by Rupee crunch. *BBS Online News*. Retrieved from http://www.bbs.bt/news/?p=10449

BBS. (2013). Free electricity to rural households. Retrieved from http://www.bbs.bt/news/?p=32694

BCCL. (2014). *Annual Report 2013*. Phuentsholing, Bhutan.

BEA. (2013). *Bhutan Power Corporation Limited Tariff Review Report*. Thimphu.

Beer, J. H. de, & McDermott, M. J. (1996). The economic value of non-timber forest products in Southeast Asia. Netherlands Committee for IUCN, Amsterdam, The Netherlands. *The Economic Value of Non-Timber Forest Products in Southeast Asia. 2nd Ed. Netherlands Committee for IUCN, Amsterdam, the Netherlands.*, -.

Belli, P., Anderson, J., Barnum, H., Dixon, J., & Tan, J.-P. (1998). *Handbook on economic analysis of investment operations*: Citeseer. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.176.1056&rep=rep1&type=pdf

Bengtsson, J., Ahnström, J., & Weibull, A.-C. (2005). The effects of organic agriculture on biodiversity and abundance: a meta-analysis. *Journal of Applied Ecology*, *42*(2), 261–269. https://doi.org/10.1111/j.1365-2664.2005.01005.x

Bernard, A., Haurie, A., Vielle, M., & Viguier, L. (2008). A two-level dynamic game of carbon emission trading between Russia, China, and Annex B countries. *Journal of Economic Dynamics and Control*, *32*(6), 1830–1856. https://doi.org/10.1016/j.jedc.2007.07.001

BFAL. (2014). *Annual Report 2013*. Phuentsholing, Bhutan.

Binswanger, H. P., & Rosenzweig, M. R. (1981). *Contractual arrangements, employment, and wages in rural labor markets: a critical review* (Studies in Employment and Rural Development No. 67). Washington D.C., USA. Retrieved from http://documents.worldbank.org/curated/en/412971467997610342/Contractual-arrangements-employment-and-wages-in-rural-labor-markets-a-critical-review

Blanchflower, D. G., & Oswald, A. J. (1995). An introduction to the wage curve. *The Journal of Economic Perspectives*, 153–167. Retrieved from http://www.jstor.org/stable/2138431

Board, S. (2009). *Firm's Problem*. Los Angeles, USA. Retrieved from http://www.econ.ucla.edu/sboard/teaching/econ11_09/econ11_09_lecture5.pdf

Boeters, S., & Savard, L. (2013). The labor market in computable general equilibrium models. *Handbook of Computable General Equilibrium Modeling*, *1*, 1645–1718. Retrieved from https://ideas.repec.org/h/eee/hacchp/v1y2013icp1645-1718.html

Böhringer, C., Carbone, J. C., & Rutherford, T. F. (2016). The Strategic Value of Carbon Tariffs. *American Economic Journal: Economic Policy*, *8*(1), 28–51. https://doi.org/10.1257/pol.20130327

Border, K. C. (2001). *Examples of Cost and Production Functions*. Pasadena, USA. Retrieved from Caltech website: people.hss.caltech.edu/~kcb/Notes/CostFunctionExamples.pdf

Borjas, G. (2000). *Labor Economics* (2nd ed.). Boston, USA: Irwin/McGraw-Hill.

Boserup, E. (2005). *The Conditions of Agricultural Growth*. New York, USA: Routledge.

Bouët, A., Dimaranan, B. V., & Valin, H. (2010). *Modeling the global trade and environmental impacts of biofuel policies* (IFPRI Discussion Paper No. 01018). Washington DC.

Bouët, A., Femenia, F., & Laborde, D. (2014). *Taking into account the evolution of world food demand in CGE simulations of policy reforms: the role of demand systems* (Presented at the 17th Annual Conference on Global Economic Analysis, Dakar, Senegal). Retrieved from https://www.gtap.agecon.purdue.edu/resources/download/6876.pdf

Boulanger, P., Dudu, H., Ferrari, E., & Philippidis, G. (2016). Russian Roulette at the Trade Table: A Specific Factors CGE Analysis of an Agri-food Import Ban. *Journal of Agricultural Economics*, *67*(2), 272–291. https://doi.org/10.1111/1477-9552.12156

Boyreau, G., & Rama, M. (2015). *Bhutan Macroeconomic and Public Finance Policy Note: Hydropower Impact and Public Finance Reforms towards Economic Self-Reliance*. Washington DC, USA. Retrieved from https://openknowledge.worldbank.org/handle/10986/24581

BPC. (2013). *Annual Report 2012*. Thimphu, Bhutan.

Breisinger, C., Thomas, M., & Thurlow, James. (2009). *Social accounting matrices and multiplier analysis: An introduction with exercises*. Washington D.C., USA: Intl Food Policy Res Inst.

Brooks, J. S. (2013). Avoiding the Limits to Growth: Gross National Happiness in Bhutan as a Model for Sustainable Development. *Sustainability*, *5*(9), 3640–3664. https://doi.org/10.3390/su5093640

Bruggeman, D., Meyfroidt, P., & Lambin, Eric F. (2016). Forest cover changes in Bhutan: Revisiting the forest transition. *Applied Geography*, *67*, 49–66. https://doi.org/10.1016/j.apgeog.2015.11.019

Brundtland, G. (1987). Our common future: Report of the 1987 World Commission on Environment and Development. *United Nations, Oslo*, *1*, 59.

Buffum, B., Gratzer, G., & Tenzin, Y. (2008). The sustainability of selection cutting in a late successional broadleaved community forest in Bhutan. *Forest Ecology and Management*, *256*(12), 2084–2091. Retrieved from http://www.sciencedirect.com/science/article/pii/S037811270800594X

Calzadilla, A., Rehdanz, K., Betts, R., Falloon, P., Wiltshire, A., & Tol, R. S. J. (2013). Climate change impacts on global agriculture. *Climatic Change*, *120*(1), 357–374. https://doi.org/10.1007/s10584-013-0822-4

Card, D. (1994). *Intertemporal Labor Supply: An Assessment* (Advances in Econometrics, Sixth World Congress). Cambridge University Press.

Cassman, Kenneth. (2007). Can organic agriculture feed the world—science to the rescue? *Renewable Agriculture and Food Systems*, *22*(02), 83–84. https://doi.org/10.1017/S1742170507001986

Castañeda, A., Doan, D., Newhouse, D., Nguyen, M. C., Uematsu, H., & Azevedo, J. P. (2018). A New Profile of the Global Poor. *World Development*, *101*, 250–267. https://doi.org/10.1016/j.worlddev.2017.08.002

Centre for Bhutan Studies & GNH Research. (2015). *A compass towards a just and harmonious society: 2015 GNH Survey Report*. Thimphu, Bhutan. Retrieved from Centre for Bhutan Studies & GNH Research website:

http://www.grossnationalhappiness.com/wp-content/uploads/2017/01/Final-GNH-Report-jp-21.3.17-ilovepdf-compressed.pdf

Chambers, R. (2012). Foreword. In S. Devereux, R. Sabates-Wheeler, & R. Longhurst (Eds.), *Seasonality, rural livelihoods and development* (xv-viii). Routledge.

Chambers, R., Longhurst, R., & Pacey, A. (1981). *Seasonal dimensions to rural poverty*: Frances Pinter. Retrieved from https://opendocs.ids.ac.uk/opendocs/bitstream/handle/123456789/136/rc166.pdf?sequence=2

Chettri, G., Ghimiray, M., & Floyd, C. N. (2003). Effects of farmyard manure, fertilizers and green manuring in rice-wheat systems in Bhutan: results from a long-term experiment. *Experimental Agriculture*, *39*(02), 129–144.

Chiang, A. C., & Wainwright, K. (2005). *Fundamental Methods of Mathematical Economics // Fundamental methods of mathematical economics* (4th International Edition // 4. ed., internat. ed., [reprint.]). *McGraw-Hill international edition*. New York, USA: McGraw-Hill.

Christensen, G., Fileccia, T., & Gulliver, A. (2012). *Bhutan - Agricultural sector review: Issues, institutions and policies*. Rome.

Christiaensen, L., Demery, L., & Kuhl, J. (2011). The (evolving) role of agriculture in poverty reduction—An empirical perspective. *Journal of Development Economics*, *96*(2), 239–254. https://doi.org/10.1016/j.jdeveco.2010.10.006

CIA. (2012). *Bhutan Administrative Divisions 2012*. Washington D.C., USA: U.S. Central Intelligence Agency. Retrieved from http://legacy.lib.utexas.edu/maps/middle_east_and_asia/txu-pclmaps-oclc-780922902-bhutan_admin-2012.jpg

Cicowiez, M., Lofgren, H., & Escobar, P. (2017). *How many households does a CGE model need and how should they be disaggregated?* (5308 Conference Paper - 20th Global Economic Analysis Conference No. 5308). Purdue, USA. Retrieved from https://www.gtap.agecon.purdue.edu/resources/download/8539.pdf

Coady, D., Parry, I., Sears, L., & Shang, B. (2017). How Large Are Global Fossil Fuel Subsidies? *World Development*, *91*, 11–27. https://doi.org/10.1016/j.worlddev.2016.10.004

Combes Motel, P., Choumert, J., Minea, A., & Sterner, T. (2014). Explorations in the Environment–Development Dilemma. *Environmental and Resource Economics*, *57*(4), 479–485. https://doi.org/10.1007/s10640-013-9745-9

Connolly, M. (2008). Here comes the rain again: Weather and the intertemporal substitution of leisure. *Journal of Labor Economics*, *26*(1), 73–100.

Connor, D. J. (2008). Organic agriculture cannot feed the world. *Field Crops Research*, *106*(2), 187–190.

Cook, J. D. (2010). *Determining distribution parameters from quantiles*. Houston, Texas. Retrieved from University of Texas website: http://biostats.bepress.com/cgi/viewcontent.cgi?article=1055&context=mdandersonbiostat

Covey, K., Carroll, C. J. W., Duguid, M. C., Dorji, Kuenzang, Dorji, Tsewang, Tashi, S., . . . Ashton, M. (2015). Developmental dynamics following selective logging of an evergreen oak forest in the Eastern Himalaya, Bhutan: Structure, composition, and spatial pattern. *Forest Ecology and Management*, *336*, 163–173. Retrieved from http://www.sciencedirect.com/science/article/pii/S0378112714005866

Dabbert, S., Haring, A. M., & Zanoli, R. (2004). *Organic farming: Policies and prospects*: Zed Books.

Danzer, A. M. (2013). Benefit Generosity and the Income Effect on Labour Supply: Quasi-Experimental Evidence. *The Economic Journal*, *123*(571), 1059–1084. https://doi.org/10.1111/ecoj.12006

Dasgupta, S., Deichmann, U., Meisner, C., & Wheeler, D. (2005). Where is the Poverty–Environment Nexus? Evidence from Cambodia, Lao PDR, and Vietnam. *World Development*, *33*(4), 617–638. https://doi.org/10.1016/j.worlddev.2004.10.003

Datt, G., & Ravallion, M. (1998). Farm productivity and rural poverty in India. *Journal of Development Studies*, *34*(4), 62–85. https://doi.org/10.1080/00220389808422529

Deaton, A. (1997). *The analysis of household surveys: A microeconometric approach to development policy* (1. print). Baltimore Md. u.a.: Johns Hopkins Univ. Press.

Dellink, R. B. (2003). Economic impacts of pollution and abatement: A dynamic empirical modelling assessment (PhD Dissertation). VU University Amsterdam, Amsterdam.

Dema, Y., Dorji, Karma Dema, Pem, T., & Tenzin, N. (2012). Long term study on potato-maize based farming system as managed by the farmers of Eastern Bhutan. *Journal of RNR Bhutan*, *8*(1), 53–62.

Dercon, S., & Krishnan, P. (2000). Vulnerability, seasonality and poverty in Ethiopia. *Journal of Development Studies*, *36*(6), 25–53. https://doi.org/10.1080/00220380008422653

Dervis, K., Melo, J. de, & Robinson, Sherman. (1982). *General equilibrium models for development policy* (No. 0521270308). New York, USA.

Devarajan, S., Lewis, J. D., & Robinson, Sherman. (1990). Policy lessons from trade-focused, two-sector models. *Journal of Policy Modeling*, *12*(4), 625–657.

Devarajan, S., & Robinson, Sherman. (2005). The Influence of Computable General Equilibrium Models on Policy. *Frontiers in Applied General Equilibrium Modeling: in Honor of Herbert Scarf*, 402.

Devereux, S. (2016). Social protection for enhanced food security in sub-Saharan Africa. *Food Policy*, *60*, 52–62. https://doi.org/10.1016/j.foodpol.2015.03.009

Devereux, S., Sabates-Wheeler, R., & Longhurst, R. (Eds.). (2012). *Seasonality, rural livelihoods and development*: Routledge.

DGPC. (2013). *Annual Report 2012*. Thimphu, Bhutan.

DGPC. (2014). *Annual Report 2013*. Thimphu, Bhutan.

Dhamodaran, T. K., & Babu, S. (2011). Potential of community level utilization of coconut shell and stem wood for charcoal and activated carbon in Kerala. *Journal of the Indian Academy of Wood Science*, *8*(2), 89–96. Retrieved from http://link.springer.com/article/10.1007/s13196-012-0024-0

Dherani, M., Pope, D., Mascarenhas, M., Smith, K., Weber, Martin, & Bruce, N. (2008). Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis. *Bulletin of the World Health Organization*, *86*(5), 390. Retrieved from http://www.scielosp.org/scielo.php?pid=S0042-96862008000500017&script=sci_arttext&tlng=es

DHI. (2013). *Annual Report 2012*. Thimphu, Bhutan.

DHI. (2014). *Annual Report 2013*. Thimphu, Bhutan.

Dixon, P., & Jorgenson, D. W. (2013). Introduction. In *Handbook of Computable General Equilibrium Modeling. Handbook of Computable General Equilibrium Modeling SET, Vols. 1A and 1B* (Vol. 1, pp. 1–22). Elsevier. https://doi.org/10.1016/B978-0-444-59568-3.00001-8

Dixon, P., & Rimmer, M. T. (2011). You can't have a CGE recession without excess capacity. *Economic Modelling*, *28*(1-2), 602–613. Retrieved from https://www.sciencedirect.com/science/article/pii/S0264999310001082

Dorji, N., Flinn, J. C., & Maranan, C. (1990). *Rice Production in the Wangdiphodrang-Punakha Valley of Bhutan* (IRRI Research Paper Series No. 140). Manila, Philippines.

Dorji, R., & Schmidt, K. (2014). *Review of Community Forestry and Analysis of its Strengths and Weaknesses for Future Directions*. Thimphu, Bhutan.

Dorosh, P., & Hazell, Peter. (2003). Growth Linkages, Price Effects and Income Distribution in Sub-Saharan Africa. *Journal of African Economics*, *12*(2), 207–235. https://doi.org/10.1093/jae/12.2.207

Duba, S., Ghimiray, Mahesh, & Gurung, Tayan. (2008). *Promoting organic farming in Bhutan*. Thimphu, Bhutan.

Dukpa, C. (2015). *Questions on Ara production*. Email. Stuttgart, Germany.

Dukpa, C., & Feuerbacher, Arndt. (2018). *Participatory compilation of seasonal calendars in nine Bhutanese districts* (mimeo).

Dukpa, C., & Namgay, T. (2014). *Gewog centre altitude data*. Email. Stuttgart, Germany.

Dukpa, K. (2015). *Interview at MoAF-PPD on food balance in Bhutan and underlying coefficients*. Oral. Thimphu, Bhutan.

Dukpa, T., Wangchuk, P., Rinchen, Wangdi K., & Roder, W. (2007). Changes and innovations in the management of shifting cultivation land in Bhutan. In M. Cairns (Ed.), *Voices from the Forest: Integrating Indigenous Knowledge into Sustainable Upland Farming* (pp. 692–699). London: Earthscan.

Duraiappah, A. K. (1998). Poverty and environmental degradation: A review and analysis of the nexus. *World Development*, *26*(12), 2169–2179. https://doi.org/10.1016/S0305-750X(98)00100-4

Eickhout, Bas, van Meijl, Hans, Tabeau, Andrzej, & Stehfest, E. (2009). The impact of environmental and climate constraints on global food supply. *Economic Analysis of Land Use in Global Climate Change Policy*, *14*, 206.

Ellis, F. (1998). Household strategies and rural livelihood diversification. *Journal of Development Studies*, *35*(1), 1–38. https://doi.org/10.1080/00220389808422553

Emmerich, F. G., & Luengo, C. A. (1996). Babassu charcoal: A sulfurless renewable thermo-reducing feedstock for steelmaking. *Biomass and Bioenergy*, *10*(1), 41–44. https://doi.org/10.1016/0961-9534(95)00060-7

European Council. (2007). Council regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing regulation (EEC) No 2092/91. *Off. J. Eur. Union*, *189*, 1–23.

Evenson, R. E., & Gollin, D. (2003). Assessing the impact of the green revolution, 1960 to 2000. *Science (New York, N.Y.)*, *300*(5620), 758–762. https://doi.org/10.1126/science.1078710

Evers, M., Mooij, R. de, & van Vuuren, D. (2008). The Wage Elasticity of Labour Supply: A Synthesis of Empirical Estimates. *De Economist*, *156*(1), 25–43. https://doi.org/10.1007/s10645-007-9080-z

Ezzati, M., & Kammen, D. M. (2001). Indoor air pollution from biomass combustion and acute respiratory infections in Kenya: an exposure-response study. *The Lancet*, *358*(9282), 619–624. Retrieved from http://www.sciencedirect.com/science/article/pii/S0140673601057774

Fafchamps, M. (1993). Sequential labor decisions under uncertainty: An estimable household model of West-African farmers. *Econometrica: Journal of the Econometric Society*, 1173–1197. Retrieved from http://www.jstor.org/stable/2951497

Fairweather, J. R. (1999). Understanding how farmers choose between organic and conventional production: Results from New Zealand and policy implications. *Agriculture and Human Values*, *16*(1), 51–63. https://doi.org/10.1023/A:1007522819471

FAO. (1983). *Wood Fuel Surveys* (Forestry for local community development programme). Rome. Retrieved from Food and agriculture Organization of the United Nation website: http://www.fao.org/docrep/q1085e/q1085e00.htm#Contents

FAO. (2009). *Declaration of the world summit on food security*. Rome, Italy.

FAO. (2012). *Bhutan - Agricultural Sector review Vol. 1*. Rome, Italy.

FAO. (2017). FAOSTAT database. Retrieved from http://www.fao.org/faostat/en/

Fehr, E., & Goette, L. (2007). Do Workers Work More if Wages Are High? Evidence from a Randomized Field Experiment. *American Economic Review*, *97*(1), 298–317. https://doi.org/10.1257/aer.97.1.298

Feuerbacher, Arndt, Dukpa, C., & Grethe, H. (2017). *A 2012 Social Accounting Matrix (SAM) for Bhutan with a detailed representation of the agricultural sector: Technical Documentation* (Working Paper No. 94). Berlin. Retrieved from Department of Agricultural Economics, Faculty of Life Sciences, Humboldt-Universität zu Berlin website: https://www.agrar.hu-berlin.de/de/institut/departments/daoe/publ/wp/wp94.pdf

Feuerbacher, Arndt, & Grethe, H. (2017). *Incorporating seasonality of labour markets in a general equilibrium framework*. Paper presented at the 20th Annual Conference on Global Economic Analysis, Purdue, USA.

Feuerbacher, Arndt, Luckmann, J., Boysen, O., & Grethe, H. (2017). *The 100% Organic Agriculture Policy in Bhutan – A gift or a curse?* (GTAP Resources No. 4874). Purdue. Retrieved from https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=4874

Feuerbacher, Arndt, Luckmann, J., Boysen, O., Zikeli, S., & Grethe, H. (2018). Is Bhutan destined for 100% organic? Assessing the economy-wide effects of a large-scale conversion policy. *PloS One*, *13*(6), e0199025. https://doi.org/10.1371/journal.pone.0199025

Feuerbacher, Arndt, Siebold, M., Chhetri, A., Lippert, C., & Sander, K. (2016). Increasing forest utilization within Bhutan's forest conservation framework: The economic benefits of charcoal production. *Forest Policy and Economics*, *73*, 99–111. https://doi.org/10.1016/j.forpol.2016.08.007

Feuerbacher, Arndt C. (2014). Development of a 2007 Social Accounting Matrix (SAM) for Bhutan and Multiplier-Based Policy Experiments (Master Thesis). University of Hohenheim, Stuttgart.

Filipski, M., Aboudrare, A., Lybbert, T. J., & Taylor, J. Edward. (2017). Spice Price Spikes: Simulating Impacts of Saffron Price Volatility in a Gendered Local Economy-Wide Model. *World Development*, *91*, 84–99. Retrieved from http://www.sciencedirect.com/science/article/pii/S0305750X16305204

Finnoff, D., & Tschirhart, J. (2008). Linking dynamic economic and ecological general equilibrium models. *Resource and Energy Economics*, *30*(2), 91–114. Retrieved from http://www.sciencedirect.com/science/article/pii/S0928765507000450

Fisher, D. U., & Knutson, R. D. (2013). Uniqueness of Agricultural Labor Markets. *American Journal of Agricultural Economics*, *95*(2), 463–469. https://doi.org/10.1093/ajae/aas088

Fitzherbert, E. B., Struebig, M. J., Morel, A., Danielsen, F., Brühl, C. A., Donald, P. F., & Phalan, B. (2008). How will oil palm expansion affect biodiversity? *Trends in Ecology & Evolution*, *23*(10), 538–545. https://doi.org/10.1016/j.tree.2008.06.012

Flagg, J. A. (2015). Aiming for zero: what makes nations adopt carbon neutral pledges? *Environmental Sociology*, *1*(3), 202–212. https://doi.org/10.1080/23251042.2015.1041213

Fontana, M., & Wood, A. (2000). Modeling the Effects of Trade on Women, at Work and at Home. *World Development*, *28*(7), 1173–1190. https://doi.org/10.1016/S0305-750X(00)00033-4

Franz, W. (2013). *Arbeitsmarktökonomik* (8., aktualisierte und ergänzte Auflage). *Springer-Lehrbuch*. Berlin, Heidelberg: Springer Gabler.

FRMD. (2017). *Land Use and Land Cover of Bhutan 2016, Maps and Statistics*. Thimphu, Bhutan.

Ghaley, B. B., & Christiansen, J. L. (2010). On-farm assessment of mineral nitrogen and cultivar effects on rice productivity in Bhutan highlands. *Acta Agriculturae Scandinavica, Section B - Plant Soil Science*, *60*(5), 460–471. https://doi.org/10.1080/09064710903156295

Ghimiray, Mahesh. (2012). An analysis of rice varietal improvement and adoption rate by farmers in Bhutan. *Journal of Renewable Natural Resources Bhutan*, *8*(1), 13–24.

Ghimiray, Mahesh, Chhetri, M., & Dukpa, W. (2009). *Rice Production Practices for Low Altitude Belt: Field Manual*. Retrieved from Council for RNR Research Bhutan website: http://rcbajo.gov.bt/wp-content/uploads/2016/03/Rice-production-guide-for-south.pdf

Ghimiray, Mahesh, Dorji, Karma D., Katwal Bdr., T., Penjore, U., Dorji, S., Pem, S., . . . Pradhan, K. (2008). *Rice in Bhutan: A Source Book*. Thimphu, Bhutan.

Gilani, H., Shrestha, H., Murthy, M. S. R., Phuntso, P., Pradhan, S., Bajracharya, B., & Shrestha, B. (2015). Decadal land cover change dynamics in Bhutan. *Journal of Environmental Management*, *148*, 91–100. https://doi.org/10.1016/j.jenvman.2014.02.014

Ginsburgh, V. A., & Keyzer, M. (2002). *The structure of applied general equilibrium models* (1st MIT Press paperback ed.). Cambridge, Mass.: MIT Press.

GNHC. (2009). *Tenth Five Year Plan 2008-2013: Volume 1: Main Document*. Thimphu, Bhutan.

GNHC. (2013). *Eleventh Five Year Plan 2013-2018: Volume 1: Main Document*. Thimphu.

GNHC. (2018). Mandate. Retrieved from https://www.gnhc.gov.bt/en/?page_id=524

Goldberg, J. (2016). Kwacha Gonna Do? Experimental Evidence about Labor Supply in Rural Malawi. *American Economic Journal: Applied Economics*, *8*(1), 129–149. https://doi.org/10.1257/app.20130369

Gosai, M. A., & Sulewski, L. (2014). Urban attraction: Bhutanese internal rural–urban migration. *Asian Geographer*, *31*(1), 1–16. https://doi.org/10.1080/10225706.2013.790830

Gurung, J., Tamang, N.B., Dorji, T., Gyeltshen, J., Wangdi, J., & Maya Rizal, G. (2015). *Optimizing Feed and Fodder Production and Utilization*. Jakar, Bhutan.

Gurung, Tayan. (2011). Analyse comparée de l'usage de la modélisation d'accompagnement pour faciliter la gestion adaptative de l'eau agricole au Bhoutan (Phd dissertation). Université de Paris Ouest Nanterre-La Défense, Paris. Retrieved from https://www.commod.org/content/download/4416/32897/version/1/file/Gurung_2011_PhD.pdf

Haggblade, S., Hazell, Peter, & Reardon, T. (2010). The Rural Non-farm Economy: Prospects for Growth and Poverty Reduction. *World Development*, *38*(10), 1429–1441. https://doi.org/10.1016/j.worlddev.2009.06.008

Halberg, N., Sulser, T. B., Høgh-Jensen, H., Rosegrant, M. W., & Knudsen, M. T. (2006). The impact of organic farming on food security in a regional and global perspective. In N. Halberg, H. F. Alroe, & M. T. Knudsen (Eds.), *Global development of organic agriculture: challenges and prospects* (pp. 277–322). CABI.

Hayden, A. (2015). Bhutan: Blazing a Trail to a Postgrowth Future? Or Stepping on the Treadmill of Production? *The Journal of Environment & Development*, *24*(2), 161–186. https://doi.org/10.1177/1070496515579199

Hazell, Peter B. R., & Norton, R. D. (1986). *Mathematical programming for economic analysis in agriculture*: Macmillan New York. Retrieved from http://agrecon.mcgill.ca/courses/320/hazell/mathprogfront.pdf

Heckman, J. J., & MaCurdy, T. (1982). Corrigendum on a life cycle model of female labour supply. *The Review of Economic Studies*, *49*(4), 659–660.

Hertel, T., McDougall, R., Narayanan, B., & Aguiar, A. (2008). *Chapter 14: Behavioral Parameters, GTAP 7 Data Base Documentation*. West Lafayette, USA.

Hertel, Thomas. (1997a). *Global Trade Analysis: Modeling and Applications*. Cambridge university press.

Hertel, Thomas. (1997b). *Global trade analysis: modeling and applications*: Cambridge university press.

Hertel, Thomas. (2002). Chapter 26 Applied general equilibrium analysis of agricultural and resource policies. In *Handbook of Agricultural Economics : Agriculture and its External Linkages* (pp. 1373–1419). Elsevier. https://doi.org/10.1016/S1574-0072(02)10008-9

Hertel, Thomas, McDougall Robert A., Narayanan G., B., & Aguiar, Angel. (2016). Chapter 14 - Behavioral parameters. In B. G. Narayanan, A. Aguiar, & and R. McDougall. (Eds.), *Global Trade, Assistance, and Production: The GTAP 9 Data Base* (p. 14). Purdue, USA.

Hogarth, N. J., Belcher, B., Campbell, B., & Stacey, N. (2013). The Role of Forest-Related Income in Household Economies and Rural Livelihoods in the Border-Region of Southern China. *World Development*, *43*, 111–123. https://doi.org/10.1016/j.worlddev.2012.10.010

Hu, Z. W., Zhang, J., Zuo, H. B., Tian, M., Liu, Z. J., & Yang, T. (2011). Substitution of Biomass for Coal and Coke in Ironmaking Process. *Advanced Materials Research*, *236-238*, 77–82. https://doi.org/10.4028/www.scientific.net/AMR.236-238.77

IFOAM. (2014). *The IFOAM norms for organic production and processing: Version 2014.* Bonn, Germany.

ILO. (2012). *International Standard Classifciation of Occupations (ISCO-08) Volume 1.* Geneva, Switzerland.

ILO. (2015). *ILOSTAT*. Dataset. Genève, Switzerland. Retrieved from http://www.ilo.org/ilostat

Irz, X., Lin, L., Thirtle, C., & Wiggins, S. (2001). Agricultural Productivity Growth and Poverty Alleviation. *Development Policy Review*, *19*(4), 449–466. https://doi.org/10.1111/1467-7679.00144

IUCN. (2015). *IUCN Red List of Threatened Species.*

Jacobsen, L., & Frandsen, S. (1999). *Analysis of the economic consequences of restructuring Danish agriculture for organic production*. Copenhagen, Denmark.

Jadin, I., Meyfroidt, P., & Lambin, Eric F. (2015). Forest protection and economic development by offshoring wood extraction: Bhutan's clean development path. *Regional Environmental Change*, 1–15. https://doi.org/10.1007/s10113-014-0749-y

Jadin, I., Meyfroidt, P., & Lambin, Eric F. (2016). Forest protection and economic development by offshoring wood extraction: Bhutan's clean development path. *Regional Environmental Change*, *16*(2), 401–415. https://doi.org/10.1007/s10113-014-0749-y

Janvry, Alain, & Kanbur, R. (Eds.). (2006). *Economic Studies in Inequality, Social Exclusion and Well-Being: Vol. 1. Poverty, Inequality and Development: Essays in Honor of Erik Thorbecke*. Boston, MA: Springer Science+Business Media Inc.

Janvry, Alain de, & Sadoulet, E. (2010). Agricultural Growth and Poverty Reduction: Additional Evidence. *The World Bank Research Observer*, *25*(1), 1–20. https://doi.org/10.1093/wbro/lkp015

Jarvis, L., & Vera-Toscano, E. (2004). Seasonal Adjustment in a Market for Female Agricultural Workers. *American Journal of Agricultural Economics*, *86*(1), 254–266. https://doi.org/10.1111/j.0092-5853.2004.00576.x

Jayne, T. S., Yamano, T., Weber, Michael, Tschirley, D., Benfica, R., Chapoto, A., & Zulu, B. (2003). Smallholder income and land distribution in Africa: implications for poverty reduction strategies. *Food Policy*, *28*(3), 253–275. https://doi.org/10.1016/S0306-9192(03)00046-0

Jenkins, T. L., & Sutherland, J. W. (2014). A cost model for forest-based biofuel production and its application to optimal facility size determination. *Forest Policy and Economics*, *38*, 32–39. https://doi.org/10.1016/j.forpol.2013.08.004

Johansen, L. (1960). *A multi-sector study of economic growth*. Amsterdam, Holland: North-Holland Pub. Co,.

Joshi, S., & Gurung, B. (2009). *Value Chain Analysis of Dairy in Merak and Sakteng.*

Jussila, M., Tamminen, S., & Kinnunen Jouko. (2012). *The estimation of LES demand elasticities for CGE models* (VATT Working Papers No. 39). Helsinki, Finland. Retrieved from Government Institute for Economic Research website: http://www.doria.fi/bitstream/handle/10024/148777/wp39.pdf?sequence=1&isAllowed=y

Kammen, D. M., & Lew, D. J. (2005). Review of Technologies for the Production and Use of Charcoal. *Renewable and Appropriate Energy Laboratory Report*, *1*. Retrieved from http://rael.berkeley.edu/old_drupal/sites/default/files/old-site-files/2005/Kammen-Lew-Charcoal-2005.pdf

Karan, P. P. (1963). Geopolitical Structure of Bhutan. *India Quarterly: a Journal of International Affairs*, *19*(3), 203–213. https://doi.org/10.1177/097492846301900301

Karma Feeds. (2015a). *Data inquiry for production in 2012*. Email. Phuentsholing, Bhutan.

Karma Feeds. (2015b). *Input costs for production*. Email. Phuentsholing, Bhutan.

Katwal, T. B. (2013). *Multiple cropping in Bhutanese agriculture: Present status and opportunities*. Thimphu. Retrieved from http://www.nbc.gov.bt/wp-content/uploads/2010/06/Multiple-Cropping-Paper-Bhutan-for-SAC-1.pdf

Katwal, T. B. (2016). *Cropping calendar for cereals across various agroecological zones*. Email. Thimphu, Bhutan.

Katwal Bdr., T. (2016). *Cropping calendar for cereals across various agroecological zones*. Email. Thimphu, Bhutan.

Keller, W. J. (1980). *Tax incidence*. *(Contributions to economic analysis: 134)*. Amsterdam usw.: North-Holland Publ. Co.

Kharka, D. S. (2015). *Institutionalizing Performance Management among DHI SOEs in Bhutan*. Hanoi, Vietnam.

King, B. B. (1985). What is a SAM? A layman's guide to social accounting matrices. In G. Pyatt & J. I. Round (Eds.), *Social Accounting Matrices, A Basis for Planning: A World Bank Symposium. A World Bank Symposium* (pp. 12–29). Washington DC.

Kleinwechter, U. (2011). Village level impacts of trade reform in China (PhD Dissertation). University of Hohenheim, Stuttgart. Retrieved from http://opus.uni-hohenheim.de/volltexte/2011/630/

Kleinwechter, U., & Grethe, H. (2015). National Wage Trends and Migration in a Chinese Village Economy: A Micro Level Modeling Approach Based on a Composite Utility Function. *American Journal of Agricultural Economics*, *97*(3), 701–726. https://doi.org/10.1093/ajae/aau070

Kubiszewski, I., Costanza, R., Dorji, Lham, Thoennes, P., & Tshering, K. (2013). An initial estimate of the value of ecosystem services in Bhutan. *Ecosystem Services*, *3*, e11-e21.

Kuiper, M. H. (2005). Village modeling: a Chinese recipe for blending general equilibrium and household modeling (PhD Dissertation). Wageningen University, Wageningen, NL. Retrieved from http://library.wur.nl/WebQuery/wda/abstract/1744830

Lamsang, T. (2017, April 3). Punatsangchu I to be delayed to Dec 2022 and Punatsangchu II till Sept 2019. *The Bhutanese*. Retrieved from https://thebhutanese.bt/punatsangchu-i-to-be-delayed-to-dec-2022-and-punatsangchu-ii-till-sept-2019/

Lele, N., & Joshi, P. (2009). Analyzing deforestation rates, spatial forest cover changes and identifying critical areas of forest cover changes in North-East India during 1972-1999. *Environmental Monitoring and Assessment*, *156*(1-4), 159–170. https://doi.org/10.1007/s10661-008-0472-6

Lélé, S. M. (1991). Sustainable development: A critical review. *World Development*, *19*(6), 607–621. https://doi.org/10.1016/0305-750X(91)90197-P

Lindsey, P. A., Chapron, G., Petracca, L. S., Burnham, D., Hayward, M. W., Henschel, P., . . . Dickman, A. (2017). Relative efforts of countries to conserve world's megafauna. *Global Ecology and Conservation*, *10*, 243–252. https://doi.org/10.1016/j.gecco.2017.03.003

Lofgren, H., Harris, R. L., & Robinson, Sherman. (2002). *A standard computable general equilibrium (CGE) model in GAMS*. Washington D.C., USA: Intl Food Policy Res Inst.

Lotze-Campen, H., Popp, A., Beringer, T., Müller, C., Bondeau, A., Rost, S., & Lucht, W. (2010). Scenarios of global bioenergy production: The trade-offs between agricultural expansion, intensification and trade. *Ecological Modelling*, *221*(18), 2188–2196. https://doi.org/10.1016/j.ecolmodel.2009.10.002

Machlup, F. (1958). Equilibrium and Disequilibrium: Misplaced Concreteness and Disguised Politics. *The Economic Journal*, *68*(269), 1. https://doi.org/10.2307/2227241

Mann, C. E., & Hobbs, P. R. (1988). *Wheat and wheat development in Bhutan*. Mexico City, Mexico.

Matson, P. (1997). Agricultural Intensification and Ecosystem Properties. *Science*, *277*(5325), 504–509. https://doi.org/10.1126/science.277.5325.504

McDonald, S., & Robinson, S. (2006). *User Guide for Version 3.3 of SAM Estimation Program*. Sussex, UK.

McDonald, Scott. (2013). *STAGE 2: A User Guide (version 2)*. Oxford, UK.

McDonald, Scott, & Thierfelder, K. (2015). A Static Applied General Equilibrium Model: Technical Documentation: STAGE Version 2: January 2015. *Model Documentation*.

McKenzie, Lionel. (1954). On equilibrium in Graham's model of world trade and other competitive systems. *Econometrica: Journal of the Econometric Society*, 147–161. Retrieved from http://www.jstor.org/stable/1907539

McKenzie, Lionel W. (1959). On the Existence of General Equilibrium for a Competitive Market. *Econometrica*, *27*(1), 54. https://doi.org/10.2307/1907777

McKitrick, R. R. (1998). The econometric critique of computable general equilibrium modeling: the role of functional forms. *Economic Modelling*, *15*(4), 543–573.

McShane, T. O., Hirsch, P. D., Trung, T. C., Songorwa, A. N., Kinzig, A., Monteferri, B., . . . O'Connor, S. (2011). Hard choices: Making trade-offs between biodiversity conservation and human well-being. *Biological Conservation*, *144*(3), 966–972. https://doi.org/10.1016/j.biocon.2010.04.038

Meadows, Donella, Meadows, Dennis, Randers, J., & Behrens III, W. W.^. (1977). *The limits to growth: A report for the Club of Rome's project on the predicament of mankind* (2.ed., 4. print). *A Potomac Associates book*. New York NY: Universe Books.

Mehta, M. P., Rabgyal, J., & Acharya, S. (2015a). *Commodity Chain Analysis of Ginger in Bhutan*. Thimphu, Bhutan.

Mehta, M. P., Rabgyal, J., & Acharya, S. (2015b). *Commodity Chain Analysis of Large Cardamom in Bhutan*. Thimphu, Bhutan.

Melo, Jaime de, & Robinson, Sherman. (1989). Product differentiation and the treatment of foreign trade in computable general equilibrium models of small economies. *Journal of International Economics*, *27*(1-2), 47–67. https://doi.org/10.1016/0022-1996(89)90077-9

Meyer, S., Glaser, B., & Quicker, P. (2011). Technical, economical, and climate-related aspects of biochar production technologies: a literature review. *Environmental Science & Technology*, *45*(22), 9473–9483. https://doi.org/10.1021/es201792c

Minten, B., & Dukpa, C. (2010a). *An analysis of household food demand in Bhutan*. Thimphu: Ministry of Agriculture and Forests of Bhutan.

Minten, B., & Dukpa, C. (2010b). *Technology adoption, agricultural productivity, and road infrastructure in Bhutan*. Thimphu, Bhutan.

Mitra-Kahn, B. H. (2008). Debunking the myths of computable general equilibrium models. Retrieved from http://www.academia.edu/download/2913349/4i5u50tdmoybjlj.pdf

MoAF. (2006). *Smallholder Fruits and Vegetable Production Possibilities: A Baseline Study of Five Selected Dzongkhags in Bhutan*. Thimphu, Bhutan.

MoAF. (2009). *Agricultural Census 2008 - Microdata*. Thimphu, Bhutan.

MoAF. (2011). *Forest Development in Bhutan: Policies, Programmes and Institutions*. Thimphu, Bhutan.

MoAF. (2012a). *Cost of rice production in different agro-ecological zones*. Thimphu, Bhutan.

MoAF. (2012b). *Forestry -Facts, figures and trends 2011*. Thimphu, Bhutan.

MoAF. (2013a). *Agricultural Sample Survey 2012 - Dataset*. Thimphu, Bhutan.

MoAF. (2013b). *Agricultural Sample Survey Report 2012*. Thimphu, Bhutan.

MoAF. (2013c). *Forest Resource Potential Assessment of Bhutan 2013*. Thimphu, Bhutan.

MoAF. (2013d). *Livestock Census 2012 micro-data*. Thimphu, Bhutan.

MoAF. (2013e). *Production Cost for Major Vegetables in Bhutan*. Thimphu, Bhutan.

MoAF. (2014). *Agricultural Sample Survey 2013 - Dataset*. Thimphu, Bhutan.

MoAF. (2015). *Bhutan RNR statistics 2015*. Thimphu, Bhutan.

MoAF. (2016a). *Forest Facts & Figures*. Thimphu, Bhutan.

MoAF. (2016b). *Microdata on the Agricultural Sample Survey rounds conducted in 2012, 2013, 2014 and 2015 first and second year half*. Thimphu, Bhutan.

MoAF. (2016c). *State of Climate Change Report for the RNR Sector*. Thimphu, Bhutan. Retrieved from Ministry of Agriculture & Forests website: http://www.moaf.gov.bt/download/Publications/State-of-the-Climate-Change-Report-2016_FINAL.pdf

MoAF. (2017). *Electric fence inventory*. Thimphu, Bhutan.

MoAF. (2018). *Agriculture Statistics 2017*. Thimphu, Bhutan.

MoEA. (2012). *Diagnostic Trade Integration Study*. Thimphu, Bhutan.

MoEA. (2015a). *Corporate annual reports - visible inspection at Chamber of Commerce*. personal inspection. Thimphu, Bhutan.

MoEA. (2015b). *Cottage and Small-Industry 2013 - Dataset*. Thimphu, Bhutan.

MoEA. (2015c). *Medium and Large Industries*. Excel sheet. Thimphu, Bhutan.

MoF. (2010a). *Bhutan Trade Statistics 2009*. Thimphu, Bhutan.

MoF. (2010b). *Fiscal Incentives 2010*. Thimphu, Bhutan.

MoF. (2012a). *Annual Financial Statements 2011/2012*. Thimphu, Bhutan.

MoF. (2012b). *Annual Financial Statements 2011/2012*. Thimphu, Bhutan.

MoF. (2012c). *Bhutan Trade Classification: Custom Tariff and Sales Tax Schedul*. Fifth Edition: January 2012. Thimphu, Bhutan.

MoF. (2013a). *Annual Financial Statements 2012/2013*. Thimphu, Bhutan.

MoF. (2013b). *Bhutan Trade Statistics 2012*. Thimphu, Bhutan.

MoF. (2013c). *National Revenue Report 2012-2013*. Thimphu, Bhutan.

MoF. (2014). *Bhutan Trade Statistics 2013*. Thimphu, Bhutan.

MoF. (2015). *Bhutan Trade Statistics 2014*. Thimphu, Bhutan.

MoF. (2016). About Customs and Excise Division:. Retrieved from http://www.drc.gov.bt/drc/customs-excise

Moktan, M. R. (2014). Social and Ecological Consequences of Commercial Harvesting of Oak for Firewood in Bhutan. *Mountain Research and Development*, *34*(2), 139–146. https://doi.org/10.1659/MRD-JOURNAL-D-12-00113.1

Moktan, M. R., Gratzer, G., Richards, W. H., Rai, T. B., & Dukpa, D. (2009). Regeneration and structure of mixed conifer forests under single-tree harvest management in the western Bhutan Himalayas. *Forest Ecology and Management*, *258*(3), 243–255. https://doi.org/10.1016/j.foreco.2009.04.013

Moktan, M. R., Gratzer, G., Richards, W. H., Rai, T. B., Dukpa, D., & Tenzin, K. (2009). Regeneration of mixed conifer forests under group tree selection harvest management in western Bhutan Himalayas. *Forest Ecology and Management*, *257*(10), 2121–2132. Retrieved from http://www.sciencedirect.com/science/article/pii/S0378112709001376

Moktan, M. R., Norbu, L., & Choden, Kunzang. (2016). Can community forestry contribute to household income and sustainable forestry practices in rural area? A case study from Tshapey and Zariphensum in Bhutan. *Forest Policy and Economics*, *62*, 149–157. Retrieved from http://www.sciencedirect.com/science/article/pii/S1389934115300411

MoLHR. (2010). *Establishment Census 2010.* Thimphu, Bhutan.

MoLHR. (2013a). *Labor Force Survey 2012*. Thimphu, Bhutan.

MoLHR. (2013b). *Extract of the labor market information system (LMIS)*. Personal meeting. Thimphu, Bhutan.

Moore, J. A., & Gamroth, M. J. (1982). Calculating the fertilizer value of manure form livestock operations. *Agricultural Communications Oregon State University Administrative Service A442 EC*, *1094*, 1–7.

Muller, A., Schader, C., Scialabba, N. E.-H., Brüggemann, J., Isensee, A., Erb, K.-H., . . . El-Hage Scialabba, N. (2017). Strategies for feeding the world more sustainably with organic agriculture. *Nature Communications*, *8*(1), 1290. https://doi.org/10.1038/s41467-017-01410-w

Musyoka, M. W., Adamtey, N., Muriuki, Anne W., & Cadisch, G. (2017). Effect of organic and conventional farming systems on nitrogen use efficiency of potato, maize and vegetables in the Central highlands of Kenya. *European Journal of Agronomy*, *86*, 24–36.

Mwampamba, T. H., Ghilardi, A., Sander, K., & Chaix, K. J. (2013). Dispelling common misconceptions to improve attitudes and policy outlook on charcoal in developing countries. *Energy for Sustainable Development*, *17*(2), 75–85. https://doi.org/10.1016/j.esd.2013.01.001

NAB. (2018). About National Assembly of Bhutan: Overview. Retrieved from http://www.nab.gov.bt/en/about/overview-national-assembly

Narain, U., Toman, M., & Jiang, Z. (2014). *Note on Green Growth for Bhutan* (World Bank License: CC BY 3.0 IGO). Washington DC, USA. Retrieved from World Bank website: https://openknowledge.worldbank.org/handle/10986/20402

Nelson, G. C., Valin, H., Sands, R. D., Havlík, P., Ahammad, H., Deryng, D., . . . Heyhoe, E. (2014). Climate change effects on agriculture: Economic responses to biophysical shocks. *Proceedings of the National Academy of Sciences*, *111*(9), 3274–3279.

Neuhoff, D., Tashi, S., Rahmann, G., & Denich, M. (2014). Organic agriculture in Bhutan: potential and challenges: Organic Agriculture. *Org. Agr.*, *4*(3), 209–221. https://doi.org/10.1007/s13165-014-0075-1

Nkonya, E., Srinivasan, R., Anderson, W., & Kato, E. (2014). Assessing the Economic Benefits of Sustainable Land Management Practices in Bhutan. *IFPRI Discussion Paper*, *2014*(01361).

NLC. (2014). *Altitude data of gewog centres in Bhutan*. Thimphu, Bhutan.

NOP. (2016). About Us. Retrieved from http://www.nop.gov.bt/about-us/

Norgate, T., & Langberg, D. (2009). Environmental and economic aspects of charcoal use in steelmaking. *ISIJ International*, *49*(4), 587–595. Retrieved from http://jlc.jst.go.jp/DN/JALC/00329273185?from=Google

Nørstebø, V. S., & Johansen, U. (2013). Optimal transportation of logs and location of quay facilities in coastal regions of Norway. *Forest Policy and Economics*, *26*, 71–81. https://doi.org/10.1016/j.forpol.2012.08.009

NRC. (2010). *Toward sustainable agricultural systems in the 21st. century*. Washington DC, USA: The National Academies Press.

NRDCL. (2009). *Annual Report 2008*. Thimphu, Bhutan.

NRDCL. (2012). *Annual Report 2012*. Thimphu, Bhutan.

NRDCL. (2013). *Annual Report 2012*. Thimphu, Bhutan.

NRDCL. (2014). *Firewood prices 2008 - 2014 from NRDCL field divisions.*

NSB. (2003). *Bhutan Living Standard Survey 2003*. Thimphu, Bhutan.

NSB. (2007). *Bhutan Living Standard Survey (BLSS) 2007 Report*. Thimphu, Bhutan.

NSB. (2008). *DZONGKHAG POPULATION PROJECTIONS 2006-2015*. Thimphu, Bhutan.

NSB. (2011). *National Account Statistics 2011*. Thimphu, Bhutan.

NSB. (2012). *Statistical Yearbook 2012*. Thimphu, Bhutan. Retrieved from www.nsb.gov.bt

NSB. (2013). *National Account Statistics 2013*. Thimphu, Bhutan.

NSB. (2014). *National Account Statistics 2014*. Thimphu, Bhutan.

NSB. (2015). *Quarterly observed commodity prices per district*. email. Thimphu, Bhutan.

NSB. (2017a). *National Accounts Statistics 2017*. Thimphu, Bhutan. Retrieved from National Statistics Bureau website: http://www.nsb.gov.bt/publication/download.php?id=1268

NSB. (2017b). *Statistical Yearbook of Bhutan 2017*. Thimphu, Bhutan. Retrieved from National Statistics Bureau (NSB) of Bhutan website: http://www.nsb.gov.bt/publication/download.php?id=1386

NSB. (2018a). *2017 Population and Housing Census of Bhutan: National Report*. Thimphu, Bhutan. Retrieved from National Statistics Bureau (NSB) of Bhutan website: http://www.nsb.gov.bt/publication/download.php?id=1352

NSB. (2018b). *2017 Population and Housing Census of Bhutan: National Report*. Thimphu, Bhutan. Retrieved from National Statistics Bureau (NSB) of Bhutan website: http://www.nsb.gov.bt/publication/download.php?id=1352

NSB, & ADB. (2012). *Bhutan Living Standard Survey 2012 - dataset*. Thimphu, Bhutan.

NSB, & World Bank. (2012). *Bhutan Poverty Analysis 2012*. Thimphu, Bhutan. Retrieved from National Statistics Bureau; World Bank website: http://www.nsb.gov.bt/publication/files/pub6pg3078cg.pdf

NSB, & World Bank. (2017). *Bhutan Poverty Analysis 2017*. Thimphu, Bhutan. Retrieved from National Statistics Bureau; World Bank website: http://www.nsb.gov.bt/publication/files/pub6pg3078cg.pdf

Nyaupane, G. P., & Timothy, D. J. (2010). Power, regionalism and tourism policy in Bhutan. *Annals of Tourism Research*, *37*(4), 969–988. https://doi.org/10.1016/j.annals.2010.03.006

OECD. (2001). *Definition Mixed Income.* (Glossary of statistical terms). Retrieved from Organisation of Economic and Development Co-operation (OECD) website: http://stats.oecd.org/glossary/detail.asp?ID=1668

Openshaw, K. (2010). Biomass energy: Employment generation and its contribution to poverty alleviation. *Biomass and Bioenergy*, *34*(3), 365–378. Retrieved from http://www.sciencedirect.com/science/article/pii/S0961953409002372

Paul, S. (2015, September 28). To build a greener economy, Bhutan wants to go organic by 2020. *Reuters*. Retrieved from http://www.reuters.com/article/us-bhutan-emissions-farming-idUSKCN0RS0DO20150928

Pauw, K. (2003). *Functional Forms Used in CGE Models: Modelling Production and Commodity Flows* (PROVIDE Project Background Paper No. 5). Elsenburg, South Africa.

PCAL. (2014). *Annual Report 2013*. Thimphu, Bhutan.

Pearce, D., Barbier, Edward, & Markandya, A. (2013). *Sustainable Development: Economics and Environment in the Third World*. Hoboken: Taylor and Francis.

Penjor, T., Dorji, Lhao, Nima, C., Yangzom, D., Chhetri, P., Norbu, T., & Dorki, L. (2014). *Fabricated electric fencing (FEF) System: A new approach to mitigate human-wildlife conflict in Bhutan* (Human-Wildlife Conflict Resolution in the Mountains of SAARC - Success Stories). Thimphu, Bhutan.

Penjore, D. (2004). Security of Bhutan: Walking Between the Giants. *Journal of Bhutan Studies*, *10*, 108–131. Retrieved from http://www.dspace.cam.ac.uk/handle/1810/227045

Perroni, C., & Rutherford, T. F. (1995). Regular flexibility of nested CES functions. *European Economic Review*, *39*(2), 335–343. https://doi.org/10.1016/0014-2921(94)00018-U

Phuntsho, S., Schmidt, K., Kuyakanon, R.S. and Temphel, K.J. (2011). *Community Forestry in Bhutan: Putting People at the Heart of Poverty Reduction*. Jakar and Thimphu, Bhutan.

Pingali, P. L. (2012). Green revolution: impacts, limits, and the path ahead. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(31), 12302–12308. https://doi.org/10.1073/pnas.0912953109

Ponisio, L. C., M'Gonigle, L. K., Mace, K., Palomino, J., Valpine, P. d., & Kremen, C. (2014). *Data from: Diversification practices reduce organic to conventional yield gap: Diversification practices reduce organic to conventional yield gap.*

Ponisio, L. C., M'Gonigle, L. K., Mace, K., Palomino, J., Valpine, P. d., & Kremen, C. (2015). Diversification practices reduce organic to conventional yield gap. *Proc. R. Soc. B*, *282*(1799), 20141396. https://doi.org/10.1098/rspb.2014.1396

Ponti, T. de, Rijk, B., & van Ittersum, M. K. (2012). The crop yield gap between organic and conventional agriculture. *Agricultural Systems*, *108*, 1–9.

Pradhan, B., Saluja, M. R., & Sharma, A. K. (2013). *A Social Accounting Matrix for India 2007-08* (IEG Working Paper No. 326). Delhi.

Pretty, J. N., Ball, A. S., Lang, T., & Morison, J.I.L. (2005). Farm costs and food miles: An assessment of the full cost of the UK weekly food basket. *Food Policy*, *30*(1), 1–19. https://doi.org/10.1016/j.foodpol.2005.02.001

Punt, C. (2013). Modelling multi-product industries in computable general equilibrium (CGE) models. Stellenbosch: Stellenbosch University. Retrieved from https://scholar.sun.ac.za/handle/10019.1/79959

Pyatt, G. (1988). A SAM approach to modeling. *Journal of Policy Modeling*, *10*(3), 327–352. https://doi.org/10.1016/0161-8938(88)90026-9

Pyatt, G., & Round, J. I. (1985). Social Accounting Matrices for Development Planning. In G. Pyatt & J. I. Round (Eds.), *Social Accounting Matrices, A Basis for Planning: A World Bank Symposium. A World Bank Symposium* (pp. 52–69). Washington D.C., USA.

Rahut, D. B., Ali, A., & Behera, B. (2015). Household participation and effects of community forest management on income and poverty levels: Empirical evidence from Bhutan. *Forest Policy and Economics*, *61*, 20–29. https://doi.org/10.1016/j.forpol.2015.06.006

Rahut, D. B., Ali, A., & Behera, B. (2016). Domestic use of dirty energy and its effects on human health: Empirical evidence from Bhutan. *International Journal of Sustainable Energy*, *36*(10), 983–993. https://doi.org/10.1080/14786451.2016.1154855

Rahut, D. B., Behera, B., & Ali, A. (2016). Household energy choice and consumption intensity: Empirical evidence from Bhutan. *Renewable and Sustainable Energy Reviews*, *53*, 993–1009. https://doi.org/10.1016/j.rser.2015.09.019

RC Khangma. (2003). *RNR Technical Recommendations*. Khangma, Bhutan.

RC Wengkhar. (2015). *Cropping calendars for fruits and vegetables across agroecological-zones in Bhutan*. Wengkhar, Bhutan.

Reardon, T., Berdegué, J., Barrett, C. B., & Stamoulis, K. (2007). Household income diversification into rural nonfarm activities. *Transforming the Rural Nonfarm Economy: Opportunities and Threats in the Developing World*, 115–140.

Reardon, T., Stamoulis, K., Cruz, M. E., Berdegué, J., & Banks, B. (1998). *Rural non-farm income in developing countries: Special Chapter* (The state of food and agriculture No. 283-356). Rome, Italy. Retrieved from FAO website: http://www.fao.org/docrep/w9500e/w9500e00.htm

Reganold, J. P. (2012). The fruits of organic farming. *Nature*, *485*(7397), 176–177.

Reganold, J. P., & Wachter, J. M. (2016). Organic agriculture in the twenty-first century. *Nature Plants*, *2*, 15221.

Remedio, E. M., & Domac, J. U. (2003). Socio-economic analysis of bioenergy systems: A focus on employment. *FAO Forestry Department. Wood Energy Programme, Ed. Rome: FAO*, *53*. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.456.692&rep=rep1&type=pdf

Reumerman, P. J., & Frederiks, B. (2002). Charcoal Production with Reduced Emissions: A description of the CARBO GROUP charcoal production technology. *12th European Conference on Biomass for Energy, Industry and Climate Protection*.

RGoB. (2006). *Forest and Nature Conservation Rules of Bhutan*. Thimphu, Bhutan.

RGoB. (2007). *The land act of Bhutan 2007*. Thimphu, Bhutan.

RGoB. (2008). *The Constitution of the Kingdom of Bhutan*. Thimphu, Bhutan.

RGoB. (2009). *The Local Government Act of Bhutan 2009*. Thimphu, Bhutan. Retrieved from http://www.mohca.gov.bt/download/LGAct2018Final.pdf

RGoB. (2010). *Economic development policy of the kingdom of Bhutan*. Thimphu, Bhutan.

RGoB. (2011). *Renewable natural resources (RNR) research policy of Bhutan*. Thimphu, Bhutan.

RGoB. (2012). *Bhutan: In Pursuit of sustainable development: National report for the United Nations Conference on Sustainable Development 2012*. Thimphu, Bhutan.

RGoB. (2017). *Forest and Nature Conservation Rules and Regulations of Bhutan*. Thimphu, Bhutan.

Rinzin, C. (2015). *Cost of Production for Rice and Maize*. Email. Thimphu, Bhutan.

RMA. (2012). *Monetary Policy Statement June 2012*. Thimphu, Bhutan.

RMA. (2013). *Annual Report 2011/12*. Thimphu, Bhutan.

RMA. (2014a). *Annual Report 2012/13*. Thimphu, Bhutan.

RMA. (2014b). *Annual Report 2012/13*. Thimphu, Bhutan.

RMA. (2015). *Monthly Statistical Bulletin - February 2015 Issue*. Thimphu, Bhutan. Retrieved from Royal Monetary Authority website: http://www.rma.org.bt/monthly%20statistical%20bulletintp.jsp

RMA. (2017). *Annual Report 2016/17*. Thimphu, Bhutan.

Robinson, E. (2016). Resource-Dependent Livelihoods and the Natural Resource Base. *Annual Review of Resource Economics*, *8*(1), 281–301. https://doi.org/10.1146/annurev-resource-100815-095521

Robinson, Sherman. (1991). Macroeconomics, financial variables, and computable general equilibrium models. *World Development*, *19*(11), 1509–1525. https://doi.org/10.1016/0305-750X(91)90003-Z

Robinson, Sherman. (2006). Macro Models and Multipliers: Leontief, Stone, Keynes, and CGE Models. In A. Janvry & R. Kanbur (Eds.), *Economic Studies in Inequality, Social Exclusion and Well-Being: Vol. 1. Poverty, Inequality and Development: Essays in Honor of Erik Thorbecke* (pp. 205–232). Boston, MA: Springer Science+Business Media Inc. https://doi.org/10.1007/0-387-29748-0_11

Robinson, Sherman, Cattaneo, A., & El-Said, M. (2001). Updating and estimating a social accounting matrix using cross entropy methods. *Economic Systems Research*, *13*(1), 47–64.

Robinson, Sherman, & Lofgren, H. (2005). Macro models and poverty analysis: Theoretical tensions and empirical practice. *Development Policy Review*, *23*(3), 267–283. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1467-7679.2005.00286.x/full

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F. S., Lambin, Eric, . . . Schellnhuber, H. J. (2009). Planetary boundaries: exploring the safe operating space for humanity. *Ecology and Society*, *14*(2).

Roder, W., Wangdi, K., Gyamtsho, P., & Dorji, K. (2001). *Feeding the Herds: Improving Fodder Resources in Bhutan*. Kathmandu, Nepal.

Roder, Walter, Gratzer, G., & Wangdi, Kinzang. (2002). Cattle grazing in the conifer forests of Bhutan. *Mountain Research and Development*, *22*(4), 368–374.

Roder, Walter, Nidup, K., & Chettri, Ganesh. (2008). *The Potato in Bhutan*. Thimphu, Bhutan.

Rodríguez-Rodríguez, D., Bomhard, B., Butchart, S. H.M., & Foster, M. (2011). Progress towards international targets for protected area coverage in mountains: A multi-scale assessment. *Biological Conservation*, *144*(12), 2978–2983. https://doi.org/10.1016/j.biocon.2011.08.023

Röhrig, F. (2016). Adoption of Sustainable Land Management technologies among smallholder farmers in Eastern Bhutan: A microeconomic assessement using a mathematical programming model approach (Master thesis). University of Hohenheim, Stuttgart-Hohenheim, Germany.

Rosenzweig, M. R. (1988). Chapter 15 Labor markets in low-income countries. In *Handbook of Development Economics* (pp. 713–762). Elsevier. https://doi.org/10.1016/S1573-4471(88)01018-6

RSTA. (2012). *Official hiring rates for trucks*. Thimphu, Bhutan.

RSTA. (2014). *Road Map Bhutan*. Thimphu, Bhutan.

Ruthenberg, H. (1971). *Farming systems in the tropics* (Ed. 3). Oxford, UK: Oxford University Press.

Rutten, M., Shutes, L., & Meijerink, G. (2013). Sit down at the ball game: How trade barriers make the world less food secure. *Food Policy*, *38*, 1–10. https://doi.org/10.1016/j.foodpol.2012.09.002

Sadoulet, E., & Janvry, Alain de. (1995). *Quantitative development policy analysis* (1st ed.). Baltimore: Johns Hopkins University Press.

Samdup, T., Udo, H. M.J., Eilers, C., Ibrahim, M. N.M., & van der Zijpp, A. J. (2010). Crossbreeding and intensification of smallholder crop–cattle farming systems in Bhutan. *Livestock Science*, *132*(1), 126–134. Retrieved from http://www.sciencedirect.com/science/article/pii/S1871141310001915

Sarap, K., & Sarangi, T. K. (2009). Malfunctioning of forest institutions in Orissa. *Economic and Political Weekly*, 18–22. Retrieved from http://www.jstor.org/stable/25663535

Sariyev, O., Gurung, Tulsi, Feuerbacher, Arndt, & Loos, T. (2017). *Study on intra-household decision-making and food security: Primary data collected in Dagana and Tsirang, Bhutan* (mimeo).

Scarf, H. (1967a). The approximation of fixed points of a continuous mapping. *SIAM Journal on Applied Mathematics*, *15*(5), 1328–1343.

Scarf, H. (1967b). *On the computation of equilibrium prices* (Vol. 232): Cowles Foundation for Research in Economics at Yale University. Retrieved from http://dido.wss.yale.edu/~hes/pub/p0271.pdf

Scherr, S. J. (2000). A downward spiral? Research evidence on the relationship between poverty and natural resource degradation. *Food Policy*, *25*(4), 479–498. https://doi.org/10.1016/S0306-9192(00)00022-1

Schindele, W. (2004). *Forest Resources Potential Assessment (FRPA) for Bhutan*. Bhutan-German Sustainable RNR Development Project. Altusried, Germany.

Schofield, S. (1974). Seasonal factors affecting nutrition in different age groups and especially preschool children. *The Journal of Development Studies*, *11*(1), 22–40.

Sears, R., Phuntso, S., Dorji, Tshewang, Choden, Kinley, Norbu, N., & Baral, H. (2017). *Forest ecosystem services and the pillars of Bhutan's Gross National Happiness* (Occasional Paper No. 178). Bogor, Indonesia.

Sen, Amartya. (1988). Chapter 1 The concept of development. *Handbook of Development Economics*, *1*, 9–26. https://doi.org/10.1016/S1573-4471(88)01004-6

Sen, Amartya K. (1966). Peasants and Dualism with or without Surplus Labor. *The Journal of Political Economy*, 425–450. Retrieved from http://www.jstor.org/stable/1829592

Seufert, V., Ramankutty, N., & Foley, J. A. (2012). Comparing the yields of organic and conventional agriculture. *Nature*, *485*(7397), 229–232.

Seufert, V., Ramankutty, N., & Mayerhofer, T. (2017). What is this thing called organic? – How organic farming is codified in regulations. *Food Policy*, *68*, 10–20. https://doi.org/10.1016/j.foodpol.2016.12.009

Shoven, J. B., & Whalley, J. (1972). A general equilibrium calculation of the effects of differential taxation of income from capital in the U.S. *Journal of Public Economics*, *1*(3-4), 281–321. https://doi.org/10.1016/0047-2727(72)90009-6

Shoven, J. B., & Whalley, J. (1973). General equilibrium with taxes: A computational procedure and an existence proof. *The Review of Economic Studies*, *40*(4), 475–489. Retrieved from http://www.jstor.org/stable/2296582

Shrestha, S., Katwal Bdr., T., Ghaley, B. B., Pulami, T. M., Chophyll, K., Wangchuk, Sherab, & Wangdi, N. (2006). *Adoption and Impact Assessment of Improved Maize Technologies in Bhutan Resource: First draft report*. Thimphu, Bhutan.

Shrestha, S., Katwal Bdr., T., & Ghalley BB. (2006). *Adoption and Impact Assessment of Improved Maize Technologies in Bhutan*. Thimphu, Bhutan.

Siebert, Stephen F., & Belsky, Jill M. (2014). Historic livelihoods and land uses as ecological disturbances and their role in enhancing biodiversity: An example from Bhutan. *Biological Conservation*, *177*, 82–89. https://doi.org/10.1016/j.biocon.2014.06.015

Siebert, Stephen F., & Belsky, Jill M. (2015). Managed fuelwood harvesting for energy, income and conservation: An opportunity for Bhutan. *Biomass and Bioenergy*, *74*, 220–223. https://doi.org/10.1016/j.biombioe.2015.01.013

Siemons, R. V., & Baaijens, L. (2012). An Inovative Carbonisation Retort: Technology and Environmental Impact. *Scientific and Technical Journal of the Society of Thermal Engineers of Serbia*. (2).

Skoufias, E. (1996). Intertemporal substitution in labor supply: Micro evidence from rural India. *Journal of Development Economics*, *51*(2), 217–237. Retrieved from http://www.sciencedirect.com/science/article/pii/S0304387896004130

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., . . . Sörlin, S. (2015). Sustainability. Planetary boundaries: guiding human development on a changing planet. *Science (New York, N.Y.)*, *347*(6223), 1259855. https://doi.org/10.1126/science.1259855

Stevenson, J. R., Villoria, N., Byerlee, D., Kelley, T., & Maredia, M. (2013). Green Revolution research saved an estimated 18 to 27 million hectares from being brought into agricultural production. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(21), 8363–8368. https://doi.org/10.1073/pnas.1208065110

Stone, R. (1962). *A social accounting matrix for 1960*: Department of Applied Economics. University of Cambridge.

Stone, R. (1986). Nobel memorial lecture 1984. The accounts of society. *Journal of Applied Econometrics*, *1*(1), 5–28. https://doi.org/10.1002/jae.3950010103

Sukla, N. K., Guru, R. D., & Negi, Y. S. (1992). *Physical and Mechanical Properties of Some Bhutan Timbers* (Tshenden No. 1). Dehra Dun, India.

Sukla, N. K., & Negi, Y. S. (1994). *Physical and mechanical properties of woods tested at the Forest Research Institute*. Dehra Dun, India.

Sunderlin, W. D., Angelsen, A., Belcher, B., Burgers, P., Nasi, R., Santoso, L., & Wunder, S. (2005). Livelihoods, forests, and conservation in developing countries: An Overview. *World Development*, *33*(9), 1383–1402. https://doi.org/10.1016/j.worlddev.2004.10.004

Suopajärvi, H., & Fabritius, T. (2013). Towards More Sustainable Ironmaking—An Analysis of Energy Wood Availability in Finland and the Economics of Charcoal Production. *Sustainability*, *5*(3), 1188–1207. https://doi.org/10.3390/su5031188

Tashi, S. (2015). The Prospects of Organic Farming in Bhutan (Dissertation). University of Bonn, Bonn, Germany.

Tashi, S., & Wangchuk, K. (2016). Organic vs. conventional rice production: comparative assessment under farmers' condition in Bhutan. *Organic Agriculture*, *6*(4), 255–265. https://doi.org/10.1007/s13165-015-0132-4

Taylor, J. E., Yunez-Naude, A., & Dyer, G. (1999). Agricultural Price Policy, Employment, and Migration in a Diversified Rural Economy: A Village-Town CGE Analysis from Mexico. *American Journal of Agricultural Economics*, *81*(3), 653–662. https://doi.org/10.2307/1244030

Taylor, J. Edward, Charlton, D., & Yúnez-Naude, A. (2012). The End of Farm Labor Abundance. *Applied Economic Perspectives and Policy*, *34*(4), 587–598. https://doi.org/10.1093/aepp/pps036

Thinley, J. (2011). *Making a Commitment to Organic Agriculture: Statement on Bhutan's organic policy by Prime Minister of Bhutan, Jigmi Y.Thinley*. Thimphu, Bhutan.

Thinley, K. (2015). *Interview at MoAF on utilization of machinery in Bhutan*. Oral. Thimphu, Bhutan.

Thinley U. (2002). Reduced impact logging in Bhutan. In T. Enters, P. B. Durst, G. B. Applegate, P. C. S. Kho, & G. Man (Eds.), *Applying Reduced Impact Logging to Advance Sustainable Forest Management* (pp. 91–100).

Tilman, D., Cassman, Kenneth G., Matson, Pamela, Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature*, *418*(6898), 671–677. https://doi.org/10.1038/nature01014

Toman, M. (2012). *"Green Growth": An Exploratory Review*. Washington D.C., USA: The World Bank.

Ton, P. (2013). *Productivity and Profitability of Organic Farming Systems in East Africa*. Bonn, Germany. Retrieved from IFOAM website: https://www.ifoam.bio/sites/default/files/page/files/osea_ii_oa_prod_prof_report_final.pdf

Tortajada, C., & Saklani, U. (2018). Hydropower-based collaboration in South Asia: The case of India and Bhutan. *Energy Policy*, *117*, 316–325. https://doi.org/10.1016/j.enpol.2018.02.046

Transparency International. (2018). Corruption Perception Index 2017. Retrieved from Transparency International

Troost, C., & Berger, T. (2015). Dealing with Uncertainty in Agent-Based Simulation: Farm-Level Modeling of Adaptation to Climate Change in Southwest Germany. *American Journal of Agricultural Economics*, *97*(3), 833–854. https://doi.org/10.1093/ajae/aau076

Tuomisto, H. L., Hodge, I. D., Riordan, P., & Macdonald, D. (2012). Does organic farming reduce environmental impacts? – A meta-analysis of European research. *Journal of Environmental Management*, *112*, 309–320. https://doi.org/10.1016/j.jenvman.2012.08.018

Tweeten, L. (1999). The Economics of Global Food Security. *Applied Economic Perspectives and Policy*, *21*(2), 473–488. https://doi.org/10.2307/1349892

Uddin, S., Taplin, R., & Yu, X. (2007). Energy, environment and development in Bhutan. *Renewable and Sustainable Energy Reviews*, *11*(9), 2083–2103. https://doi.org/10.1016/j.rser.2006.03.008

UN. (2002). *International Standard Industrial Classification of All Economic Activities (ISIC) Revision 3.1*. New York, USA. Retrieved from Department of Economic and Social Affairs - Statistics Division website: http://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=17

UN. (2008). *Central Product Classification (CPC) Ver.2*. New York, USA. Retrieved from http://unstats.un.org/unsd/cr/registry/cpc-2.asp

UN. (2009). *System of National Accounts 2008*. New York, USA. Retrieved from https://unstats.un.org/unsd/nationalaccount/docs/sna2008.pdf

UN. (2010). *Extended Balance of Payments Services classification (EBOPS) 2010*. New York, USA. Retrieved from UN website: https://www.oecd.org/std/its/EBOPS-2010.pdf

UN. (2012). *Manual on Statistics of International Trade in Services 2010 (MSITS 2010)*. Geneva, Luxembourg, Madrid, New York, Paris and Washington D.C. Retrieved from http://unstats.un.org/unsd/tradeserv/tfsits/manual.htm

UN. (2015a). *UN comtrade database*. New York, USA. Retrieved from United Nations website: http://comtrade.un.org/

UN. (2015b). *UN ServiceTrade database*. New York, USA.

UN. (2016). *Sustainable Development Goals Report 2016*. New York, USA: UN.

UN. (2018). Least Developed Country Category: Bhutan Profile. Retrieved from https://www.un.org/development/desa/dpad/least-developed-country-category-bhutan.html

UNCTAD. (2016). *UNCTADstat: Data on economic trends - national accounts*. Geneva, Switzerland. Retrieved from http://unctadstat.unctad.org/EN/

UNDP. (2018). Human Development Index and its components. Retrieved from http://hdr.undp.org/en/composite/HDI

UNEP-WCMC. (2013). *Mountain Area per country*. Washington DC, USA.

Ura, K., Alkire, S., Zangmo, T., & Wangdi, K. (2012). *A short guide to gross national happiness index*. Thimphu: Centre for Bhutan Studies.

Vaitla, B., Devereux, S., & Swan, S. H. (2009). Seasonal hunger: A neglected problem with proven solutions. *PLoS Medicine*, *6*(6), e1000101. Retrieved from http://journals.plos.org/plosmedicine/article?id=10.1371/journal.pmed.1000101

Valin, H., Sands, R. D., van der Mensbrugghe, D., Nelson, G. C., Ahammad, H., Blanc, E., . . . Willenbockel, D. (2014). The future of food demand: understanding differences in global economic models. *Agricultural Economics*, *45*(1), 51–67. https://doi.org/10.1111/agec.12089

Van der Mensbrugghe, D. (2005). *LINKAGE Technical Reference Document*. Washington DC, USA. Retrieved from http://documents.worldbank.org/curated/en/200941468322749541/pdf/468360WP0Box331LIC10LinkageTechNote.pdf

Van Meijl, H., van Rheenen, T., Tabeau, A., & Eickhout, B. (2006). The impact of different policy environments on agricultural land use in Europe. *Scenario-Based Studies of Future Land Use in Europe*, *114*(1), 21–38. https://doi.org/10.1016/j.agee.2005.11.006

Van Noord, H. (2010). *Feasibility of REDD+ in Bhutan: A scoping study*. Thimphu, Bhutan.

Verma, R. (2017). Gross National Happiness: meaning, measure and degrowth in a living development alternative. *Journal of Political Ecology*, *24*(1), 476. https://doi.org/10.2458/v24i1.20885

Wangchuk, D., & Katwal Bdr., T. (2014). *Promoting hybrid maize as spring crop under rice-fallow systems: Success and lessons learnt*. Thimphu, Bhutan.

Wangchuk, K., & Dorji, T. (2008). *Animal feed production and management in Bhutan*. Dhaka, Bangladesh. Retrieved from SAARC Agriculture Centre website: https://www.researchgate.net/publication/268210367_Animal_Feed_Production_and_Management_in_Bhutan

Wangchuk, Sangay, Siebert, Stephen, & Belsky, Jill. (2014). Fuelwood Use and Availability in Bhutan: Implications for National Policy and Local Forest Management. *Human Ecology*, *42*(1), 127–135. https://doi.org/10.1007/s10745-013-9634-4

Wangchuk, T., Mazaheri, M., Clifford, S., Dudzinska, M. R., He, C., Buonanno, G., & Morawska, L. (2015). Children's personal exposure to air pollution in rural villages in Bhutan. *Environmental Research*, *140*, 691–698. https://doi.org/10.1016/j.envres.2015.06.006

Watson, C., Atkinson, D., Gosling, P., Jackson, L. R., & Rayns, F. W. (2002). Managing soil fertility in organic farming systems. *Soil Use and Management*, *18.* https://doi.org/10.1111/j.1475-2743.2002.tb00265.x

Wing, I. S. (2004). *Computable General Equilibrium Models and Their Use in Economy-Wide Policy Analysis* (Technical Note No. 6). Cambridge, USA. Retrieved from MIT Joint Program on the Science and Policy of Global Change website: http://web.mit.edu/globalchange/www/MITJPSPGC_TechNote6.pdf

Winkler, D. (2008). Yartsa Gunbu (Cordyceps sinensis) and the Fungal Commodification of Tibet's Rural Economy. *Economic Botany*, *62*(3), 291–305. https://doi.org/10.1007/s12231-008-9038-3

Wodon, Q., & Beegle, K. (2012). Labor shortages despite underemployment? Seasonality in time use in Malawi. In M. C. Blackden & Q. Wodon (Eds.), *World Bank Working Paper: Vol. 73. Gender, Time Use, and Poverty in Sub-Saharan Africa* (pp. 97–116). Washington, DC: World Bank.

Wolfsmayr, U. J., & Rauch, P. (2014). The primary forest fuel supply chain: A literature review. *Biomass and Bioenergy*, *60*, 203–221. https://doi.org/10.1016/j.biombioe.2013.10.025

World Bank. (1985). *Staff appraisal report Bhutan Calcium Carbide Project* (No. 5430-BHT). Washington DC, USA.

World Bank. (1992). *Project Completion Report Bhutan Calcium Carbide Project* (No. 11359). Washington DC, USA.

World Bank. (2010). *Social Protection in Bhutan: Overview*. Washington DC, USA. Retrieved from http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/SOUTHASIAEXT/0,,contentMDK:22181755~pagePK:146736~piPK:146830~theSitePK:223547,00.html

World Bank. (2011). *Wood-Based Biomass Energy Development for Sub-Saharan Africa – Issues and Approaches* (Africa Renewable Energy Access program (AFREA)). Washington DC, USA.

World Bank. (2014). *Bhutan Country Snapshot*. Washington DC, USA.

World Bank. (2018). *World Development Indicators*. Dataset. Washington DC, USA. Retrieved from http://data.worldbank.org/data-catalog/world-development-indicators

Wunder, S., Angelsen, A., & Belcher, B. (2014). Forests, Livelihoods, and Conservation: Broadening the Empirical Base. *World Development*, *64*, S1-S11. https://doi.org/10.1016/j.worlddev.2014.03.007

WWF Bhutan. (2016). What We Do: WWF Bhutan. Retrieved from http://www.wwfbhutan.org.bt/_what_we_do/

Yangka, D., & Diesendorf, M. (2016). Modeling the benefits of electric cooking in Bhutan: A long term perspective. *Renewable and Sustainable Energy Reviews*, *59*, 494–503. https://doi.org/10.1016/j.rser.2015.12.265

Yeshey. (2012). Economics of mechanizing rice cultivation at RNRRDC Bajo. *Journal of Renewable Natural Resources Bhutan*, *8*(1), 42–52.

Yeshey, & Bajgai, Y. (2014). An assessment of glyphosate use and its cost effectiveness as a substitute for farm labor on paddy terrace bunds. *Journal of RNR Bhutan*, *10*(1), 27–34.

Zellner, A. (1962). An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias. *Journal of the American Statistical Association*, *57*(298), 348–368. https://doi.org/10.1080/01621459.1962.10480664

Zhang, X., Yang, J., & Wang, S. (2011). China has reached the Lewis turning point. *China Economic Review*, *22*(4), 542–554. Retrieved from http://www.sciencedirect.com/science/article/pii/S1043951X11000587

Zulu, L. (2010). The forbidden fuel: Charcoal, urban woodfuel demand and supply dynamics, community forest management and woodfuel policy in Malawi. *Large-Scale Wind Power in Electricity Markets with Regular Papers*, *38*(7), 3717–3730. https://doi.org/10.1016/j.enpol.2010.02.050

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