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Impact of the Exit from Nuclear and Fossil-fuel Energy on the German Economy

A General Equilibrium Analysis with Special Emphasis on Agriculture and Electricity

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Content

List of Figures

Addendum

List of Tables

Addendum

Abbreviations

A	
AGEB	Working group on energy balance
AGEE	Working group on renewable energy statistics
B	
BMWi	German Ministry of Economic Affairs and Energy
bn	Billion
C	
ct	Cent
CES	Constant Elasticity of Substitution
CET	Constant Elasticity of Transformation
CGE	Computable General Equilibrium
COFOG	Government expenditure by function
COIOP	Classification of individual consumption by purpose
CPA	Classification of products by activity
CPI	Consumer Price Index
E	
EEG	Renewable Energy Act
EEX	European Energy Exchange
e.g.	exempli gratia
EnWG	Energy Industry Act
€	Euro
F	
FADN	Farm Accountancy Data Network
FOC	First Order Condition
G	
GCE	Generalised Cross Entropy method
GDP	Gross Domestic Product
GNDI	Gross National Disposable Income
GNI	Gross National Income
GVA	Gross Value Added
GWh	Gigawatt hour
H	
ha	Hectare
I	
i.e.	id est
IEA	Integrated Economic Accounts
K	
kWh	Kilowatt hour
L	
LES	Linear Expenditure System

M	
MPP	Marginal Physical Product
MRP	Marginal Revenue Product
MW	Megawatt
N	
NABEG	Act to Accelerate the Expansion of Electricity Networks
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne
NNDI	Net National Disposable Income
NNI	Net National Income
O	
OTC	Over-the-counter
P	
PJ	Petajoule
S	
SAM	Social Accounting Matrix
SNA	System of National Accounts
STAGE	Static Applied General Equilibrium Model
SUT	Supply and Use Tables
T	
TV	Transaction Value
TWh	Terawatt hour
V	
VAT	Value-added tax
VBA	Visual Basic Application

1 Introduction

1.1 Background and objectives

The German energy sector is currently experiencing a transformation process from a nuclear- and fossil-oriented to a renewable-oriented resource base. Initial point of this process was the implementation of the *Energy Concept* by the German government in 2010, also known as the *Energiewende* (Energy Shift). The *Energy Concept* comprises a fundamental long-term restructuring of the energy supply system until 2050 and represents a holistic approach. In addition to the comprehensive establishment of renewable energy resources, the German government intends to achieve further objectives that comprise a) the improvement of climate protection, b) affordable energy prices for consumers, c) a high level of economic competitiveness and development as well as d) a reduction of import dependency on energy commodities (BMWi 2010, BMBU 2012). The development of a sustainable energy supply system therefore involves environmental, economic and social objectives, which have to be considered simultaneously.

The change in the electricity sector should primarily take place on the basis of nuclear power. This technology should serve as a 'bridge technology' until renewable-based electricity generation has been sufficiently expanded. However, as a consequence of the Fukushima Daiichi (Japan) nuclear accident in March 2011, the German government reconsidered the long-term role of nuclear power with the result to phase-out nuclear power plants by 2022. In order to phase-out nuclear power more quickly, the process of reorganising the German electricity supply on the basis of renewable sources needed to be substantially accelerated. Thus, the *Energy Package* was implemented by the German government in July 2011 as legal basis for the nuclear phase-out and the faster expansion of technologies to generate electricity on a renewable basis (BMWi 2012, Hübner et al. 2012).

Wind, solar and biomass represent the most important renewable energy sources for electricity generation in Germany. While the supply of wind- and solar-based electricity generation is achieved by short-term marginal costs, which tend to be zero, the provision of electricity on a biomass basis causes higher costs in the agricultural sector (AEE 2013).

Generally, agriculture got a special role in the context of the *Energiewende* because agriculture is concerned by the energy policy in several ways. On the one hand, agriculture got a role as a 'new player' on the electricity market due to the possibility to generate electricity based on biogas. On the other hand, this sector is a big consumer of electricity and therefore directly affected by changing electricity prices and economic effects caused by the implementation of the *Energiewende* (BMWi 2016).

In addition, the technological development and state support for the use of agricultural commodities for energy production within the framework of the Renewable Energy Sources Act (EEG) have expanded the traditional use spectrum of agricultural products. Consequently, competition for production factors, especially for land, has intensified over the last decade (Theuvsen 2010). Furthermore, agriculture is increasingly competing for the final use of agricultural commodities as feed, food or energy (Hermeling & Wölfing 2011, Bringezu et al. 2008, Faulstich 2012).

In order to determine the economic, environmental and social impacts of the comprehensive restructuring process of the energy sector on the German economy - and in particular on agriculture and the electricity sector - this research focusses on the achievement of two objectives.

The *first objective* is the provision of an analytical framework that is able to capture the complexity of the *Energiewende* and the interrelations between the agents of the German economy and that allows for a monitoring and policy advice.

Since electricity is a commodity used by all economic agents as intermediate input or for final consumption, changes in the electricity supply system have an impact on the whole economy. Computable General Equilibrium (CGE) models provide a systematic approach to capture and analyse these complex direct and indirect impacts on all agents of an economy.

There already exist several models that explicitly focus on the German energy sector. The energy system model TIMES captures technological aspects of the electricity market (Remme 2007). The dynamic Input-Output model DIOGENES (Vögele 2001), the CGE model LEAN (Welsch and Ochsen 2002) or the global trade CGE model GTAP_E (Burniaux and Truong 2002) focus on economic or trade impacts of changes in the energy sector. However, these models either focus on technological aspects or often present the agents of an economy on an aggregated level.

In order to contribute to an improvement of the analysis of the impacts of the *Energiewende* on the German economy, this study intends the development and application of the single-country CGE model STAGE_D for Germany, based on the **St**atic **A**pplied **G**eneral **E**quilibrium Model (STAGE) (McDonald 2007).

The model STAGE_D shall be able to capture the agents of the economy and their interrelation on a more detailed level. Compared to existing CGE models for Germany, the model STAGE_D should also allow for multiple production technologies for electricity generation that encompass existing technologies (nuclear, coal, gas, etc.) and new technologies (wind, solar and biomass) to generate the homogenous product[1] electricity with different cost structures.

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[1] In this study the terms products, goods and commodities are used synonymously. The same holds for the terms activity, sector and industry.

Furthermore, it is intended to improve the presentation of the agricultural sector in the framework of CGE analyses for Germany. In the model STAGE_D, the agricultural sector shall be presented as a multi-product sector in order to differentiate agricultural activities on a regional level on the basis of the federal states (*Bundesländer*). This means that a particular agricultural activity in the model a) represents all farms of that region and b) is able to produce multiple output, i.e. crops, livestock as well as biomass for biogas generation. This consideration allows the model to capture regional differences in the production structure.

To determine also environmental impacts of structural changes in the electricity sector, STAGE_D should also comprise carbon emissions caused by the use of energy commodities by industries and households.

To give the model STAGE_D these planned capabilities, it is necessary to develop an adequate and detailed database, which represents the electricity and agricultural sectors in a disaggregated form. The underlying database for STAGE_D should therefore be developed in form of a Social Accounting Matrix (SAM) on the basis of the Supply and Use Tables (SUT) and in accordance with the principles and accounting rules of the System of National Accounts (SNA). In addition, carbon emissions of various production systems have to be recorded by a satellite account.

The *second objective* of this research is the application of the model STAGE_D to analyse the impact of the nuclear phase-out and the complete implementation of the *Energiewende* in the electricity sector on the German economy. For this, it is intended to calculate and analyse three scenarios with STAGE_D. The first scenario, ‘Phase_out`, shall capture the impacts of an immediate and entire nuclear phase-out on the agents of the German economy. Within scenario ‘Complete’ the economic, ecological and social impacts of the complete implementation of the objectives of the *Energiewende* in the electricity sector shall be considered. A third scenario ‘Biomass’ shall provide conclusions about the importance of electricity generation based on biomass in the agricultural sector in the context of the *Energiewende*.

1.2 Outline of the study

The structure of this study follows the tasks specified by the development and application of STAGE_D and the underlying SAM.

Chapter 2 starts with the introduction of the theoretical background that underlies the development of the SAM. The SAM is based on the accounting rules of the SNA, presented in section 2.2. This section describes the conceptual elements and valuation of transactions on the frame of the SNA. Additionally, the accounts and application of the SNA are presented. A closer look is done here on the differences between SUT and Input Output Tables (IOT), in order to explain the decision to develop STAGE_D on the basis of SUTs. The question of "What is a SAM" is answered in section 2.3. Based on the explanation of how a SAM captures the circular flow of an economy, this section also explains the accounts of a SAM and the importance of a balanced SAM. In this study, the SAM serves simultaneously as database as well as an analytical framework to calibrate the model STAGE_D. This SAM approach to modelling is introduced in section 2.4. In this context also accounting identities and prices as well as the meaning of equilibrium conditions and model closures are presented.

Chapter 3 focuses on the STAGE base model that represents the basis for the modifications done to develop STAGE_D. After a brief introduction to general equilibrium theory in section 3.2, the underlying behavioural relationships (section 3.3) as well as price and quantity relationships are presented in the sections 3.4 and 3.5. Moreover focusses this chapter on the implementation of production (section 3.6), trade (section 3.7) and households (section 3.8) as well as the basic model closures (section 3.9) in STAGE.

The development of the German SAM from the macro SAM until the disaggregated balanced SAM, applied for the calibration of STAGE_D, is on focus of chapter 4. After a summarising introduction of the process in section 4.2, the chapter concentrates on the development of the macro SAM in section 4.3. With regard to the research focus, a disaggregation of the agricultural and electricity sector as well as the development of a satellite account for carbon emissions is required. How the accounts have been disaggregated and which data was used for this work is presented in section 4.4. Finally the disaggregated database was again aggregated for the application in STAGE_D. The applied tool and the final version of the SAM, on which STAGE_D is based for this research, is presented in section 4.5. A summary of the chapter can be found in section 4.6.

Chapter 5 presents the modifications of STAGE_D made in the context of this study to prepare the model for the application to analyse the economic, environmental and social impacts of the *Energiewende* in the case study. The modification of the nested production function and the mathematical implementation into STAGE_D are introduced in section 5.2. The implementation of carbon emissions into the model is shown in section 5.3. Finally, section 5.4 presents the applied parameters of functional forms in the case study.

The case study itself is divided into two parts. The first descriptive part, presented in chapter 6, provides insights into the framework conditions and specifics of the German electricity sector and the role of the agricultural sector in this context. Section 6.2 introduces the political framework of the *Energiewende*. To get an impression of the structure of the German electricity sector, section 6.3 gives information about electricity generation and the resources use, while section 6.4 takes a closer look at electricity generation based on renewable. In addition to electricity supply, electricity use in Germany is shown in section 6.5. To what extend Germany depends on energy imports is presented in section 6.6. The German electricity sector is characterised by some specifics, which are explained in section 6.7. A closer look at the development and composition of electricity prices gives section 6.8. Specifics of the grid and the development of electricity trade are described in section 6.9. Finally, this chapter presents the impact of the use of renewable energy sources on the prevention of carbon emissions in section 6.10.

Chapter 7 comprises the second part of the case study - the application of STAGE_D. Starting with the introduction of the scenarios in section 7.2 and the applied model closures in section 7.3, this chapter presents the results of the analysis in section 7.4. The analysis of the scenarios focusses on the impacts on GDP, the electricity sector itself, other sectors of the economy, factor income and prices, households, trade and carbon emissions. It takes also a closer look at the impacts of the *Energiewende* on the agricultural sector. A sensitivity analysis of the applied elasticities is presented in section 7.5. This chapter closes with a summary of the scenario results and presents the conclusions as well as recommendations for further improvements and applications of STAGE_D in section 7.6.

The final chapter 8 summarises the findings of this study.

2 Theory of Social Accounting and Social Accounting Matrices

2.1 Introduction

The methodical emphasis of this study is the development of a single-country CGE model for Germany - STAGE_D. Starting point for the development of STAGE_D is the construction of the underlying database – the SAM. This chapter presents the theoretical background and methodical framework, in which the German SAM is developed and applied.

The chapter is structured as follows. Because a SAM can be considered as a systematic data and classification system that follows the standards of the System of National Accounts (SNA), section 2.2 provides an introduction to the SNA. The conceptual elements of the SNA are presented in 2.2.1. Section 2.2.2 takes a closer look at the valuation of transactions. The accounts of the SNA are described in section 2.2.3 and an overview of economic indicators generated on the basis of the SNA is given in section 2.2.4.

A more detailed presentation of the theoretical framework of SUTs, which are building the basis of the German SAM, is presented in section 2.2.5. By using a SAM based on SUTs as database for STAGE_D, the model represents an exception in the frame of existing CGE models. Most CGE models are based on IOTs. Therefore, section 2.2.6 concentrates on some characteristics of IOTs to explain why the application of a SUT-based SAM has to be preferred in order to capture the complex interrelations and technological specifics of the *Energiewende*.

The theoretical background of a SAM is the emphasis of section 2.3, starting in section 2.3.1 with a description of the circular flow of an economy, which is captured in the framework of a SAM. The accounts of a SAM are described in section 2.3.2. The introduction of the SAM framework closes with the presentation of the methods for balancing a SAM in section 2.3.3.

Next to its function as a database, a SAM can also be applied as an analytical framework. The SAM approach to modelling comprises the relationship between a SAM as database for a CGE model and the presentation of economic theory. Section 2.4 describes the role of a SAM as database for modelling, starting with an introduction of the SAM approach to modelling in section 2.4.1. A closer consideration of accounting identities and prices is given in section 2.4.2, which comprises the transaction-value form of a SAM and the interdependencies of prices. The introduction of a SAM as database closes in section 2.4.3 with the presentation of equilibrium conditions and model closures. Chapter 2 is summarised in section 2.5.

2.2 The System of National Accounts

The System of National Account, coordinated by the United Nations Statistics Office,: ”… is the internationally agreed standard set of recommendations on how to compile measures of economic activity in accordance with strict accounting conventions based on economic principles. The recommendations are expressed in terms of a set of concepts, definitions, classifications and accounting rules that comprise the internationally agreed standard for measuring such items as gross domestic product (GDP), the most frequently quoted indicator of economic performance.” (United Nations 2009, page 1).

The purpose of the SNA is the provision of a comprehensive conceptual accounting framework for compiling and reporting macroeconomic statistics in order to analyse and evaluate the performance of an economy. It records the distribution of production between the economic agents - consumers, enterprises, the government and other countries. In addition, the SNA describes the income flows between these agents, taxation and transfers as well as the distribution for consumption, savings and investments. Another function of the accounting system is the standardisation of definitions of components of the economic system and their valuation.

To ensure the use of the SNA in these fields, the accounts included in this framework conform to following criteria. They are:

- comprehensive, because they include all activities and agents of the economy,
- consistent, because of the underlying determining accounting rules,
- integrated, because all effects of an agents action are covered (Eurostat 2013).

The current SNA of 2008 (United Nations 2009) is a revised version of the 2003 SNA. It is the fifth version, going back to the year 1947. In this year, the United Nations Statistical Commission emphasised the need for consistent international statistical standards for the compilation and update of comparable statistics to cover a large array of policy needs (United Nations 2014). The 1947 Report (United Nations 1947) was published by the Sub-Committee on National Income Statistics of the League of Nations Committee of Statistical Experts under the leadership of Richard Stone and plays a key role in the development of the conceptual framework of national accounting (United Nations 2017).

2.2.1 Conceptual elements

The SNA is able to capture and describe economies worldwide - from least developed countries, developing countries, transition economies and developed countries. Because it captures all characteristics of an economy, the 2008 SNA can be considered as a: “… system of macroeconomic accounts based on a set of concepts, definitions, classifications and registration rules. It provides a framework within economic data can be collected and analysed to assist decision-makers and provide guidance on economic policies." (Eurostat 2013, page 59).

Based on the SNA construction rules, an economy can be described in a simplified way. Therefore, the complexity of an economy is presented on an aggregated level. There are two ways to describe an economy:

1.) The classification by industry, called 'functional classification', is linked to SUTs and represents the economy wide production and flows of goods and services. This classification shows the balance between supply and demand. Here, the units of an economy are defined by their technical-productive profile.

2.) The second way to characterise an economy is the 'institutional classification', where the units of an economy are defined according to their economic behaviour, function and objectives. This classification focuses on income generation, distribution and how capital is generated and financed. The 'institutional classification' is based on the Integrated Economic Accounts (IEA) (United Nations 2009).

The transactions of economic agents are recorded in the SNA by defined accounting rules. The basis for national accounts is built up according to business accounting. The two-side presentation is converted into a T-account for a nation. In the SNA the right side comprises the resources for the transactions and the left side the use of the transaction. The principle of double-entry is also applied in the accounts of the SNA. The accounts comprise 'horizontal' double entries, i.e. if an institution provides a good or service to another institution, the transaction has to be recorded in the other account too. Here, the transaction is an entry in the resource account of one institution and in the use account of the other institution. Transactions have to be done twice in the account of the same institution, a) as a resource position and b) as a use position. This way of bookkeeping is called 'vertical' double-entry. This 'vertical' double-entry guarantees that the total of transactions recorded in the use account equals the total in the resources account (Eurostat 2013).

The objective of tables, accounts and balance sheets, applied in the SNA, is to record a) economic actions within a given time period and b) the effects of these actions on the stocks of assets and liabilities at the beginning and the end of that time period. The time period usually comprises one financial year. The described actions are called economic flows and relate to production, consumption, savings and investments etc. of all institutional units of an economy. The effects of economic flows, which comprise transactions and other economic flows, are the creation, transformation, exchange or transfer of economic value. In addition, economic flows can change the volume, composition or value of liabilities and assets (ibid).

2.2.2 Valuation of transactions

In order to capture economic flows in the SNA, transactions must be recorded for all accounts in all sectors at the same value. In an economy the value of transactions is oriented on the current market price. To ensure this, the SNA applies various transaction valuation methods of treating taxes and subsidies on products, value-added taxes and other deductible taxes as well as trade and transport margins on goods and services. For the measurement of output two kinds of prices are used: the basic price and the producers' price. The relationships between these prices and the purchasers' price are shown in Figure 1.

Figure 1: Relationships between prices in the 2008 SNA

Basic price
+
Taxes on products excluding invoiced VAT
-
Subsidies on products
=
Producer price
+
VAT not deductible by the purchaser
+
Separately invoiced transport charges
+
Wholesaler and retailer margins
=
Purchaser price

Source: Eurostat (2014)

The basic price is defined as the price the producer receives from the purchaser for a unit of output. This price includes subsidies on products the producer received during production or sale, but no taxes and transport charges. The basic price can be regarded as the relevant price for decision makers for supply (United Nations 2009).

The producers' price is the price the producer receives from the purchaser for a unit of output including taxes on products, with the exception of value-added tax (VAT) and excluding subsidies on products. It also excludes any transport charges. The producer price is the basic price plus any non-deductible taxes on products and less any subsidies on products (OECD 2005).

The purchasers' price is the price most relevant for buyers and represents the price including VAT not deductible by the purchaser, the separately invoiced transport charges as well as the wholesaler and retail margins. It is the price paid by the purchaser for the delivery of a unit of output at the time and place required by the purchaser (United Nations 2009).

2.2.3 Accounts in the 2008 SNA

Due to the large number of individual transactions during an economic period, the number of transactions has to be structured and aggregated. The SNA therefore comprises five accounts according to the standard SNA classification (United Nations 2009, Eurostat 2014):

1. Current accounts: Current accounts include the production account and accounts that capture primary and secondary distribution of income, as well as the use of income. Additionally, these accounts include the world account, which records imports and exports of goods and services.

2. Accumulation accounts: Accumulation accounts involve four types: a) the capital account, b) financial accounts, c) the other changes in assets accounts and d) the revaluation account. These accounts deal with changes in the values of assets, the registration of transactions in non-financial and financial assets and other changes in the volume of assets.

3. Balance sheets: Balance sheets capture the values of asset and liability stocks at the beginning and the end of an accounting period.

4. Goods and services account: This account implies that the total amount of goods and services supplied in an economy equals the total use of goods and services. This identity corresponds to the following:

Output + Imports + Taxes (less subsidies) on products

=

Intermediate consumption + Final consumption + Exports + Capital formation

The account can be considered as the basic identity of the SNA. All other accounts of the SNA are developed around this goods and services account in the way of additional transactions relating to income and savings generation, distribution and redistribution.

5. Accounts for the rest of the world: Entries in the accounts for the rest of the world show the value of goods and services that are imported into the economy from the rest of the world and those that are produced on the domestic market and exported to the rest of the world. These accounts have the function to capture the full range of transactions between the national economy and the rest of the world. The entries correspond to the entries in the balance of payments, as set out in the 'Balance of Payments and Investment Position Manual' 6th edition (IMF 2009).

2.2.4 Economic indicators generated by the SNA

The main objectives of the SNA are the provision of internationally comparative indicators and key figures for macroeconomic analysis as well as for domestic and foreign comparison. The so-called ‘aggregates’ represent composite values that respectively focus on one special aspect of an economic activity. Aggregates generated in the framework of the SNA provide a detailed, complete and simplified picture of the current economic situation of a country. On this basis, conclusions about the development of an economy and its actors can be drawn.

Some aggregates can be derived directly from the totals of single transactions. Other aggregates result from aggregating balancing items of sector accounts like value added, disposal income or savings (Eurostat 2013). A balancing item can be described as a resulting number derived by the application of general accounting rules and considering specific entries on both sides of one account. Balancing items are used to generate macroeconomic indicators. The main aggregates for measuring economic performance are the Gross Domestic Product (GDP), Gross National Income (GNI) and Net National Income (NNI) and Gross/ Net National Disposable Income (GNDI/NNDI) (United Nations 2009).

One of the most common aggregate is the GDP. The estimation of the GDP of an economy can be done by the application of three approaches: a) The *production* approach, b) the *expenditure* approach and c) the *income* approach. The production and expenditure approaches are based on information provided by SUTs. SUTs include a combined and balanced set of various national accounts. By means of SUT, GDP can be deducted on the base of the production approach or expenditure approach, depending on the coverage of data at whole economy level and the product level (Eurostat 2013).

SUTs represent a core element of the German Social Accounting Matrix developed in the frame of this research. Therefore, the next section provides a closer examination of the aggregates and accounting identities of SUTs.

2.2.5 Supply and Use Tables

SUTs comprise a set of matrices that describe how the supply of goods and services is generated by domestic industries and imports and how goods and services are allocated for final use between intermediate or final consumption as well as for exports (Federal Statistical Office 2010b). Table 1 presents a simplified framework of Supply and Use Tables.

Table 1: A simplified Supply and Use framework

Supply table

		Industries			**Imports**	**Trade and transport margins**	**Taxes less subsidies on products**	**Total**
		Agriculture	**Industry**	**Services activites**				
Products	**Agricultural products**	Output by products and by industry at basic prices			Imports by product	Trade and transport margins by product	Taxes less subsidies on products by product	**Total supply by product at purchaser price**
	Industrial products							
	Services							
Total		**Total output at basic prices by industry**			**Total imports**	**Total trade and transport margins**	**Total taxes less subsidies on products**	**Total supply at purchaser price**

Use table

		Industries			**Final uses**			**Total**
		Agriculture	**Industry**	**Services activites**	**Final consumption**	**Gross capital formation**	**Exports**	
Products	**Agricultural products**	Intermediate consumption by product and by industry			Final uses by product and by category			**Total use by product at purchaser price**
	Industrial products							
	Services							
Value added		Value added by component and by industry at basic prices						**Value added**
Total		**Total output at basic prices by industry**			**Total final uses by category**			

Source: OECD (2017)

The Supply table

The Supply table covers the supply of goods and services by product and industry, with a distinction between domestic industries and imports. Furthermore, this table comprises trade and transport margins as well as taxes and subsidies on products. These components sum up to the total supply of goods and services valuated at basic prices (Eurostat 2014).

In the production matrix, domestic output by sectors, is shown by the value of products. The main product of an industry is reported on the main diagonal of the production matrix. Compared to IOTs in the Supply table also secondary or coupled products are recorded. These products are captured beside the main diagonal.

The Use table

The Use table captures the use of goods and services by industries. Use is divided into intermediate consumption by industries, final consumption, gross capital formation and exports. Next to this, the table includes the value added by industries, gross fixed capital formation and changes in inventories and valuables (Eurostat 2014). The columns represent the cost of production of each industry. The intermediate consumption identifies the goods and services that are used to produce primary and secondary products.

In the Supply table, as well as in Use table, the number of industries and products can differ, i.e. one industry can produce more than one product. Therefore, the classification of products in the Supply table can be more detailed than the classification of industries, but the same level of detail for products has to be hold in the use table. The level of disaggregation for products is variable (Punt 2013).

Accounting identities of SUTs

In a closed economy, supply has to be equal to use by definition. To ensure this, three accounting identities have to hold for each commodity (Eurostat 2014).

1. **Identity by industry:**

The identity by industry indicates that the total output by industry is equal to total input by industry.

Output by industry = Input by industry.

Under this condition the output of an industry equals the intermediate consumption plus Gross Value Added (GVA).

2. Identity by product:

The identity by product indicates that the total supply by products is equal to total use by products.

Total supply by product = Total use of product.

To achieve this identity it is necessary to estimate supply and use at the same price. Therefore, the prices in SUTs for each product are estimated at purchasers' prices.

Supply at purchasers' price =
Output at basic prices + Imports at basic prices
+ Trade margins + Transport margins + Taxes (less subsidies) on products

Use at purchasers' price =
Consumption of intermediate inputs + Exports + Final consumption expenditure
+ Gross capital formation

3. Identity for Gross Value Added:

The total GVA is equal to the sum of the GVA of each industry.

$$\text{Total GVA} = \sum \text{GVA of each industry}$$

The GVA of an industry is received by deducting intermediate consumption from output.

By integrating value added into the framework of SUTs, the following accounting relation comes into effect:

Output – Intermediate consumption
=
Value added
=
Compensation of employees + Taxes on production + Net operating surplus

The German SUTs are compiled on an annual basis by the Federal Statistical Office and follow the accounting rules of the SNA. With respect to the classification of commodities and activities the tables follow internationally harmonised classification systems (Federal Statistical Office 2008d). These systems comprise the:

- Classification of activities: Nomenclature statistique des activités économiques dans la Communauté européenne = NACE,
- Classification of products by activity (CPA),

- Classification of individual consumption by purpose (COIOP),
- Government expenditure by function (COFOG).

2.2.6 Input-Output Tables

SUTs provide the statistical basis to create symmetric IOTs. For their compilation various assumptions and adjustments are necessary. These comprise:

- the derivation of domestic and import use matrices,
- the valuation of the use matrix at basic prices,
- the decision about the compilation of a product-by-product or industry-by-industry IOT,
- the determination and distribution of secondary products (McDonald 2007).

In IOTs, the classification of products or industries is identical in rows and columns. The underlying assumption is that each industry produces a single commodity and each commodity is exclusively produced by a single industry. An IOT is therefore referred to as symmetric - the intermediate part of the production matrix is square (Eurostat 2008). Due to the necessary adjustments, an IOT can be regarded as a reduced form of a combined SUT, because it combines information from the supply table and the use table into one single table. During the transformation of data from SUTs into IOTs, assumptions about the relations between input and output have to be made, so that either the product or the industry dimension is lost. IOTs are compiled either as product-by-product tables with underlying technology assumptions or industry-by-industry tables that are based on sales structure assumptions.

The relation of industries and products can be regarded as conceptual difference between SUTs and IOTs. In SUTs, statistics relate products to industries, while in symmetric IOTs statistics relate products to products or industries to industries.

Technology assumptions to generate product-by-product IOTs

Product-by-product IOTs can be derived by the application of a) the product technology assumption and b) the industry technology assumption.

a) If the IOT is based on the product technology assumption, each product is produced by its own characteristic way. There is no differentiation between the industries that produce it.

b) Under the industry technology assumption, each industry has its characteristic and unique input structure, but there is no differentiation of its product mix.

Sales structure assumptions to create industry-by-industry IOTs

To derive industry-by-industry IOTs, either assumptions about c) the fixed industry sales structure or d) the fixed product sales structure have to be made.

c) With an underlying fixed industry sales structure assumption, the IOT is characterised by specific sales structures for each industry, regardless of its production mix.

d) The fixed product sales structure assumption includes that each product has its own sales structure, irrespective of the producing industry.

The decision, which kind of IOT is applied, depends on the economic focus of the analysis. Industry-by-industry IOTs represent market transactions in a better way than product-by-product IOTs. Product-by-product IOTs on the other hand are regarded as more homogeneous in terms of cost structures and production activities (Eurostat 2008).

In a real economy, an industry often produces more than one product, as a subsidiary product, a by-product or a joint product (United Nations 2009). These secondary products create a problem while the development of symmetric IOTs. While the supply table presents secondary products apart the main diagonal, this kind of products have to be reallocated in IOTs, because it assumes that one industry only produces one single product.

Compared to IOTs, in SUTs the same product can also be produced by different industries. This property of SUTs becomes important for this research. It allows capturing a) the agricultural sector as multi-product industry and b) the production of the homogeneous product electricity by different industries in the German SAM and in STAGE_D.

IOTs are valued at basic prices by using information of the supply table, also valued at basic prices and the use table, valued at purchaser prices. In a supply system at basic prices like in IOTs, the columns for trade and transport margins and net taxes on products of the use table become redundant. The valuation matrices are derived from the use table at purchaser prices (Eurostat 2008).

Table 2 presents a simplified framework of a product-by-product IOT, generated on the base of the product technology assumption. A similar IOT could be presented for an industry-by-industry IOT. Here, the first quadrant would contain an industry-by-industry matrix instead of the product-by-product matrix.

Table 2: Simplified framework of a product-by-product Input-Output Table of supply and use at basic prices

	Homogeneous industries			Final use of products			
	Primary sector (Agriculture, forestry, fishery)	**Secondary sector (Industries)**	**Tertiary sector (Services)**	**Consumption by households, non-profit organisations, government**	**Changes in valuables and inventories**	**Export FOB**	**Output at basic prices**
Products primary sector (Agriculture, forestry, fishery)	Intermediate consumption at basic prices			Final demand at basic prices			
Products secondary sector (Industries)							
Products tertiary sector (Services)							
Total at basic prices							
Taxes less subsidies on products							
Direct purchases abroad by residents							
Domestic purchases by non-residents							
Total at purchasers´price							
Compensation of employees	Value added at basic prices			▨			
Other net taxes on production							
Consumption of fixed capital							
Net operating surplus							
Value added at basic prices							
Output at basic prices							
Imports CIF	Imports CIF			▨			
Input at basic prices							

▨ = empty

Source: Based on Eurostat (2008)

2.3 What is a Social Accounting Matrix?

A SAM captures the whole circular flow of an economy in a square matrix format. That means that a SAM includes all transactions and transfers between different institutions and production activities and their interrelationships via factor and product markets within the economy and the rest of the world. All transactions are captured by the application of a single-entry form of booking that can be expressed by the following formula:

$$T = \left[t_{jk}\right] \tag{E 1}$$

Every covered economic agent has its own row and column in the matrix T. Rows and columns are identically ordered. Each transaction between two agents is considered by two transactions: a) receipts of transactor j are captured in the SAM in the row of j and b) expenditures by k are included in the column of k. Consequently, t_{jk} is the value of all earnings of j from k during the observed time period. The other way around, t_{kj} records the payments to k done by j. Because a SAM is an accounting framework, the SAM accounts have to balance. This presumes that the corresponding row and column totals have to be equal (Pyatt 1988).

Round (2003) summarises the main features of a SAM as follows:

1. The accounts of a SAM are represented as a square matrix, where income and expenditure of each account appears in the corresponding row and column of the account. Incomes are captured in the rows and expenditures in the columns of the account. Therefore, each transaction in any cell of the SAM explicitly displays the interconnections between the agents due to the matrix format. Compared to traditional accounts, every entry appears only once, according to the principle of double-entry book keeping.
2. A SAM is comprehensive, i.e. a SAM pictures all economic activities, which comprise consumption, production, accumulation and distribution (Lofgren et al. 2002).
3. A SAM is flexible in the way that, next to the basic components, there is a great flexibility for disaggregating a SAM. The possibilities for disaggregation comprise on the one hand the detail of disaggregation of commodities and on the other hand the agents of the economy.

The name ‘Social Accounting matrix’ includes the attribute ‘social’, because households represent an important part of a SAM and the distributional features are an important component for the description of an economy (Round 2003).

The development of a SAM offers diverse advantages. The construction of a SAM combines data from various data sources, which often subject to the rules of the SNA. But it also allows for the combination of other data sources that capture the structural characteristic of an economy.

Furthermore, a SAM represents a relatively simple and illustrative tool to display information about interdependencies in an economy. Additionally, a SAM can be used as database and analytical framework for modelling (see chapter 2.4) (Pyatt 1988, King 1985).

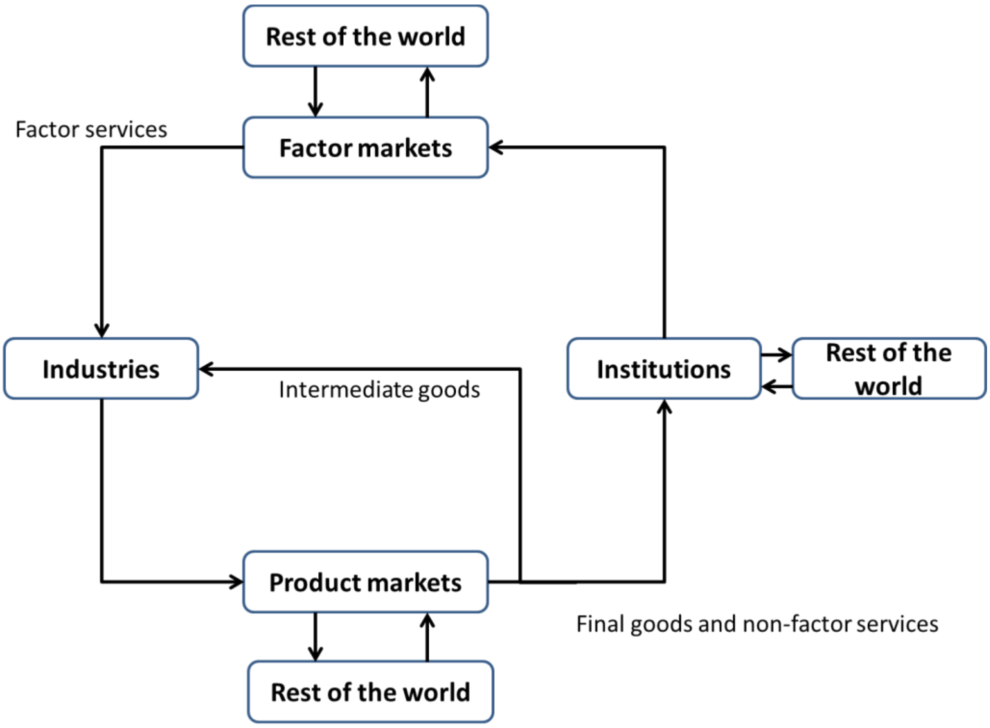
Round (2003a) describes a SAM as a 'meso-level framework' that serves as a bridge between macroeconomic considerations and a more detailed view on the agents of the economy and their interrelationships.

The following sections describe the basic structure of a SAM, starting with the presentation of how the circular flow of an economy is captured in a SAM.

2.3.1 The circular flow of the economy captured in a Social Accounting Matrix

As a consequence of the characteristics of a SAM, the equality of row and column totals, a SAM includes all components of the circular flow in a matrix format (McDonald 2013). Figure 2 shows the circular flow in the economy in a simplified way. Following the direction of the arrows, this figure represents the flow of goods and services between agents. If going the opposite way, the arrows would describe the classic circular flow of income within an economy (Pyatt 1988).

Figure 2: Circular flow in the economy



Source: Punt (2013)

Starting point for the description of the circular flow are the industries. Industries produce goods and services and sell them to other industries for intermediate use or to institutions like households, government or enterprises for final consumption. In case of an open economy, final consumption also comprises exports. Furthermore, final goods can be used during the accounting period or can be stored for use in the future. Imports represent a supplement to domestic production on the product market. Trading interactions between the economy and the rest of the world can also take place between institutions and factor markets. The interactions on factor markets include, for example, workers who are selling their manpower abroad or foreigners who are working in the mentioned economy. Institutions sell factor services on factor markets. Seller of these factor services - labour, capital and land - are the industries. Payments for factor services include salaries and wages as well as returns to capital and land. Punt (2013) expanded the standard picture of the circular flow by payments between institutions and the rest of the world. These include household remittances and foreign aid/ funds.

SUTs, presented in section 2.2.5, comprise detailed information about production and consumption, but do not show the whole picture of the circular flow, because they miss the link between income distribution (factors) and consumption (institutions). There are three necessary mappings, identified by Pyatt (1999), in order to capture the entire circular flow in a SAM. They comprise a) the mapping of value added from industries to factors, b) the mapping of factor income to institutions and c) the mapping of income of institutions into demand for goods and non-factor services. Next to this, information about transfers between institutions is required. These transfer payments include unrequited transfers, property income of rent, interest and the payment of dividends by corporate firms to their stakeholders.

A SAM is characterised by capturing all components of the circular flow in a matrix format by recording the values of transactions between two agents. These transactions are identified by entries in the row and column accounts (see Table 3).

Table 3: Schematic structure of a SAM for modelling

Expenditures → **Receipts ↓**	**1. Commodities**	**2. Activities**	**3. Factors**	**4. Households**	**5. Enterprises**	**6. Government**	**7. Savings/ Investment**	**8. Rest of the world**	**TOTAL**
1. Commodities		Intermediate inputs (Use matrix)		Private consumption		Government consumption	Investment and stock change	Exports	**Product demand**
2. Activities	Domestic production (Supply matrix)								**Production (gross output)**
3. Factors		Value-added						Factor income from RoW	**Factor income**
4. Households			Factor income to households	Inter-household transfer	Transfer to households, corporation income	Transfer to households		Remittances to households from RoW	**Household income**
5. Enterprises			Factor income to enterprises			Transfer to enterprises		Enterprise income from RoW	**Enterprise income**
6. Government	Taxes less subidies on products	Taxes less subsidies on production	Factor income to government, factor taxes	Transfer to government, direct household taxes	Transfer to government, direct enterprise taxes			Transfers from RoW	**Government income**
7. Savings/ Investment				Household savings	Enterprise savings	Government savings	Total stock changes	Capital account balance	**Savings**
8. Rest of the world	Imports of goods and services		Factor income to RoW		Transfers to RoW	Transfers to RoW			**Foreign exchange outflow**
TOTAL	**Product supply**	**Cost of production**	**Factor expenditure**	**Household expenditure**	**Enterprise expenditure**	**Government expenditure**	**Investment**	**Foreign exchange inflow**	

Source: Lofgren et al. (2002), Punt et al. (2003a)

The SAM structure, shown in Table 3, can be regarded as representative for the base SAM developed and applied for this research.

How the entries in a SAM are interpreted, is demonstrated here by using the example of commodities. The entries in the commodities rows represent the values of commodity sales to the appropriate agents, who are identified in the column. Commodities can be used as intermediate inputs by activities (industries), as final consumption by households, by the government, enterprises, investments or exports. The columns for commodities show the supply side and identify the purchasers of commodities. Commodities can be supplied by domestic activities or can be imported. Furthermore, commodity accounts include expenditures for trade and transport services as well as commodity specific taxes (McDonald 2013).

The next section gives a more detailed overview of the accounts of a SAM.

2.3.2 The accounts of a Social Accounting Matrix

A SAM comprises assets, institutions and transactions as main fundamentals of social accounting, which are usually constructed by six types of accounts (Pyatt 1991, Punt et al. 2003a). The scope of the accounts is not fixed and can be disaggregated according to the research objective and data availability. Each account is presented by a row and a column in the matrix. Entries in the row represent for the transactions going into an account, while the columns show transactions leaving the account. For each account in the SAM, the total revenue (row total) corresponds to the total expenditure (column total) (Pyatt 1991, Lofgren et al. 2001, Robinson 2003b).

In a SAM, the following relation is given: The entry t in the ith row and jth column is the expenditure of the jth account on the product of the ith account and simultaneously the income of the jth account due to sales to the ith account. If y comprises the total of an account, consequently the row and column totals have to be equal by definition (Drud et al. 1986, Pyatt 1988).

$$y = \sum_{j} t_{ij} = \sum_{i} t_{ij} \tag{E 2}$$

Commodity accounts

Commodity accounts include the supply and use of goods and services during an accounting period. Commodities can be used as intermediate inputs for production processes of industries or they will receive final demand, what comprises their final consumption, exports or commodities will become part of stock changes.

Commodities produced and sold on the market are automatically captured in a SAM by a transaction. Goods and services that are not traded on markets, such as self-consumption of producers or capital formation, are recorded in the account of the final users. In this case prices have to be estimated (United Nations 2009). Prices and quantities also have to be estimated for non-market goods and services.

All domestically produced commodities are valued at the same price and include all relevant sales taxes and tariffs. As a consequence, the prices in a row are the same, independently which agent sells the commodity. One exception of the price definition in a row is the export price that is derived by a function of exogenously determined export prices (Punt et al. 2003a).

Production accounts

Production or industry accounts cover the production costs in the columns and the revenues received by selling products in the rows. In the SAM framework, producing industries are called activities. Domestic production is captured in the rows of the activity accounts and the column of the commodity account. Total domestic supply includes domestically produced goods plus imports.

The cost of production of an activity comprises the costs for intermediate inputs as well as wages and rents paid for the production factors labour, land and capital. All purchases that are completely used for production in the accounting period are assigned to intermediate inputs. Inputs purchased but not used during this period relate to stock changes and are a part of final demand.

The purchase of factor services is recorded as value added at basic prices. Therefore, the information of the columns of the activity accounts can be used to calculate GDP (Punt et al. 2003a, United Nations 2009).

Factor accounts

Factor accounts include land, labour and capital. These factors represent real assets and are owned by institutions. The factor accounts comprise payments for factor use in the rows. Returns to land, wages for labour and returns to capital are captured in the columns.

Institution accounts

An institution is an economic entity that is able to own assets, incur liabilities and conduct transactions. In a SAM typically households, corporations and the government are covered. The SNA 2008 identifies three basic economic actions that can be undertaken by an institution: 1) production of goods and services, 2) consumption and 3) accumulation of capital (United Nations 2009).

Capital accounts

Capital accounts present all asset related transactions and purchases that are not consumed during the considered period. Payments recorded in the capital account therefore refer to investments and stocks.

Rest of the world account

The account for the rest of the world shows the transactions between domestic institutions of the related economy with the rest of the world. It covers the international trade of goods and services, factor income and payments as well as transfers between institutions.

2.3.3 Balancing a SAM

As underlying database for STAGE_D, a SAM for Germany is developed and disaggregated as part of this study. The development of the SAM and the disaggregation process required the combination of data from different statistical sources, which were often not consistent. Additionally, in some cases necessary data were not available. Due to the conditions that each account must balance and the row and column sums have to equate, a method is necessary to estimate missing data and filling the gaps to achieve a balanced SAM. Various methods such as the RAS method, the Stone-Byron method and the Cross Entropy method are available for estimating missing data and to balance a SAM (see Round 2003b, Fofana et al. 2005).

In this study the Generalised Cross Entropy (GCE) method is applied for the estimation of missing data and to balance the German SAM. The GCE method is based on the Cross Entropy method. Both methods are described here in more detail.

The Cross Entropy Method

The Cross Entropy Method developed by Golan, Judge and Robinson (1994), applies an entropy-based minimand and a constraint set for balancing a SAM. The minimand is derived from a coefficient structure of the SAM (A*). The initial column coefficients (A) are used rather than the transaction flows (X*). Furthermore the minimand includes the estimation of a set of error weights (w_{ij}), which are part of the generation of error variables (e_i). This minimand is included into the estimation of error weights (w_{ij}), which are a component of the calculation of the error variables (e_i).

$$L(A^*, W: A) = \sum_{i,j} a^*_{ij}\, ln\left(\frac{a^*_{ij}}{a_{ij}}\right) + \sum_{i,h} w_{ij} \ln(nw_{ih}) \qquad \text{(E 3)}$$

Error variables (e_i) are not included into the minimand, but ensure the balancing of the corresponding row and column totals. Error weights (w_{ij}) and error variables (e_i) are elements of the constraint set that ensures the maintenance of accounting relationships between coefficients and flows and additionally to accounting constraints (Round 2003b, Punt 2010).

The Generalised Cross Entropy Method

The GCE Method was developed by Golan, Judge and Robinson (1994) and updated by Robinson, Cattaneo and El-Said (2001). The method treats every cell in a SAM with an error support set whose weights are estimated. This method uses a prior for each estimated value and uses measurement errors. During the balancing process a comparison is made between measurement errors and the estimates. The measured error distribution is able to explain the difference between the measured values and the estimated values. The method allows reliable data to have a higher weight than data of lower quality. Additionally, this approach allows special treatment of row and column totals and macro-aggregates, what improves the estimation process (Robinson et al. 2001).

2.4 A SAM as database for modelling

2.4.1 The SAM approach to modelling

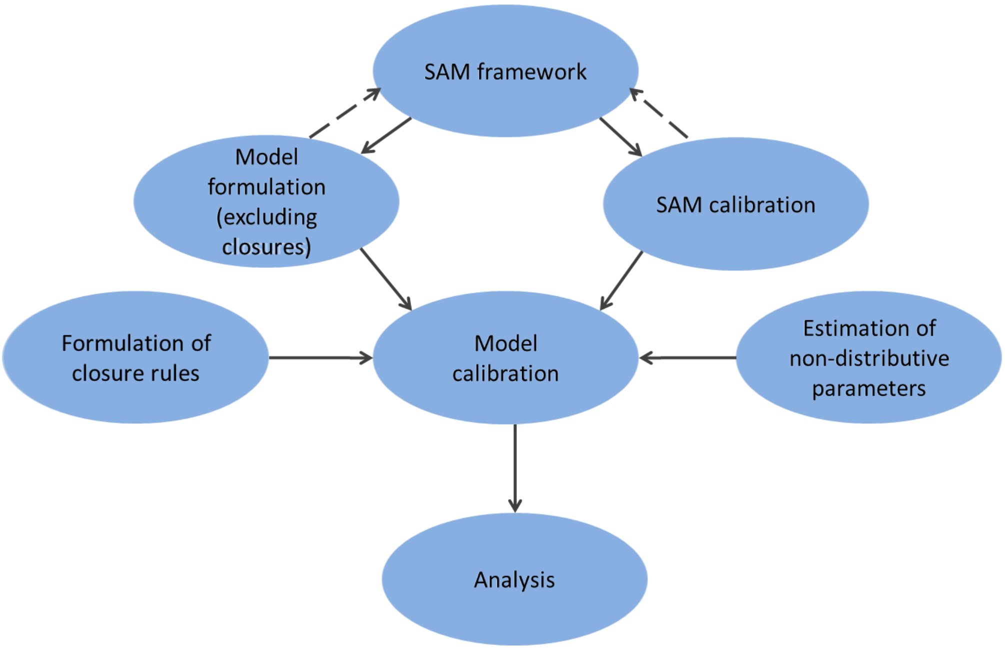
The practical implementation of the SAM approach to modelling comprises two parallel proceedings: 1) the development of the data and theory in the SAM and 2) the development of the (CGE) model with regard to the research question. This section presents the SAM approach to modelling, based on the paper of Pyatt (1988).

Relationship between database and model

Figure 3 illustrates the SAM perspective on model construction with regard to the relationship between the model and its underlying database. Starting from the initial SAM framework, there exist two parallel spaces for further development: a) the formulation of the model and b) the calibration of the SAM. The model formulation requires the determination of the model behaviour for each cell of the SAM by a set of equations. The SAM calibration includes the data development and the balancing process (see section 2.3.3).

The broken arrows in Figure 3 illustrate the interactions during model formulation and the calibration of the SAM. For instance, a lack of primary data leads to the composition of a relatively simple and aggregated SAM. Furthermore, theoretical considerations in the model formulation often give arguments for a detailed disaggregation and conceptual adjustments of the SAM. Both issues have feedback effects on the initial SAM framework.

Figure 3: The SAM approach to modelling



Source: Pyatt (1988)

After finishing this iterative process with the result of a complete SAM framework, two versions of the SAM exist: a) one SAM that includes the specification of behavioural relationships in transaction value form and b) a second SAM, which relates to the first version and presents a balanced set of data that records the value for each transaction in the base period presented. These two versions of the SAM (Model formulation, SAM calibration) are shown in Figure 3 by the arrows leading to the model calibration. Before turning into the analysis, two further contributions to the calibration of the model have to be done: the formulation of closure rules and the estimation of non-distributive parameters.

Three stages to develop a SAM-based model

Pyatt (1988) describes the approach for developing a SAM-based model in three stages:

1) The first stage covers the choice of the research question and the corresponding model focus. On this basis decisions about the aggregation level of activities, commodities, factors and institutions have to be taken.
2) The second stage comprises the specification of the transaction value form of the model.
3) The third stage includes the selection of closure rules.

The *first stage* comprises the general focus of the model with regard to the research question and the resulting SAM structure. Classification systems become particularly important because they are not independent. Pyatt (1988) indicates that the choice of commodity disaggregation has influence on the way how activities should be disaggregated. In parallel, the choice of grouping the activities has an impact on the disaggregation of factors and institutions. Due to the implication of the circular flow (see chapter 2.3.1) and the coherent interdependencies captured in a SAM and in the model, the modeler has to be aware that the detailed disaggregation of one part of the economy also requires consideration of the other parts of the economy.

The *second stage* of the SAM approach to modelling is based on the concept of two versions of a SAM.

a) One version includes the values of transactions.
b) The other version deals with the algebraic expression for determining the corresponding transaction value (Drud et al. 1986, Pyatt 1988).

The reason for two SAM versions is the respective application of the SAM. The first SAM version serves as a database, the second SAM version as basis for the model. In its role as basis for a model, a SAM includes the algebraic expressions, the so-called transaction value (TV) form, of the underlying model. This SAM ensures that each value in the SAM can be expressed by the model through a specific equation. In the end, all equations of the model must be solved simultaneously in order to create a complete and consistent SAM. The SAM approach to modelling provides the possibility to determine transaction values by modelling prices and quantity flows based on a set of equations. Quantity equations can be derived from the transaction-value form of the model, because quantities are the result of value flows and prices. This is a difference to other approaches, in which equations have to be separately specified to determine prices and quantities (Drud et al. 1986, Pyatt 1988).

The advantages of having a pair of a SAM in a data and algebraic format are described by Drud et al. (1986) as follows:

- The disaggregation level of a SAM has to consider the data availability and the research question. The simultaneous development of data and theory captures this issue.
- The framework of a SAM increases data quality due to the requirements of a SAM to be complete and consistent.
- Explaining the transaction-values of the SAM by the model improves the understanding of the model structure.
- The complementary pairs of a SAM ensure the calibration of a CGE model. The model can always reproduce the base case.

Based on the transaction-value SAM, the underlying price system of the model and the SAM as well as the accounting identities and other assumptions of the model can be deducted. The price system and the accounting identities will be discussed in more detail in the next section 2.4.2.

The *third stage* of the SAM approach to modelling is the choice of closures. According to Drud et al. (1986), the system derived from the equations in the transaction-value form of the model in the second stage is underdetermined for describing an economy. Therefore, additional restrictions in form of closures are required to derive a fully determined system. Model closures are described in more details in section 2.4.3 and 3.9.

2.4.2 Accounting identities and prices

According to Pyatt (1988), there is only one fundamental economic law, which declares that every income relates to a corresponding expenditure. A SAM can be regarded as an implementation of this law, because a balanced SAM completely captures the incomes and expenditures of an economy. Pyatt (1988) describes a SAM as a quantitative picture of the economy by capturing and summarising all flows as transactions. The monetary value of any transaction in a SAM is reported in transaction values, that simply is the multiplication of prices by the quantity.

As described in section 2.4.1, the application of the SAM approach to modelling provides two versions of a SAM: 1) an empirical version that includes the data framework and 2) a theoretical version, where the SAM serves as a framework that presents economic theory by describing the behavioural relationships of the agents. In this second version, the cells of the SAM do not include algebraic expressions. Instead of this, the cells include conceptual terms that determine transaction values. Compared to the description of a model as a set of equations defining prices and quantities, the distinctive feature by using the SAM approach to modelling is the description of how the value of each transaction is expressed (Drud et al. 1986).

2.4.2.1 The transaction-value form

For the description of a model in the TV form, decisions about the determination of the elements of the SAM and the behavioural assumptions have to be made. Each number captured in a SAM has to be represented by an algebraic statement that describes how the transaction is defined. Every algebraic statement is therefore a function of income depending on prices.

Following the notation of Pyatt (1988), assuming a given SAM matrix T, the single entries in TV form in the j^{th} row and k^{th} column of the SAM (t_{jk}) are defined as a set of equations according to:

$$t_{jk} = t_{jk}(y; p, f, \lambda) \tag{E 4}$$

The value of a transaction is a function of the income vector y, which depends on a vector of product and non-factor service prices (p), a vector of factor prices (f) and the exchange rate (λ). The value of the element is a function of income and prices. There are no quantities in this function, but it is recognised that each quantity (q) can be determined as y/p. Based on the condition that the sum of the row is equal to the sum of the corresponding column, the following equation can be derived (Pyatt 1988).

$$\mathrm{Ti} = y = \mathrm{T'i} \tag{E 5}$$

Here i is a summation vector. Therefore, the $\mathrm{j^{th}}$ element of γ (γ_j) is the sum of a) all elements in the $\mathrm{j^{th}}$ row of $T\left(\sum_k t_{jk}\right)$ and b) all elements the $\mathrm{j^{th}}$ column $T\left(\sum_j t_{jk}\right)$. Consequently, γ_j represents both: the total income and the total expenditure of the transactor (j), which have to be equal.

Pyatt (1988) describes the advantage of expressing a model in TV form in the 'ready understanding' of the models characteristics. He notes, that if equation (E 4) is substituted for each t_{jk} into equation (E 5), then two sets of equations are derived, which are fundamental to the model structure - one set for the row summation and one set for the column summation of T. The formulation of the model is complete if one additional set of equation is formulated, which comprise the closure rules.

Equations for column summation

The column summation equations of activity and commodity accounts ensure compliance with the following condition: If total costs are equal to total revenues, then average revenues have to be equal to average costs. Therefore, prices are interdependent. This relation is captured in the column summation equations for commodities and activities, which are presented by Pyatt (1988) as follows:

$$\mathrm{p} = p(y; p, f, \lambda) \tag{E 6}$$

This equation characterises the first of three equations describing a macro model. It shows that commodity and activity prices not only depend on each other, but also on factor prices (f), the exchange rate (λ) and the income level (scale of output) of activities (y). Usually, this type of equation is linear homogeneous. Under the assumption that the scale of production is constant, a doubling of input prices causes a doubling of output prices.

Pyatt (1988) distinguishes three types of TV specifications for each cell of the SAM in the context of SAM:

a) In the *first case*, $\mathrm{t_{jk}}$ depends on income (y) (see equation (E 4)) and the cells are endogenous. The matrix of endogenous transactions is denoted by N.

b) In the second case, tjk is independent of income and the cells are exogenous. These transactions are represented as positive matrix elements X.

c) The third case comprises a mixture of endogenous and exogenous cells. Each column comprising one or more exogenous elements has to include this type of cells to meet the adding-up condition. Therefore, these balancing cells finally include the difference between the total income of the account and the sum of the other elements of the column.

If a SAM includes both, endogenous and exogenous cells, the SAM matrix T can be described as follows:

$$T = N + X \tag{E 7}$$

Referred to Pyatt (1988) another column summation equation can be derived:

$$y' = i'T = i'N + i'X \tag{E 8}$$

If row and column sums are equal, then $i'X$ is zero and $i'N$ is equal to y'. The sums of the columns show the production or supply of an economy. They express the costs of production and include a differentiation of goods and services. This form of column summation equation is used to derive the row summation equations, which are presented in the next part.

Equations for row summation

The row summation equations comprise the second set of equations to describe the basic model structure by:

$$y = n + x \tag{E 9}$$

where n and x represent the column vectors of the sums of row N and X, respectively.

This type of equation refers to the demand side of the economy and shows how total income of each account is derived from endogenous and exogenous demand.

System closing equations

As final step of the application of the SAM approach to modelling, Pyatt (1988) mentions the choice of closure rules, which present the third type of equation to describe a basic model. These equations are necessary to close the system and typically focus on factor markets and capital accounts.

The column summation equation $\mathrm{p} = p(y; p, f, \lambda)$ and the row summation equation $y = n + x$ give $[p] + [y] - 1$ independent equations. Therefore, a third set of $[f] + 2$ equations is required to close the system. These equations refer to the closure rules.

Because row and column summation equations are linear homogeneous, at least one of the closures has to be nonlinear by setting one price as numéraire for the entire system. All other prices are measured relative to this price.

2.4.2.2 Interdependence of prices

Pyatt (1988) explains the interdependence of prices in SAM-based models as follows. Based on the column sums of commodities and activities and the requirement that total cost must be equal to total revenue, the price (average revenue) must equal average cost, which depend on prices. The interdependence between prices is therefore determined by the column summation equations for activities and commodities (see equation (E 6)). This equation shows that product and industry prices depend on each other.

The prices in a CGE model are derived from accounting identities and follow economic theory. By definition, row and column totals of a SAM have to be equal. These transactions totals can be expressed as price multiplied by quantity. The quantity supplied by a commodity has to be equal to the quantity demanded. Entries in the column of a SAM record the expenditures to supply the commodity to the economy. Thus, this implicit price must be equal to the average cost to supply the commodity. Since row and column totals must be equal and the quantities supplied must be the same as demanded, the price for the row total must be equal to the average cost caused by the supply of the commodity. The interdependence between prices in CGE models are therefore derived by the structural information of the columns of a SAM (McDonald 2013).

Law of one price

The law of one price explains the price definition in a SAM for modelling and declares in this context why prices are common across the rows of the SAM.

As already mentioned, in a SAM the entry in the ith row and jth column is equal to the expenditure of the jth account on the product of the ith account. The entry is also the income to the ith account from sales of its products to the jth account. Under the condition that a SAM is complete and consistent, the total income and total expenditure must be the same for each account (Punt 2013).

McDonald (2011) describes this relation as follows:

$$\sum_i p_{ij}\, q_{ij} = \sum_i T_{ij} = \sum_j T_{ij} = \sum_j p_{ij} q_{ij} \;\; \forall i = j \tag{E 10}$$

where p is the price and q the quantity. This equation represents the assumption that prices are homogeneous along each row of the SAM and therefore the price for any transaction in one row is the same, irrespective of the agent who buys it (Drud et al. 1986). This fact is the so-called law of one price because it indicates the requirement that each price in the model is uniquely determined (McDonald 2011). If the price is unique, it is irrespective which agent buys the product, because the product is homogeneous. This implies that the quantities in any row are measured in the same units and can be summed up to the row totals. The row totals are defined as the product of the respective price and the sum of quantities recorded in each transaction of the row (Punt 2013).

McDonald (2011) describes this as follows:

$$T_{ij} = \sum_{j} p_i q_{ij} = p_i\, Q_i \;\; and \;\; \sum_{j} q_{ij} \; = \; Q_i \qquad \text{(E 11)}$$

By definition, row and column totals must be equal in a SAM, but the prices in the column relate to different goods and services. The prices are not the same and summing the quantities down the columns is not correct, because quantities are not in the same unit. To hold the accounting identities of a SAM, the quantities in each row should be expressed in similar units with one common single price.

2.4.3 Equilibrium conditions and model closures

Next to the equilibrium conditions, a model requires closures. In mathematical terms, model closures have to ensure that the number of equations and variables is consistent in order to solve the model. That means for the user of the model that a number of variables have to be fixed either on the original level or on a new level for scenario calculations.

From the economic point of view, the decision about model closures declares how the modeller thinks the underlying economy operates. Therefore, model closures have an important impact on the results of model calculations. Appropriate variables that can be fixed in the model are related to the foreign exchange rate, savings and investments, enterprises, the government and factors of production.

2.5 Summary

This chapter presents the interrelations between the classic accounting framework of the SNA, a SAM and the application of a SAM in in the context of modelling.

The SNA provides an internationally agreed coherent, comprehensive and complete statistical accounting framework to obtain information on the structure and development of an economy. A special focus was laid on SUT, which represent a cornerstone in the SNA to capture flows of goods and services and builds the basic database for the development of the SAM for Germany.

The theoretical and methodological frame of a SAM in the context of the SNA and the connection to modelling are a further central point of this chapter. Here especially the ability of a SAM to capture the circular flow of goods and services in an economy and characteristics of the SAM accounting framework are introduced.

Furthermore, introduces this chapter the connection between the theory of accounting with the theory of modelling. Here The SAM approach for modelling combines the function of a SAM as a database with the function of a SAM to picture economic theory by describing the content of the SAM by behavioural relationships expressed by algebraic expressions to determine transaction values.

Summarised it can be stated, that CGE models heavily depend on the quality of their database. A SAM comprises a comprehensive database that follows the clearly defined accounting rules of the SNA.

3 A Static Applied General Equilibrium Model – The STAGE base model

3.1 Introduction

The Static Applied General Equilibrium Model (STAGE) is a comparative-static model and represents the base model for the development of the modified model version STAGE_D. STAGE was developed by Scott McDonald and Karen Thierfelder (McDonald and Thierfelder 2013) and is a member of single-country CGE model descendants of a model approach described by Dervis et al. (1982) and further developed by Robinson et al. (1990), Kilkenny (1991) and Devarajan et al. (1994). STAGE is a SAM based model that is influenced by the SAM approach to modelling (Pyatt 1988), described in chapter 2.4. Therefore, also in STAGE_D the SAM serves as a database for model calibration and additionally the sub-matrices of the SAM identify agents of the economy, whose behavioural relationships are defined in the model.

This chapter introduces the basic structure of the STAGE model. After a short excursus into the general equilibrium theory in section 3.2 with focus on the definition of an economy in an equilibrium situation, the following section 3.3 identifies the behavioural relationships with reference to the sub-matrices of the SAM and the underlying functional forms for modelling. Section 3.4 considers quantity and section 3.5 price relationships in the STAGE base model. The subsequent sections give a more detailed insight in the algebraic statements of modelling production (section 3.6), trade (section 3.7) and household income and expenditure (section 3.8) in the base model. The closures of the base model are presented in section 3.9. A short summary of this chapter is given in section 3.10.

3.2 Excursus to general equilibrium theory

General equilibrium theory goes back to Leon Walras in the 1870s (Walker 2005). His theory was further developed by Arrow, Debreu and McKenzie in the 1950s (Arrow and Debreu 1954). From the 1970s onward, technological progress and increasing computing power made it possible to develop ‘computable´ models for national economies to obtain empirical solutions for general equilibrium prices and quantities.

General equilibrium theory examines the fundamentals of supply and demand in a multi-market economy, with the objective to identify the equilibrium situation where all prices are in balance. Compared to the partial equilibrium theory, which focusses on a single market, the general equilibrium theory considers all markets. Here, the economy is regarded as an interrelated system of markets. In an equilibrium situation all consumers, enterprises, industries and factor services are in equilibrium simultaneously. The equilibrium theory investigates the mechanism how choices of economic agents are coordinated across all markets in order to achieve the equilibrium situation (McKenzie 2002).

With regard to the circular flow of an economy (see section 2.3.1), a general equilibrium is achieved if the following three conditions hold:

- Market clearance,
- Zero profit,
- Income balance of households (Wing 2004).

Market clearance condition: Market clearance is the situation, in which the quantity supplied equals the quantity demanded. The market clearing price, also called equilibrium price, is the price that causes the appropriate adjustment of supply and use (ibid).

Zero profit condition: The zero profit condition for production implies the non-existence of long-term profits. The 'Zero Profit Theorem' states that firms enter into competitive markets until all possibilities for positive economic profit are reduced to zero. Therefore, a competitive firm maximises its profits by choosing the production at a price where marginal costs are equal to marginal revenues, which are equal to the marginal price (Gravelle andRees 2004).

Income balance of households' condition: This condition relates to household income and expenditure. In the equilibrium situation, income and expenditure of households have to equate. That means that the households factor endowment is fully employed and households spend their income on purchases and savings (Pandit and Shanmugam 2008).

These three conditions are applied in CGE models to solve simultaneously for a set of prices and the allocation of products and factors. But for modelling also two additional assumptions are important:

The *first* is the stability of the equilibrium for analysing the effects of changes of exogenous variables. If the equilibrium is stable, the system returns back to the point of equilibrium when it is in disequilibrium.

The *second* point is the uniqueness of the equilibrium, which is important for comparative-static analysis, like in this study (Gravelle and Rees 2004).

By running an experiment, disequilibrium is created. This is done by changing an exogenous parameter or variable in the model, i.e. for example a tax rate or factor demand by industries. The model solves for a new equilibrium. The comparison between the initial or base equilibrium with the new equilibrium shows the effects of changes in policy, technology or other external factors in the economy.

Today, CGE models are a standard tool for economic and political analysis and are widely used to analyse the aggregate welfare and distributional impacts of policies whose effects may be transferred across multiple markets (see Dervis et al. 1982). A CGE model explains the payments recorded in the database by using a set of linear and non-linear equations. These equations are solved simultaneously, whereby a CGE model has no objective function (Lofgren et al. 2002, Burfisher 2011). In a CGE model, the behaviour for consumption and production is determined by nonlinear first order conditions. It means that industries maximise their profits and consumer maximise their utility. Some of the equations represent a set of constraints that has to be satisfied by the system. These constraints affect markets for factors and commodities as well as macroeconomic aggregates like savings and investments, the government and the rest of the world (Lofgren et al. 2002). All equations in the model are solved simultaneously to find the equilibrium of the economy, where prices and quantities of supply and demand are equal in every market (Burfisher 2011).

After this brief overview of general equilibrium theory, the next section gives an introduction to the STAGE base model, starting with a closer look at behavioural relationships.

3.3 Behavioural relationships in STAGE

The accounts of a SAM determine the agents of the model. The values included in the various submatrices recorded in a SAM identify the transactions of the agents of an economy. Additionally, these transactions represent the outcome of the behavioural relationships specified in the model. Behavioural relationships identify how the economic agents, captured in a CGE model, react to exogenous changes in parameters or variables. The specification of behavioural relationships and the calibration of their parameters is one part of the calibration process of a CGE model. After the calibration, the model is able to replicate the initial conditions recorded in SAM, which represents the base equilibrium situation. This section gives an overview of the behavioural relationships in the STAGE model.

Starting point for the description is Table 4, which describes the behavioural relationships of the different agents in the STAGE standard model, structured by the sub matrices of the SAM.

Behavioural relationships in STAGE are a mix of non-linear and linear functions that express the reactions of agents recorded in the model to exogenous changes in model parameters and/or variables (McDonald 2007). Non-linear functional forms are applied in five submatrices of the SAM. These submatrices comprise (1) production in the intermediate use matrix, (2) the factor demand matrix, (3) trade in the import matrix and (4) export matrix and (5) household consumption. Depending on the particular focus of the research question, these functional forms can differ.

Table 4: Behavioural relationships in the STAGE standard model

	Commodities	**Activities**	**Factors**	**Households**	**Enterprises**	**Government**	**Capital**	**Rest of the world**	**Total**	**Prices**
Commodities	0	Leontief Input-Output coefficients	0	Utility functions (Cobb-Douglas or Stone-Geary)	Fixed in real terms	Fixed in real terms and export taxes	Fixed shares of savings	Commodity exports	**Commodity demand**	Consumer commodity price
Activities	Domestic production	0	0	0	0	0	0	0	**Constant elasticity of substitution production functions**	Prices for exports
Factors	0	Factor demands (CES)	0	0	0	0	0	Factor income from RoW	**Factor income**	
Households	0	0	Fixed shares of factor income	Fixed Shares of income	Fixed shares of dividends	Fixed (real) transfers	0	Remittances	**Household income**	
Enterprises	0	0	Fixed shares of factor income	0	0	Fixed (real) transfers	0	Transfers	**Enterprise income**	
Government	Tariff revenue/ Domestic product taxes	Indirect taxes on activities	Fixed shares of factor income/ Direct taxes on factor income	Direct taxes on household income	Fixed shares of dividends/ Direct taxes on enterprise income	0	0	Transfers	**Government income**	
Capital	0	0	Depreciation	Household savings	Enterprise savings	Government savings (residual)	0	Current account 'deficit'	**Total savings**	
Rest of the world	Commodity imports	0	Fixed shares of factor income	0	0	0	0	0	**Total 'expenditure' from RoW**	
Total	**Commodity supply**	**Activity input**	**Factor expenditure**	**Household expenditure**	**Enterprise expenditure**	**Government expenditure**	**Total investment**	**Total 'income' from RoW**		
Prices	Producer commodity prices/ Domestic and world prices for imports	Value-added prices								

Source: McDonald (2007)

3.3.1 Functional forms for modelling production, households and trade

In this section, the non-linear behavioural relationships for production, households and trade are described in more detail in their functional forms.

3.3.1.1 Functional forms for modelling production

In CGE models producers are assumed to maximise profit under technological constraints and the first order condition (FOC) of the implemented production function. These conditions determine the optimal level of resource use and the combination of factors (Punt 2013). There are various functional forms to describe production in a CGE model, e.g. the Leontief production function, the Cobb-Douglas production function or Constant Elasticity of Substitution (CES) functions (Provide 2003b).

The Leontief and Cobb-Douglas production functions can be regarded as special cases of the CES function. The Leontief production function is often applied under the assumption of fixed proportions of intermediate demand relative to the output of each industry due to the characteristic elasticity of substitution of zero. For Cobb-Douglas production functions, the elasticity of substitution between inputs is equal to one. CES functions are more flexible. The elasticity of substitution can have other values than one, but the elasticity is constant for all pairs of inputs in the function (Nicholson and Snyder 2010).

During the development of STAGE_D, the majority of modifications were made in the nested production structure by the application of different kinds of CES functions. Therefore, this type of production function is now presented in more detail.

<u>Theory and variants of the CES function</u>

CES production functions were applied to modify the nested production structure in the STAGE_D to capture the complexity of the energy policy in Germany (see chapter 5). This part of the study, some theoretical aspects and variants of the CES function are examined in more detail.

The CES function was described for the first time by Arrow, Chenery, Minhas and Solow (1961). The objective of Arrow et al. (1961) was a better representation of empirical evidence. Therefore, they developed a function with the focus on the following characteristics: a) homogeneity, b) constant elasticity of substitution between capital and labour and c) the possibility of different elasticities for different industries. They also revealed that the Leontief and Cobb-Douglas functions are special cases of the CES function. The introduction of the CES function by Arrow et al. (1961) was done for the two-factor case. Mukerji (1963) expanded this version by the n-factor case. Further developments were carried out by Sato (1967), with an extension of the multi-factor CES function to the two-level CES function.

Originally, the CES function was illustrated in the context of production under the assumption of profit maximisation. But CES functions are also applied in the context of consumption. Under the assumption of utility maximisation, a CES function builds the basis for the Linear Expenditure System (LES) utility function.

The two-factor CES production function

The presentation of the theoretical foundations of the two-factor CES production function follows the demonstration of Chiang and Wainwright (2005).

The following equation represents the two-factor CES function,

$$Q = A[\delta\, K^{-\rho} + (1-\delta)\, L^{-\rho}]^{-1/\rho}\ (A > 0; 0 < \delta < 1; -1 < \rho \neq 0) \qquad \text{(E 12)}$$

in which K and L represent two factors of production. A is the efficiency parameter, ρ (rho) the substitution parameter and δ (delta) the distribution parameter. The efficiency parameter A is a neutral efficiency parameter and serves as an indicator for the state of technology. It only effects the proportional change of output by a given set of inputs. The distribution parameter δ deals with the relative factor shares in the product. The substitution parameter ρ determines the value of the (constant) elasticity of substitution.

The CES function is homogeneous of degree 1. This can be proved by the replacement of the production factors K and L by jK and jL in equation (E 12). The output will change from Q to jQ.

$$\begin{aligned} A[\delta\,(jK)^{-\rho} + (1-\delta)\,(jL)^{-\rho}]^{-1/\rho} &= A\{j^{-\rho}[\delta\, K^{-\rho} + (1-\delta)\, L^{-\rho}]\}^{-1/\rho} \\ &= (j^{-\rho})^{-1/\rho} Q = jQ \end{aligned} \qquad \text{(E 13)}$$

Due to the homogeneity of degree 1, the linear homogeneous production function is characterised by constant returns to scale. Constant returns to scale enable the application of Euler´s theorem. Euler´s theorem implies that if the price (in terms of output units) of each input factor is equal to its marginal product, the total cost is equal to total output (Nicholson and Snyder 2010).

A CES function is always negatively sloped with strictly convex isoquants for all positive values of K and L. This can be shown by the marginal products of Q_L

$$
\begin{aligned}
Q_L \equiv \frac{\delta Q}{\delta L} \quad &= \; A\left(-\frac{1}{\rho}\right)[\delta\,(K)^{-\rho} + (1-\delta)\,(L)^{-\rho}]^{\left(-1/\rho-1\right)}(1-\delta)\,(-\rho)L^{-\rho-1} \\
&= (1-\delta)\,A[\delta\,(K)^{-\rho} + (1-\delta)\,(L)^{-\rho}]^{-(1+\rho)/\rho}\,L^{-(1+\rho)} \\
&= (1-\delta)\,\frac{A^{1+\rho}}{A^{\rho}}[\delta\,(K)^{-\rho} + (1-\delta)\,(L)^{-\rho}]^{-(1+\rho)/\rho}\,L^{-(1+\rho)} \\
&= \frac{(1-\delta)}{A^{\rho}}\left(\frac{Q}{L}\right)^{1+\rho} > 0 \text{ by (E 13)}
\end{aligned}
\tag{E 14}
$$

and similarly for Q_K,

$$
Q_K \equiv \frac{\delta Q}{\delta K} \quad = \frac{(1-\delta)}{A^{\rho}}\left(\frac{Q}{K}\right)^{1+\rho} > 0
\tag{E 15}
$$

which are defined for positive values of $K$and L (Chiang and Wainwright 2005). Therefore, the slope of the isoquants is negative.

$$
\frac{dK}{dL} = \frac{Q_L}{Q_K} \quad = -\frac{(1-\delta)}{\delta}\left(\frac{K}{L}\right)^{1+\rho} < 0
\tag{E 16}
$$

As a result, $\mathrm{d}^2\mathrm{K}/\mathrm{dL}^2$ will be greater than zero, what causes that the isoquants to be strictly convex for a positive K and L.

The marginal product (see (E 14) and (E 15)) is used to determine the elasticity of substitution of a CES function.

Therefore, the least-cost combination of the factors labour and capital $\frac{\mathrm{Q_L}}{\mathrm{Q_K}} = \frac{\mathrm{P_L}}{\mathrm{P_K}}$ has to be found, where $\mathrm{P_L}$ and $\mathrm{P_K}$ are the prices for labour (wage rate) and capital (interest rate), like shown in equation (E 17).

$$
\frac{(1-\delta)}{A^{\rho}}\left(\frac{K}{L}\right)^{1+\rho} = \frac{P_L}{P_K}
\tag{E 17}
$$

Consequently, the optimal ratio of capital-labour use can be described as follows,

$$\left(\frac{K^*}{L^*}\right) = \left(\frac{\delta}{1-\delta}\right)^{1/(1+\rho)} \left(\frac{P_L}{P_K}\right)^{1/(1+\rho)} \equiv c\left(\frac{P_L}{P_K}\right)^{1/(1+\rho)} \tag{E 18}$$

where c is a shorthand symbol for the term $\left(\frac{\delta}{1-\delta}\right)^{1/(1+\rho)}$.

By using (K^*/L^*) as a function of (P_L/P_K), the associated marginal and average functions can be presented as follows:

$$Marginal\ Function = \frac{d(K^*/L^*)}{d(P_L/P_K)} = \frac{c}{1+\rho}\left(\frac{P_L}{P_K}\right)^{\frac{1}{1+\rho}-1} \tag{E 19}$$

$$Averange\ Function = \frac{K^*/L^*}{P_L/P_K} = c\left(\frac{P_L}{P_K}\right)^{\frac{1}{1+\rho}-1} \tag{E 20}$$

The resulting elasticity of substitution is the quotient of the marginal function and the average function.

$$\sigma = \frac{Marginal\ function}{Average\ function} = \frac{1}{1+\rho} \tag{E 21}$$

This equation shows that the elasticity of substitution is a constant whose magnitude depends on the value of the substitution parameter ρ, like shown here:

$$\begin{aligned} -1 < \rho < 0 &\Rightarrow \sigma > 1 \\ \rho = 0 &\Rightarrow \sigma = 1 \\ 0 < \rho < \infty &\Rightarrow \sigma < 1 \end{aligned} \tag{E 22}$$

The first order condition for profit maximisation can be derived by including the profit maximisation condition, where the wage of factor F equals the marginal revenue product of the particular factor ($W_F = MRP_F$), into the equation for the marginal physical product of the factor (MPP_F). Hence, the relation $MPP_F * P = MRP_F = W_F$ holds, where P is the price of output. The marginal physical product is the first derivative of factor F.

The equilibrium demand for factor capital can therefore be described as follows (see Punt et al. 2003b):

$$MPP_K = \left(-\frac{1}{\rho}\right) A[\delta\, K^{-\rho} + (1-\delta) L^{-\rho}]^{-1/\rho^{-1}}[(1-\delta)\,(-\rho)\, K^{-\rho-1}]$$

$$\frac{MRP_K}{P} = A[\delta\, K^{-\rho} + (1-\delta)\, L^{-\rho}]^{-1/\rho^{-1}}[\delta\, K^{-\rho-1}] \qquad \text{(E 23)}$$

$$W_K = P\, A[\delta\, K^{-\rho} + (1-\delta)\, L^{-\rho}]^{-1/\rho^{-1}}[\delta\, K^{-\rho-1}]$$

The equilibrium factor demand for labour is derived in the same way:

$$MPP_L = \left(-\frac{1}{\rho}\right) A[\delta\, K^{-\rho} + (1-\delta) L^{-\rho}]^{-1/\rho^{-1}}[\delta\,(-\rho)\, L^{-\rho-1}]$$

$$\frac{MRP_L}{P} = A[\delta\, K^{-\rho} + (1-\delta)\, L^{-\rho}]^{-1/\rho^{-1}}[\delta\, L^{-\rho-1}] \qquad \text{(E 24)}$$

$$W_L = P\, A[\delta\, K^{-\rho} + (1-\delta)\, L^{-\rho}]^{-1/\rho^{-1}}[\delta\, L^{-\rho-1}]$$

The equations for equilibrium factor demand satisfy the first-order condition for profit maximisation. Profit maximisation can be derived by the definition of a profit function (Π) as total revenue minus total costs, which is described as follows:

$$\Pi = P\, A[\delta\, K^{-\rho} + (1-\delta)\, L^{-\rho}]^{-1/\rho^{-1}} - W_K K - W_L L \qquad \text{(E 25)}$$

By using the first order partial differentials of the profit function for K and L and solving them simultaneously, the profit equilibrium condition can be obtained (Punt 2013). The first order partial differentials of the profit functions for K and L are set to zero:

$$\frac{\partial \Pi}{\partial K} = \left(-\frac{1}{\rho}\right) P\, A[\delta\, K^{-\rho} + (1-\delta)\, L^{-\rho}]^{-1/\rho^{-1}}[-\rho\, \delta\, K^{-\rho-1}] - W_K = 0 \qquad \text{(E 26)}$$

$$\frac{\partial \Pi}{\partial L} = \left(-\frac{1}{\rho}\right) P\, A[\delta\, K^{-\rho} + (1-\delta)\, L^{-\rho}]^{-1/\rho^{-1}}[-\rho(1-\delta) L^{-\rho-1}] - W_L = 0 \qquad \text{(E 27)}$$

Under the application of the first order partial differentials of the profit function, the optimal ration for the respective factor is determined by the ratio of prices according to the profit condition described in equation (E 28).

$$\frac{W_K}{W_L} = \frac{\delta}{1-\delta}\left(\frac{L}{K}\right)^{\rho+1} \tag{E 28}$$

To receive the profit equilibrium condition, the ratio of factors has to be the dependent variable:

$$\frac{L}{K} = \left(\frac{W_K}{W_L}\,\frac{1-\delta}{\delta}\right)^{\frac{1}{\rho+1}} \tag{E 29}$$

<u>The generalised version of the two-factor CES function</u>

To allow the consideration of n factors, the CES function was further developed by Mukerji (1963). The generalised multi-factor CES function has the following form:

$$\begin{aligned} Q &= A\left[\delta_1\,{x_1}^{-\rho} + \delta_2\,{x_2}^{-\rho} + \cdots + \delta_n\,{x_n}^{-\rho}\right]^{-\varepsilon/\rho} \\ &= A\left[\sum_{i=1}^{n}\delta_i\,x_i\right]^{-\varepsilon/\rho} \end{aligned} \tag{E 30}$$

This function provided the basis for Sato (1967) to develop a two-level CES function that represent the foundation of nested production functions, which are used until today in CGE models. The two-level CES function can be described as a special case of strongly separable functions. Therefore, the allocation of factors within each factor category (capital, labour) is determined solely by relative prices of that respective category (Punt 2003b).

Similar to the case of two factors, the multiplication of each factor x_i by a factor λ causes an increase of output by factor λ^{ε}. Therefore, it is a linear homogeneous function for $\varepsilon = 1$. The first order condition for profit maximisation for this type of CES function for factor x_i is equal to the two-factor CES function and can be derived by setting the wage of factor x_i (W_i) equal to the marginal revenue product of product x_i (MRP_i). Doing this, the marginal physical product of x_i (MRP_i) is derived. The result of multiplying the marginal physical product by the price of output is the first order condition of the generalised form of the CES function.

The derivation of the first order condition of a linear homogeneous function ($\varepsilon = 1$) is described here in its mathematical form and follows Punt (2013):

$$\begin{aligned}
MPP_i &= \left(\frac{-1}{\rho}\right) A[\delta_1\, x_1{}^{-\rho} + \delta_2\, x_2{}^{-\rho} + \cdots + \delta_n\, x_n{}^{-\rho}]^{-1/\rho^{-1}}[(-\rho)\, \delta_i\, x_i{}^{-\rho-1}] \\
&= A[\delta_1\, x_1{}^{-\rho} + \delta_2\, x_2{}^{-\rho} + \cdots + \delta_n\, x_n{}^{-\rho}]^{-1/\rho^{-1}}[\delta_i\, x_i{}^{-\rho-1}] \\
MRP_i &= P\, A[\delta_1\, x_1{}^{-\rho} + \delta_2\, x_2{}^{-\rho} + \cdots + \delta_n\, x_n{}^{-\rho}]^{-1/\rho^{-1}}[\delta_i\, x_i{}^{-\rho-1}]
\end{aligned}$$

$$\begin{aligned}
W_i &= P\, A[\delta_1\, x_1{}^{-\rho} + \delta_2\, x_2{}^{-\rho} + \cdots + \delta_n\, x_n{}^{-\rho}]^{-1/\rho^{-1}}[\delta_i\, x_i{}^{-\rho-1}] \\
&= P\, A\left[\sum_{i=1}^{n} \delta_i\, x_i{}^{-\rho}\right]^{-1/\rho^{-1}} [\delta_i\, x_i{}^{-\rho-1}] \\
&= P\, Q\left[\sum_{i=1}^{n} \delta_i\, x_i{}^{-\rho}\right]^{-1} [\delta_i\, x_i{}^{-\rho-1}]
\end{aligned} \tag{E 31}$$

By given the following relationship:

$$\begin{aligned}
Q &= A\left[\sum_{i=1}^{n} \gamma_i\, x_i{}^{-\rho}\right]^{-1/\rho} \\
\left[\sum_{i=1}^{n} \gamma_i\, x_i{}^{-\rho}\right] &= \left[\frac{Q}{A}\right]^{-\rho}
\end{aligned} \tag{E 32}$$

Equation (E 31) can be restated in terms of the quantity ratio as follows:

$$\begin{aligned}
W_i &= P\, Q\left[\sum_{i=1}^{n} \gamma_i\, x_i{}^{-\rho}\right]^{-1} [\gamma_i\, x_i{}^{-\rho-1}] \\
\frac{W_i}{P} &= Q\left[\left[\frac{Q}{A}\right]^{-\rho}\right]^{-1} [\gamma_i\, x_i{}^{-\rho-1}] \\
&= Q\left[\frac{Q}{A}\right]^{-p} [\gamma_i\, x_i{}^{-\rho-1}] \\
&= \frac{Q}{Q^{-\rho} A^{\rho}} [\gamma_i\, x_i{}^{-\rho-1}]
\end{aligned} \tag{E 33}$$

$$= \frac{[\gamma_i \, x_i{}^{-\rho-1}]}{Q^{-\rho-1} \, A^{\rho}}$$

$$= \frac{\gamma_i}{A^{\rho}} \, \frac{x_i^{-\rho-1}}{Q^{-\rho-1}}$$

$$= \frac{\gamma_i}{A^{\rho}} \left[\frac{x_i}{Q}\right]^{-\rho-1}$$

$$\left[\frac{x_i}{Q}\right]^{-\rho-1} = \left[\frac{W_i}{P} \, \frac{A^{\rho}}{\gamma_i}\right]$$

$$\frac{x_i}{Q} = \left[\frac{P_i}{P} \, \frac{A^{\rho}}{\gamma_i}\right]^{\frac{1}{-\rho-1}}$$

The CES functions applied in the STAGE standard model are linear homogenous. Thus, a multiplication of all inputs by the same value causes an increase of output by the same factor. A linear homogeneous production function is characterised by the following properties:

- constant returns to scale,
- marginal products that are independent of the scale of production,
- the slopes of isoquants depend only on the input proportion, but not on the scale of production,
- the output is equal to the sum of the marginal products of the used inputs multiplied by the amount of use (Gravelle and Reese 2004, Punt 2013).

Section 3.6 gives an overview of modelling production in the STAGE base model.

3.3.1.2 Functional forms for modelling households

Private households are assumed to maximise their utility. This is done by the income allocation across commodities on the basis of their preferences and with regard to budget constraints and commodity prices. This behaviour can be represented by using a Stone-Geary or Cobb-Douglas utility function, as in the STAGE model. In STAGE, the Linear Expenditure System (LES) is based on the Stone-Geary utility function and represents the base for modelling household consumption. Therefore, the Stone-Geary and Cobb-Douglas utility functions are considered here in more detail.

The LES, introduced by Stone (1954), can be derived from maximising the Stone-Geary utility function subject to household budget constraint. The Stone-Geary utility function is a variant of the Cobb-

Douglas function and assumes that household expenditure is spent in fixed value shares to each product, so that the total disposable income is spent. The cross-price elasticity for this type of function is zero. All own-price elasticities are equal to the value of minus one. Income elasticities and the elasticities of substitution are equal to the value of one.

The application of a Cobb-Douglas utility function is associated with advantages and disadvantages. One disadvantage is the assumption of constant average budget shares. Due to this, changing consumption and trade patterns and an inobservance of Engel`s law cannot be captured. Engel`s law states that in case of rising income the proportion of income spent on food decreases, even if expenditures on food increases (Nicholson and Snyder 2010). Nevertheless, the Cobb-Douglas utility function is often used in CGE models because this functional type is convenient in the calibration and no additional elasticities are necessary. The missing consumption shares can be easily calculated from the SAM (Punt 2013, Annabi et al. 2006). The Cobb-Douglas utility function can be achieved during the calibration process of the model by setting the Frisch parameter to minus one and all income elasticities of demand equal to one. By doing this, the Stone-Geary utility function changes into the Cobb-Douglas utility function (McDonald 2007). The Frisch parameter is the negative ratio between the total and discretionary expenditure. It measures "…the sensitivity of the marginal utility of income to total expenditures and establishes a relationship between income and own-price elasticities. Own-price and cross-price elasticities can be derived by using the Frisch parameter in conjunction with income elasticity." (Jussila et al. 2012, page 7).

Compared to the Cobb-Douglas utility function, the LES does not assume unit income elasticity. Under a Stone-Geary utility function household consumption is divided into two components: the subsistence demand and the discretionary demand. The function captures both elements, which allow the user of the model to distinguish between households with different incomes (McDonald 2007). An overview how household income and expenditure is implemented into the STAGE base model is given in section 3.8.

Another aspect of modelling household behaviour in STAGE is the differentiation between domestically produced and imported commodities. Functional forms for modelling trade are considered now.

3.3.1.3 Functional forms for modelling trade

In a CGE model, final consumption is divided into intermediate consumption and final demand by domestic agents, investments and exports. Supply comprises domestically produced goods and imports. CES functions can be applied to combine domestically produced goods and imports as 'composite' goods. The optimal ratio for the demand of imported or domestic commodities is determined by their relative prices through the first order condition of the CES function. This distinction follows the Armington assumption. This assumption comprises the differentiation of products based on the origin of countries in which they are produced and the imperfect substitution between these goods (Armington 1969).

In CGE models, the behavioural relationships of exports are often defined by the Constant Elasticity of Transformation (CET) function. The supply of commodities is determined by the domestic demand and the export demand of domestically produced commodities. Under the assumption of imperfect transformation between domestic demand and export demand, due to the application of the CET function, the optimal distribution of domestically produced commodities between the domestic market and the export market is determined by the relative prices between these two markets (Punt et al. 2003b). The implementation of trade in the STAGE standard model is presented in section 3.7.

3.4 Quantity relationships in the STAGE base model

This section presents the quantity and production relationships in the STAGE base model according to McDonald (2007). Starting point are the quantity relationships presented in Figure 4.

The total demand for composite commodities in an economy (QQ_c) is a composition of the demand for intermediate inputs $(QINTD_c)$ and final demand. Final demand comprises consumption by households (QCD_c), corporations $(QED_{c,e})$, the government (QGD_c), gross fixed capital formation $(QINVD_c)$ and stock changes $(dstocconst_c)$. The products demanded are assumed to be composite products (QQ_c) by a combination of domestically produced goods (QD_c) and imported goods (QM_c). The aggregation of these goods is determined by a CES function[2] and the relevant first order condition.

Domestically produced goods, sold on the domestic market (QD_c), represent only one part of total domestic supply (QXC_c). The other part is assumed to be destined for the export market (QE_c). The distribution of goods between the domestic market and export market is governed by the Armington CET function[3]. The relative share of a product sold on each market depends on the relative price on the particular market. The product equilibrium condition ensures market clearing on the domestic market. In this case total demand and total supply of composite products (QQ_c) are equal and the total domestic supply (QXC_c) is either consumed domestically or exported.

STAGE allows the consideration of multi-product industries, i.e. one industry can produce more than one product or the other way around: a commodity can be produced by multiple industries. Consequently, the total production of a commodity is the sum of commodities produced by different

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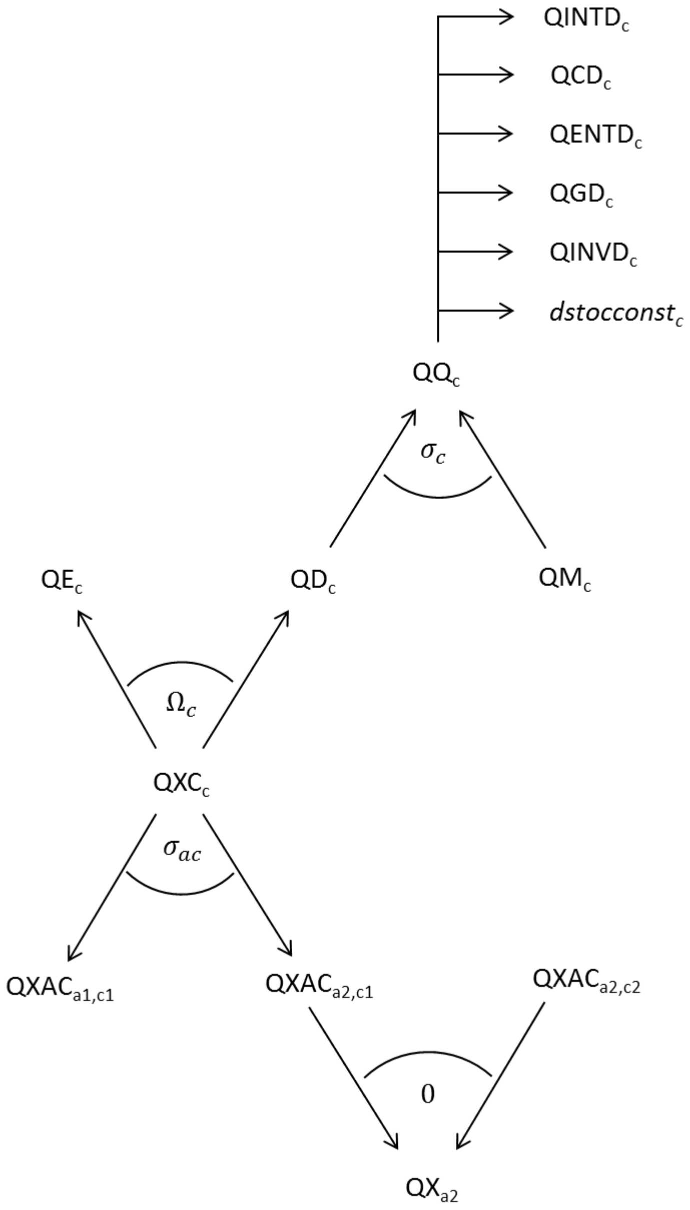
[2] The elasticity parameter used in CES functions is identified by sigma (σ).

[3] Omega (Ω) represents the elasticity parameter of the Armington CET function for exports.

activities. These commodities derive from different industries ($QXAC_{c,a}$) and are aggregated across sectors to reach the total domestic production of this commodity (QXC_c). The optimal combinations are determined by industry prices and the first order condition. Each industry produces its specific combination of products in fixed proportions. The output of $QXAC_{c,a}$ follows the conditions of the Leontief function and is a fixed proportion aggregate of the output of each industry (QX_a). The assumption of fixed proportions allows input use to be determined together with the output level, because the input level would increase in the same proportions as the level of output.

Figure 4: Quantity relationships in the STAGE base model



Source: McDonald (2007)

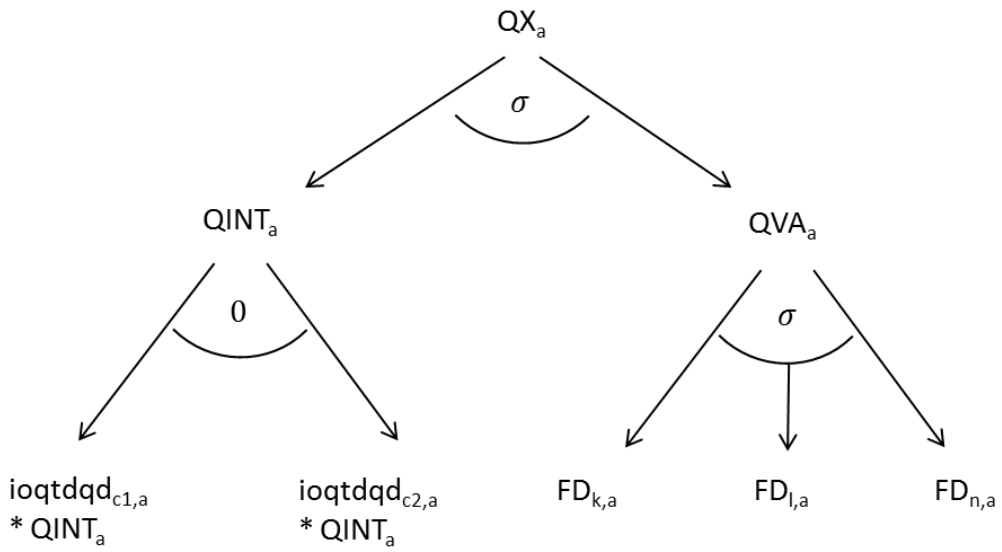
Domestically produced commodities (QXC_c), commodities produced for the domestic market (QD_c), imports (QM_c) and exports (QE_c) are valued at basic prices. Intermediate demand ($QINTD_c$) and the different parts of final demand $(QCD_c, QENTD_c, QGD_c, QINVD_c, dstocconst_c)$ are valued at purchasers´ prices.

For modelling consumption by households (QCD_c) the LES utility function is applied. Final demand by enterprises $(QENTD_c)$ and the government (QGD_c) as well as the demand for investment $(QINVD_c)$ are fixed in real terms. The demand of these parts of final demand is assumed not to be price-driven, compared to household or enterprise decisions.

In the basic version of STAGE, production is depicted as a two-level nested production structure by the application of different nested CES and Leontief production functions. The production relationships of the base version are shown in Figure 5. This figure can be regarded as continuation of Figure 4, but furthermore, as the base for the modification done in this study to develop STAGE_D (see section 5). For simplifying the illustration only two intermediate inputs and three primary inputs are recorded.

At the top level of the nested production function, the output of the industry (QX_a) is defined as a CES aggregate of intermediate input aggregate $(QINT_a)$ and the value added aggregate (QVA_a) in the default version. The elasticity of substitution (σ) between the intermediate input aggregate and value added aggregate can differ between industries. The aggregation of intermediate inputs is defined by a Leontief aggregation, which implies an elasticity of substitution of zero and a combination of inputs in fixed proportions $\left(ioqtdqd_{c,a}\right)$ per unit of aggregate intermediate input and output.

Figure 5: Production relationships in the STAGE base model



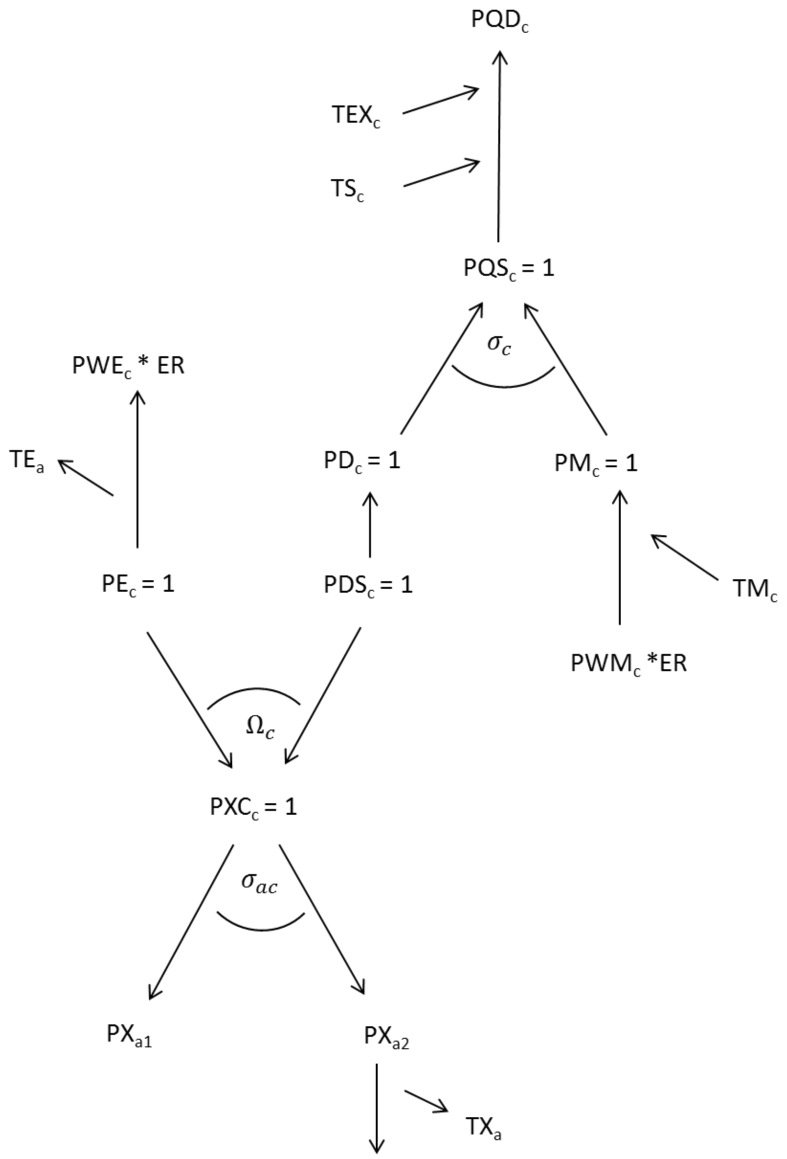
Source: McDonald (2007)

The value added aggregate (QVA_a) in the base version of STAGE is defined as a CES aggregate of the quantities of factors $\left(FD_{f,a}\right)$. The elasticity of substitution (σ) between primary inputs $\left(FD_{f,a}\right)$ can be different for each industry, but remains fixed between any pair of factors. The first order condition for the CES function is used to allocate the total factor supply between the industries. The allocation of factors depends on their relative price.

3.5 Price relationships in the STAGE base model

Figure 6 presents the price relationships in the base STAGE model. The supply price of composite commodities (PQS_c) is valued at basic prices and defined as the weighted averages of domestically produced commodities sold on the domestic market (PD_c) and the domestic prices for imported products (PM_c). The prices for imported products (PM_c) are determined by the world price (PWM_c), the exchange rate and the *ad valorem* import duties (TM_c). The supply price of composite goods is captured by a CES aggregation of domestically produced and imported products. This approach allows substitution between domestically produced and imported products based on the ratio of domestic and international prices. After adding up sales taxes (TS_c) and excise duties (TEX_c) the composite consumer price (PQD_c) is obtained. The composite consumer price (PQD_c) is valued at purchasers´ prices, because it includes taxes, VAT, transport charges and margins. The producer price of products (PXC_c) is valued at basic prices and defined by the weighted averages of the prices received for domestically produced products sold on the domestic market (PD_c) and the export market (PE_c). This composition is determined endogenously in the model through the first order condition for the optima of the CET function. The domestic export prices (PE_c) are derived by multiplying the world price of exports (PEW_c) with the exchange rate (ER) less export duties, which are defined by ad *valorem* export duties (TE_c). Here, the law of one price is violated, but this treatment allows the substitution between producing for domestic and export markets. The average price per unit of output received by an industry (PX_a) is defined by the weighted average of the producer prices of each commodity produced by each industry $\left(PXAC_{c,a}\right)$, where the weight of each product in the output mix remains constant (McDonald 2007).

Figure 6: Price relationships in the STAGE base model



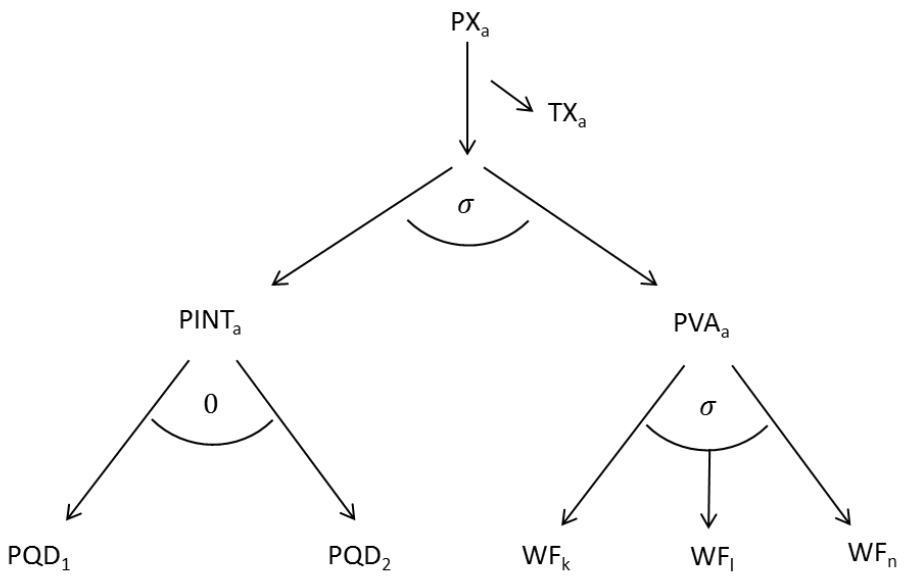
Source: McDonald (2007)

Figure 7 presents the price relationships in the production nest in the STAGE base model that can be regarded as continuation of Figure 6.

After paying indirect taxes (TX_a), the average price per unit of output received by an industry (PX_a) is divided between the price of aggregate value added (PVA_a) and the price of aggregate intermediate inputs $(PINT_a)$. The price of aggregate value added is the amount available to pay for primary input $(FD_{f,a})$. The price of aggregate intermediate inputs is defined as the weighted sum of the prices of inputs (PQD_c), where the weights are derived from the volume of each product in total intermediate input. The prices paid for intermediate inputs are the same as paid for final demand. That means that the law of one price is adhered to domestic demand, because intermediate demand

and final demand are valued at purchasers` prices. The factor prices $(WF_{f,a})$ are factor and industry specific. Different industries therefore can pay different prices for capital, labour and land.

Figure 7: Price relationships for production in the STAGE base model



Source: McDonald (2007)

3.6 Modelling production in the STAGE base model

In a CGE model, behavioural equations govern the producers' decision about their input use and level of output (see section 3.3). Producers can act as cost-minimisers, choosing the minimal cost level of inputs for a given output. But producers can also be regarded as agents who maximise their profits. In STAGE producers are assumed to maximise profit subject to technology constraints and the first order condition related to the production function. The objective of modelling production in CGE models is the determination of the optimal level of resource use and the combination of factors.

The supply price of domestically produced commodities depends on the purchaser prices for the specific commodity on the domestic and foreign markets. Following the assumption that each domestic activity produces multiple commodities in fixed proportions $(ioqxacqx)$, these proportions are used for a mapping of supply prices of commodities with the weighted average activity prices (PX_a) (see equation (E 34)).

$$PX_a = \sum_c ioqxacqx_{a,c} * PXC_c \tag{E 34}$$

As already mentioned in section 3.4, production is presented in the STAGE base version by a two-level production function, where the top level is defined as a CES or Leontief production function. If a CES function is chosen, the value of activity output can be described as the weighted sums of input expenditures in volume shares, after paying production taxes (TX_a) (see equation (E 35)). Production taxes are assumed to be *ad valorem*.

$$PX_a * (1 - TX_a) * QX_a \quad = (PVA_a * QVA_a) + (PINT_a * QINT_a) \qquad \text{(E 35)}$$

The aggregate price for intermediate inputs $(PINT_a)$ is defined as the intermediate input-output coefficient weighted sum of the prices of intermediate inputs (see equation (E 36)).

$$PINT_a \quad = \sum_c (ioqtdqd_{c,a} * PQD_c) \qquad \text{(E 36)}$$

Here, $ioqtdqd_{c,a}$ represents the intermediate input-output coefficients, where the output is the aggregated intermediate input $(QINT_a)$.

<u>The CES function at the top level nest of production</u>

In the base version of STAGE model a two-argument CES function is applied at the top level of the production nest (see equation (E 37)). The output produced by an industry a (QX_a) is determined by the aggregate value added (QVA_a) and aggregate intermediate input $(QINT_a)$, where $\delta_a\,(0 \leq \delta \leq 1)$ is the share parameter, $\rho_c^x\,(-1 \leq \rho \leq \infty)$ the substitution parameter and $AD_a^x\,(AD > 0)$ the efficiency or shift variable.

$$QX_a \quad = AD_a^x * \left(\delta_a^x * QVA_a^{-\rho_a^x} + (1 - \delta_a^x) * QINT_a^{-\rho_a^x}\right)^{-\frac{1}{\rho_a^x}} \qquad \text{(E 37)}$$

The efficiency/ shift parameter is defined as a variable, because the model provides the possibility to adjust this variable (see equation (E 38)), where $adxb$ is the base value and $dadadx$ is the absolute change in the base value. The factor $ADXADJ$ is an equi-proportionate adjustment factor. $DADX$ represents an additive adjustment factor and $adx01$ a vector of zeros and non-zeros for scaling the additive adjustment factor.

$$ADX_a \quad = [(adxb_a + dabadx_a) * ADXADJ] + (DADX * adx01_a) \qquad \text{(E 38)}$$

The first order condition defines the optimal ratio to combine value added and intermediate inputs and can be depicted in terms of the relative price of value added (PVA_a) and intermediate inputs $(PINT_a)$ (see equation (E 39)).

$$\frac{QVA_a}{QINT_a} \quad = \left[\frac{PINT_a}{PVA_a} * \frac{\delta_a}{(1 - \delta_a^x)}\right]^{-\frac{1}{\rho_a^x}} \qquad \text{(E 39)}$$

The CES function in the second level nest

The second level of the production nest is modelled as a multi-factor (n-argument) CES function to combine production factors into the value added aggregate (QVA_a) (see equation (E 40)).

$$QVA_a \quad = AD_a^{va} * \left[\sum_{f\$\delta_{f,a}^{va}} \delta_{f,a}^{va} * \ ADFD_{f,a} * FD_{f,a}^{-\rho_a^{va}} \right]^{-1/\rho_a^{va}} \qquad \text{(E 40)}$$

Accordingly, $\delta_{f,a}^{va}$ is the share parameter, ρ_a^{va} represents the substitution parameter and AD_a^{va} the efficiency factor. The first order condition for profit maximisation (see equation (E 41)) determines the wage rate of factors $\left(WF_f\right)$.

$$\begin{aligned} & WF_f * WFDIST_{f,a} * (1 + TF_{f,a} \\ & = PVA_a * AD_a^{va} * \left[\sum_{f\$\delta_{f,a}^{va}} \delta_{f,a}^{va} * ADFD_{f,a} * FD_{f,a}^{-\rho_a^{va}} \right]^{-\left(\frac{1+\rho_a^{va}}{\rho_a^{va}}\right)} * \delta_{f,a}^{va} * FD_{f,a}^{(-\rho_a^{va}-1)} \qquad \text{(E 41)} \\ & = PVA_a * QVA_a * AD_a^{va} * \left[\sum_{f\$\delta_{f,a}^{va}} \delta_{f,a}^{va} * ADFD_{f,a} * FD_{f,a}^{-\rho_a^{va}} \right]^{-1} * \\ & \qquad \delta_{f,a}^{va} * ADFD_{f,a}^{-\rho_a^{va}} * \delta_{f,a}^{va} * FD_{f,a}^{(-\rho_a^{va}-1)} \end{aligned}$$

The ratio of factor payments for factor f from activity a $\left(WFDIST_{f,a}\right)$ is included in the equation to allow for non-homogenous factors. This ratio results directly from the first order condition for profit maximisation as equality between the wage rates for each factor in each activity and the values of the marginal products of those factors in each activity. The efficiency/ shift factor is again defined as a variable with the appropriate adjustment mechanism.

The Leontief production function on the top level nest of production

Under the assumption of the Leontief technology on the top level of the production nest, the aggregate quantities of the aggregate value added (QVA_a) and intermediate inputs $(QINT_a)$ are determined by the following aggregation functions,

$$QVA_a \quad = ioqvaqx_a * QX_a \qquad \forall aqxn_a \tag{E 42}$$

$$QINT_a \quad = ioqintqx_a * QX_a \qquad \forall aqx_a \tag{E 43}$$

where $ioqvaqx$ and $ioqintqx$ are fixed volume shares of QVA_a and $QINT_a$ in the output QX_a. The application of the Leontief assumption on the top level is controlled in STAGE by the membership of the activity in the set $aqx.$ The set $aqxn$ is the complement to aqx and comprises all activities without the Leontief assumption on the top-level.

The Leontief production function at the second level nest of production

In the default version of STAGE the Leontief technology assumption is applied in the production nest for intermediate inputs on the second level. That implies that intermediate inputs are combined in fixed proportions $(ioqintqx_a)$ to generate intermediate input $(QINT_a)$ for an industry. Furthermore, it represents a multiple input use, which is applied in fixed proportions relative to the level of output (QX_a). Here, the application of a Leontief production function implies a substitution between inputs by zero.

$$QINT_a \quad = ioqintqx_a * QX_a \tag{E 44}$$

The aggregate intermediate input $(QINT_a)$ of industries has to be transformed to the intermediate input by commodity $(QINTD_c)$. This is done by using the fixed (Leontief) input coefficients of demand for commodity by activity $\left(ioqtdqdc_{c,a}\right)$. This coefficient is multiplied by the quantity of the activity specific intermediate input $(QINT_a)$, like shown in the following equation:

$$QINTD_c \quad = \sum_a ioqtdqd_{c,a} * \ QINT_a \tag{E 45}$$

Modelling commodity output

In CGE models assuming that each industry only produces one single product, the output of an industry (QX_a) would be equal to the product output (QXC_c) of that industry. In reality an industry produces in most cases more than one product. To allow STAGE for multi-product activities, assumptions have to be made with regard to the output composition of an industry, i.e. the ratio, in which different commodities are produced. Each activity produces a total output, which is the aggregate of different commodities produced by the activity $(QXAC_{a,c})$, but also the composite supply of each commodity (QXC_c). This relation is presented in equation (E 46).

$$QXC_c \quad = adxc_c * \left[\sum_{a\$\delta_{a,c}^{xc}} \delta_{a,c}^{xc} * QXAC_{a,c}^{-\rho_c^{xc}}\right]^{-1/\rho_c^{xc}} \qquad \forall cx_c \; and \; cxac_c \qquad \text{(E 46)}$$

The default version of STAGE comprises the assumption that a commodity, produced by multiple activities, is differentiated by reference to the activity that produces this commodity. Therefore, the total production of one commodity is defined as a CES aggregate of the quantities of this commodity produced by each activity. This enables the model to capture two important aspects: The model can a) differentiate between commodity qualities and b) capture different output compositions of activities. The assumption of imperfect substitution is included in the model by a CES aggregator function, where $adxc_c$ is the shift parameter, $\delta_{a,c}^{xc}$ the share parameter and ρ_c^{xc} the elasticity parameter. The first order condition for the optimal combination of commodity output is given by the following equation (E 47). The prices for each commodity produced by each activity are captured by $PXAC_{a,c}$.

$$PXAC_{a,c} \quad = PXC_c * adxc_c * \left[\sum_{a\$\delta_{a,c}^{xc}} \delta_{a,c}^{xc} * QXAC_{a,c}^{-\rho_c^{xc}}\right]^{-\left(\frac{1+\rho_c^{xc}}{\rho_c^{xc}}\right)} * \delta_{a,c}^{xc} * QXAC_{a,c}^{(-\rho_c^{xc}-1)} \qquad \text{(E 47)}$$

$$= PXC_c * QXC_c * \left[\sum_{a\$\delta_{a,c}^{xc}} \delta_{a,c}^{xc} * QXAC_{a,c}^{-\rho_c^{xc}}\right]^{-\left(\frac{1+\rho_c^{xc}}{\rho_c^{xc}}\right)} * \delta_{a,c}^{xc} * QXAC_{a,c}^{(-\rho_c^{xc}-1)} \qquad \forall cxac_c$$

Under the assumption that commodities are perfect substitutes, the model includes an alternative specification for commodity aggregation. Here, commodities produced by different activities are regarded as perfect substitutes, e.g. electricity, and modelled in the following way in the model (see equation (E 48)).

$$QXC_c \quad = \sum_a QXAC_{a,c} \qquad \forall cx_c \text{ and } cxacn_c \qquad \text{(E 48)}$$

The underlying price condition includes that $PXAC_{a,c}$ is equal to PXC for the appropriate commodity activity combination (see equation (E 49)).

$$PXAC_{a,c} \quad = PXC_c \qquad \forall cxacn_c \qquad \text{(E 49)}$$

The decision, which aggregation function is active in the model is controlled by the membership of commodities in the sets $cxac$ or $cxacn$. The set $cxac$ includes commodities that are differentiated by activities, whereby no differentiation is made in set $cxacn$.

The STAGE base model follows the assumption that the product output ratio remains constant regardless of the output level of the industry, i.e. the Leontief assumption of fixed proportions. The output ratio by activity is captured in the base model by the parameter $ioqxacqx$. The quantity of each commodity produced by each industry $\left(QXAC_{a,c}\right)$ is calculated according to the following formula (E 50):

$$QXAC_{a,c} \quad = ioqxacqx_{a,c} * QX_a \qquad \text{(E 50)}$$

This equation not only deals with the patterns of secondary production, it also provides the market clearing conditions for equality between supply and demand of domestic output.

3.7 Modelling trade in the STAGE base model

STAGE allows international trade of goods and services and therefore belongs to the category of open economy models. On the demand side, domestically produced goods and services compete with imports. On the supply side, domestically produced goods and services can be sold on domestic markets or exported. Under the Armington assumption, domestic and imported goods are imperfect substitutes. To implement this difference into CGE models, De Melo and Robinson (1985) proposed the use of CET functions to consider the imperfect substitution between domestically produced and exported goods on the supply side. For the demand side, CES functions are used in the base model (McDonald 2007).

The CET function for exports in the STAGE base model

In the basic version of STAGE a two-argument CET function and the related first order condition determine the relative share of products sold on the export market and on the domestic market.

Domestic commodity production (QXC_c) is determined by the quantity of exported goods (QE_c) and the domestic demand (QD_c), the distribution or share parameter γ $(0 \leq \gamma \leq 1)$, the substitution parameter ρ $(-1 \leq \rho \leq \infty)$ and the efficiency or shift parameter $(at > 0)$. The CET function for export is distinguished by constant return to scale and is presented by the following equation (E 51):

$$QXC_c \quad = at_c * (\gamma_c * QE_c^{\rho_c} + (1-\gamma_c) * QD_c^{\rho_c})^{\frac{1}{\rho_c}} \qquad \text{(E 51)}$$

The first order condition of this function (see (E 52)) determinates the optimal ratio between products sold on the domestic markets (QD_c) or on export markets (QE_c). This is achieved by the relative prices of exports (PE_c) and domestic prices (PD_c):

$$\frac{QE_c}{QD_c} \quad = \left[\frac{PE_c}{PD_c} * \frac{(1-\gamma_c)}{(\gamma_c)}\right]^{\frac{1}{\rho_c - 1}} \qquad \text{(E 52)}$$

The domestic price for exports (PE_c) is defined as the product of the world price of exports (PWE), the exchange rate (ER) and one minus the export tax rate (McDonald 2007).

The CES function for imports in the STAGE base model

The substitution between domestically produced goods and imported goods is implemented in STAGE by disposing a two-argument CES function. The domestic commodity demand (QQ_c) is stated by the quantity of imports (QM_c) and domestically produced goods (QD_c), the distribution or share parameter δ $(0 \leq \delta \leq 1)$, the substitution parameter ρ $(-1 \leq \rho \leq \infty)$ and the efficiency or shift parameter $(ac > 0)$. This CES function is called Armington function and is characterised by constant returns to scale. The following function (E 53) presents the Armington function in the STAGE base model:

$$QQ_c \quad = ac_c * (\delta_c * QM_c^{-\rho_c} + (1-\delta_c) * QD_c^{-\rho_c})^{-\frac{1}{\rho_c}} \qquad \text{(E 53)}$$

The optimal ratio between import (QM_c) and domestic demand (QD_c) is achieved by the first order condition (see (E 54)). This ratio depends on the relative prices of imported (PM_c) and domestically (PD_c) supplied goods, the distribution or share parameter δ and the substitution parameter ρ.

$$\frac{QM_c}{QD_c} \quad = \left[\frac{PD_c}{PM_c} * \frac{\delta_c}{(1-\delta_c)}\right]^{\frac{1}{(1+\rho_c)}} \qquad \text{(E 54)}$$

3.8 Modelling household income and expenditure in the STAGE base model

Single-country CGE models like STAGE are able to be calibrated on the basis of a SAM that includes a variety of household types. This is a difference to global CGE models, which usually comprise a single household account per region. Therefore, single country CGE models are often used to analyse impacts of political or economic changes on much more detailed types of households.

This section describes the implementation of household income and expenditure generation in STAGE following the explanation of household modelling in the STAGE documentation (McDonald 2007).

Household income

Households receive income from various sources. Factor incomes for factors owned by the household are distributed under the assumption of fixed proportions $(hovash)$. Additionally, households can receive income from transfers $(HOHO)$, payments from incorporated enterprises $(HOENT)$, transfers from the government $(hogovconst)$ or from the rest of the world $(howor)$ (see equation (E 55)).

$$YH_h = \left(\sum_f hovash_{h,f} * YFDISP_f\right) + \left(\sum_{hp} HOHO_{h,hp}\right) \qquad \text{(E 55)}$$

$$+HOENT_h + (hogovconst_h * HGADJ * CPI) + (howor_h * ER)$$

Inter-household transfers $(HOHO)$ are defined as a fixed share of household income (YH) after the payment of direct taxes and savings.

Household expenditure

Household expenditure is defined as household income after the payment of taxes, less savings and transfers to other households (see equation (E 56)).

$$HEXP_h = \big(YH_h * (1 - TYH_h)\big) * (1 - SHH_h) - \left(\sum_{hp} HOHO_{hp,h}\right) \qquad \text{(E 56)}$$

In the default version of STAGE household demand is modelled by using a LES function. This LES functional form is the only non-linear function in the model. The LES function is related to the Cobb-Douglas and CES function. Contrary to the Cobb-Douglas function, the LES function does not assume unit income elasticity (see section 3.3.1). The LES functional form in STAGE is the Stone-Geary utility function to maximise household utility (see formula (E 57)).

$$QCD_c = \frac{(\sum_h (PQD_c * qcdconst_{c,h} + \sum_h beta_{c,h} * (HEXP_h - \sum_c (PQD_c * qcdconst_{c,h}))))}{PQD_c} \qquad \text{(E 57)}$$

A Stone-Geary utility function divides household consumption demand into two parts: a) the subsistence demand $(qcdconst)$ and b) the discretionary demand. Both elements are included in equation (E 57). The discretionary demand is defined as the marginal budget share $(beta)$. The discretionary demand can be regarded as the part of the household expenditure that remains of the total household consumption expenditure after the spending in subsistence demand.

Additionally, the model offers the opportunity to change the Stone-Geary utility function into the Cobb-Douglas utility function with all income elasticities of demand equal to one. To implement this, the Frisch parameter has to change to minus one in the calibration process of the model (McDonald 2007).

3.9 Model closures

As already mentioned in section 2.4.3, a CGE model requires model closures to ensure that the numbers of equations and variables is consistent in order for the model to solve. Otherwise, the determination of model closures has an important influence on how a model works and how an economy is captured in the model (Kilkenny and Robinson 1990).

STAGE allows general and specific closure rules, in which general closure rules relate to macroeconomic conditions and specific closure rules comprise specific characteristics of the economic system.

In this section, the possible closures of the default version of STAGE are presented. The factor market closures are introduced in more detail, because they become relevant in the application of STAGE_D in the case study in chapter 7.

The foreign exchange account closure comprises the closure for the account of the rest of the world by either fixing the variable of the exchange rate or the current account balance.

The *capital account closure* ensures that the aggregate savings are equal to the aggregate investments by fixing one of these determinants. Fixing savings presumes the economy as savings-driven. Closing the economy by fixing the investments implies an investment-driven assumption of the operation of an economy.

The *enterprise account closure* enables the user of the model to fix either the volume or the value or the share of final commodity demand by enterprises.

The *closure for the government account* serves to determine fiscal policy considerations. In the base model, government savings are assumed to be a residual. The determinants of the government income and expenditure are fixed, while government savings are free to adjust.

The *numéraire* is applied in the model to serve as a base. Because the model is homogenous of degree zero in prices, STAGE defines relative prices based on the numéraire. The model provides two possibilities for price normalisation equations: a) the consumer price index (CPI) or b) the producer price index (PPI) (McDonald 2007).

3.9.1 Factor market closure

3.9.1.1 Full factor mobility and employment closure

This section presents the factor market closures in the default version of STAGE. The description follows the documentation of the STAGE (McDonald 2007).

The basic specification of factor market closures implies that all factors are fully mobile and employed. Under this assumption, the total factor supply (FS_f) is equal to total factor demand ($FD_{f,a}$). The total supply of each factor is determined exogenously (see equation (E 58)). The demand for factor f by activity a and the wage rates for factors (WF_f) are determined endogenously.

The model includes the assumption that wage rates for factors are averages and allows for variable factor payments across activities. This is captured by the variable $WFDIST_{f,a}$ that describes the sectoral proportions for factor prices. This variable influences the factor use by activities and is fixed in the base model (see (E 59)). Equation (E 60) limits the factor prices to positive values by placing the bounds around the average factor prices.

$$FS_f = \overline{FS_f} \tag{E 58}$$

$$WFDIST_{f,a} = \overline{WFDIST_{f,a}} \tag{E 59}$$

$$\begin{aligned} Min\ WF_f &= -infinity \\ Max\ WF_f &= +infinity \end{aligned} \tag{E 60}$$

3.9.1.2 Factor immobility and unemployment closure

Factor immobility and/ or factor unemployment can be determined in the model by the treatment of variables referring to factors either as a variable or as factors. In the practical implementation, a block of conditions for each factor has to be defined (E 61), where $fact$ represents a particular factor and $activ$ relates to a specific activity.

The following block of equations includes all variables referring to factors. The first four equations are the same as in the basic factor market closure, where factors are fully employed and mobile.

$$\begin{aligned} FS_{fact} &= \overline{FS_{fact}} \\ WFDIST_{fact,a} &= \overline{WFDIST_{fact,a}} \\ Min\, WF_{fact} &= -infinity \\ Max\, WF_{fact} &= +infinity \\ FD_{fact,a} &= \overline{FD_{fact,a}} \qquad \text{(E 61)} \\ WF_{fact} &= \overline{WF_{fact}} \\ WFDIST_{fact,activ} &= \overline{WFDIST_{fact,activ}} \\ Min\, FS_{fact} &= -infinity \\ Max\, FS_{fact} &= +infinity \end{aligned}$$

To make a factor activity specific without any sectoral factor mobility requires forcing the condition that factor demand is activity specific ($FD_{fact,a} = \overline{FD_{fact,a}}$). The returns to this factor must be allowed to vary, what involves relaxing condition (E 59).

Because factor demand is fixed, the factor supply is not able to vary and has to be relaxed (E 64). Up to this point, the number of equations and of variables is still the same. To run simulations, the sectoral proportions of factor prices, $WFDIST_{fact,activ}$, for a specific activity have to be fixed.

Unemployment of factors can be implemented in the factor closures by fixing the factor prices, WF_{fact} and relaxing the total supply of the factor (E 67). Additionally, the total factor supply is restricted by condition (E 68).

$$FD_{fact,a} = \overline{FD_{fact,a}} \qquad \text{(E 62)}$$

$$WFDIST_{fact,a} = \overline{WFDIST_{fact,a}} \qquad \text{(E 63)}$$

$$FS_{fact} = \overline{FS_{fact}} \qquad \text{(E 64)}$$

$$WFDIST_{fact,activ} = \overline{WFDIST_{fact,activ}} \qquad \text{(E 65)}$$

$$WF_{fact} = \overline{WF_{fact}} \quad \text{(E 66)}$$

$$FS_{fact} = \overline{FS_{fact}} \quad \text{(E 67)}$$

$$\begin{aligned} Min\ FS_{fact} &= 0 \\ Max\ FS_{fact} &= +infinity \end{aligned} \quad \text{(E 68)}$$

3.10 Summary

This chapter presents the structure of the default version of STAGE that builds the basis for the development of the German single-country CGE model STAGE_D. Compared to a large number of CGE models, whose basic code is not open source or badly documented and therefore often described as a ‘black box’, STAGE provides a comprehensive documentation and basic code for further development.

For a better understanding of the principle function of CGE models, a short introduction in the general equilibrium theory is given at the beginning of this chapter.

The methodological link between STAGE and its database, the SAM, is described by presenting the behavioural relationships included in the model. Particular attention is paid to the non-linear functional forms for modelling production, households’ behaviour and trade. The CES production function represents one of the central functional forms for capturing behavioural relationships in STAGE. This type of function is also relevant for the modification of the nested production structure of STAGE_D and is therefore described in more detail.

The main focus of this chapter is on the one hand, the presentation of the methodological and scientific background of equilibrium theory and mathematical forms of functions. On the other hand, builds this chapter the bridge between theory and practical application for modelling. The connections of price and quantity relationships of STAGE represent the core for understanding the functioning of the model. The same holds for the different ways to implement production, household income and expenditure as well as trade and the various possibilities to adapt the model to specific technological, economic or social framework conditions.

A CGE model requires closures to ensure that the numbers of equations and variables is consistent in order for the model to solve. Otherwise, model closures have an important influence on how a model works and how characteristics of an economy are captured. The basic model closures are presented in this chapter with a deeper insight to the operating principles of factor market closures.

4 Development of a Social Accounting Matrix for Germany – Own modifications

4.1 Introduction

The model STAGE_D is calibrated on the basis of a SAM for Germany, which is developed and disaggregated as part of this research. Until today the only existing SAM for Germany was developed by Klose et al. (2004) for the year 2000, based on Input-Output Tables. Due to the higher coverage of information in SUTs (see section 2.2.5) and the capability of STAGE to model multi-output activities, the decision was to establish a new SAM for Germany for the year 2007 based on SUTs´.

The decision to construct a SAM for the year 2007 is based on three facts:

- The publication of revised annual SUTs by the Federal Statistical Office occurs with a delay of three years to the current year. In the particular time when starting this research work, the development of the SAM for Germany was the first step. Although a more recent SUT was available at this time, the national accounts, including SUTs for the year 2007, represented the most complete database with regard to necessary additional data required for further disaggregation.
- Due to changes of the SNA classification system of products by activities in 2008, the results of SUTs published after 2007 are not completely comparable with those published before (Federal Statistical Office 2008d). With regard to the necessary disaggregation and the associated data requirements from various data sources, it was decided to set up the SAM on the older classification system.
- The year 2008 represents the year of the worldwide financial crisis that also affected the German economy. Therefore, a SAM for the year 2008 or 2009 would give a picture of the German economy in exceptional circumstances.

Generally, the decision to present the database in a SAM format provides advantages, which made this type of database increasingly popular in the application of whole economy models over the last years. McDonald (2013) summarises these advantages in three points. *First*, the SAM format is a formal part of the SNA and follows internationally agreed accounting standards. *Second*, the compilation of data for a single region can be compiled and related to the national account in an efficient and relatively easy manner. *Third*, the matrix format of a SAM has a greater accessibility for users and policy makers.

The most considerable difference between the SAM used in STAGE and a SAM, which is consistent with the SNA standards can be seen in the distribution of income. The STAGE SAM comprises only one phase of income distribution, but the model uses fixed proportions for the subdivision of income distribution. This reduced version of a SAM for modelling compared to a SNA SAM therefore does not violate the behavioural relationships of the model. Another difference to the SNA SAM is the presentation of a government account. Different types of tax accounts that represent tax instruments are summarised in the macro SAM of STAGE by creating a government account. Thus, government expenditure and tax revenues are more combined, what simplifies the process of modelling (ibid).

The general approach of this research is guided by the principle that the model and the database, i.e. the SAM, must be configured in such a way that both reflect the economic and political environment, which is supposed to be analysed. As such, the alternative of adapting the SAM to the CGE model is rejected; instead, the choice is made to adapt the model to the 'reality' that should be reflected in the structure and reported transactions in the SAM. In order to follow the logic of this principle, the first necessary step was the determination of the range of agents/accounts that need to be captured in the SAM.

A review of available databases indicated that the published degree of detail in the SUTs and national accounts with regard to the necessary disaggregated presentation of the energy and agricultural sector as well as the policy instruments has limitations. Therefore, additional disaggregation of inputs - intermediate use and final demand, outputs – joint- and by-production within the energy and agricultural sector and its use for further processing was required.

This chapter highlights all steps done to develop a disaggregated SAM for Germany and starts with an introductory summary in section 4.2. The point of origin for the development process is the composition of an aggregated macro SAM (see section 4.3), which is based on the national accounts of the Federal Statistical Office. In the next step, SUTs of the year 2007 were integrated into this macro SAM (see section 4.4.1). To develop a detailed, disaggregated SAM that captures the specifics of the energy and agricultural sector, different data sources have been used to provide information for the disaggregation process. The way, in which the disaggregation was achieved in both sectors is introduced in the sections 4.4.2 (agriculture) and 4.4.3 (energy). To capture also the environmental impacts of the energy policy, carbon emissions by commodity use of activities were added in form of a satellite account, whose composition is described in section 4.4.4. Because a SAM often provides more accounts than required for an explicit analysis, a SAM has to be aggregated to a size appropriate for the analysis. For this research the Excel-based programme 'SAMgator' was applied to aggregate the SAM that was finally used as database for STAGE_D. The theoretical background of 'SAMgator' is presented in section 4.5. A summary of this chapter is given in section 4.6.

4.2 The process to reach a disaggregated and balanced Social Accounting Matrix

This section gives an overview of the steps done to derive the balanced and disaggregated final German SAM, before presenting the individual development steps in the following sections in more detail. The general principle for the development of a SAM can be regarded as a sequential process and comprises a set of SAMs, where the further disaggregated SAM is built on the previously developed SAM. This stepwise approach ensures that the subsequent phases of disaggregation cannot affect the estimates of the prior steps. This procedure provides a systematic structure in the organisation of data, because there are always two SAMs at each level of the disaggregation process: one 'macro' and one 'micro' SAM. The 'macro' SAM provides the control totals and builds the frame within the disaggregation process takes part. The 'micro' SAM represents the space, in which the database is further disaggregated.

In an international comparison, the available German statistics can be regarded as very extensive and detailed. Nevertheless, the development process of a disaggregated SAM is characterised by high data requirements. Furthermore, when combining information from different data sources some parts of the SAM accounts are inconsistent and additionally often information is missing. These problems arise especially in the disaggregation of the intra- and inter-sectoral exchange of commodities. Here, official statistics provide the totals, but do not reach the data requirements for a disaggregated dataset useable for the construction of a disaggregated SAM. As a consequence, row and column totals of an account are not equal and missing data have to be estimated.

The method applied in this study for estimating the 'prior' SAM versions and estimating missing data is the GCE method that was described in section 2.3.3 in more detail. For this research GAMS code for the application of the GCE method was provided by Scott McDonald, who developed this programme together with Sherman Robinson (Robinson and McDonald 2006). This approach applies a term named *entropy* that estimates missing data or/ and balances a SAM by means of the given prior data and the predetermined constraints and targets. These targets can be regarded as a generalised unit of prior data that is part of the objective function, the so-called entropy divergence function.

After the configuration of each 'prior' SAM, the GAMS based programme was applied to solve the maximisation problems in the frame of the given constraints and to estimate a balanced SAM used as 'prior' for the next disaggregation step. Furthermore, the programme provides additional information about the estimation process, which was used to evaluate the resultant 'prior' SAM, but also to make adjustments in the database if necessary.

Starting point in the development process of the German SAM was the construction of a macro SAM (see section 4.3). The balanced macro SAM can be regarded as the 'prior' SAM for the next step for disaggregation: the integration of the information from SUT of the year 2007 (see section 4.4) into the macro SAM. The SUT-SAM comprised 71 commodity accounts, 66 activity accounts, 4 government accounts and each one account for labour, capital, households and enterprises, the stock changes and investments and the rest of the world. This extended SUT-SAM was once again balanced by applying the GCE method. The result of this estimation process represented the next prior SAM that represented the basis for the disaggregation of the agricultural sector (see section 4.4.2) and energy sector (see section 4.4.3). The basic work for the disaggregation of these two sectors was done by the application of Microsoft Excel software (Excel), because Excel offers the advantage to be more flexible to add further information for individual cells.

In the 2007 SUT the agricultural sector is represented in one single product and industry account, respectively. The energy sector is more complex and therefore included in various product and industry accounts of the 2007 SUT. Different data sources have been used as to achieve the next unbalanced but fully disaggregated 'prior' SAM. This fully in Excel disaggregated energy-agricultural SAM was compiled by using GAMS. This energy-agricultural SAM represents the 'prior' for the final SAM that was balanced by using the GCE method.

The final energy-agricultural SAM comprises 91 commodities, 86 activity accounts, 3 factor accounts, 4 government accounts and one account for households, enterprises, stock changes, savings and investments and the rest of the world respectively.

After this introductory overview, the individual steps for developing the disaggregated SAM for Germany will be explained in more detail in the next sections.

4.3 Development of the macro Social Accounting Matrix

Initial point for the development of the German SAM for the year 2007 is the construction of a macro SAM, which provides the basic control totals for each sub-matrix represented in the SAM. Table 5 shows the framework of a macro SAM and gives an overview of which submatrices are active, marked with X, and which are inactive, marked with a zero. This SAM is used for the calibration of the basic version of STAGE_D and serves as basis for the disaggregation.

Table 5: The macro SAM for the STAGE standard model

	Commodities	Activities	Factors	Households	Enterprises	Government	Capital accounts	RoW
Commodities	0	X	0	X	X	X	X	X
Activities	X	0	0	0	0	0	0	0
Factors	0	X	0	0	0	0	0	X
Households	0	0	X	0	X	X	0	X
Enterprises	0	0	X	0	0	X	0	X
Government	X	X	X	X	X	0	0	X
Capital accounts	0	0	X	X	X	X	0	X
RoW	X	0	X	X	X	X	X	0
Total	X	X	X	X	X	X	X	X

Source: McDonald (2013)

The national accounts for the year 2007 provided by the Federal Statistical Office (Federal Statistical Office 2008a) and the underlying SUTs (Federal Statistical Office 2010a) represent the main data sources for the derivation of the German macro SAM. Table 6 shows the macro SAM for Germany and Table 7 the underlying data used for the construction.

Table 6: Macro SAM for Germany for the year 2007 (in billion Euro)

	Commodities	**Activities**	**Labour**	**Capital**	**Households**	**Government**	**Indirect taxes**	**Direct taxes**	**Enterprises**	**Investments/ Stock changes**	**Rest of the World**
Commodities		2318.2			1343.0	435.6				442.5	1116.2
Activities	4494.8										
Labour		1180.4									6.4
Capital		967.9									220.4
Households			1181.0	421.2		450.5			381.6		12.5
Government				17.6	400.8		270.9	304.0			1.0
Indirect taxes	251.6	28.3									
Direct taxes					231.8				33.1		
Enterprises				643.2							4.3
Investments/ Stock changes					284.9	35.1			290.1		-167.6
Rest of the World	912.1		6.7	195.4	39.8	7.8			2.9		
Total	**5658.5**	**4494.8**	**1187.7**	**1277.3**	**2300.3**	**929.0**	**270.9**	**304.0**	**707.8**	**442.5**	**1193.2**

Source: Own calculation based on publications of the Federal Statistical Office (2008a, 2010a)

Table 7: Underlying data sources for the German macro SAM for 2007 (Part A)

Row	Column	Source	Table	
Commodity	Activities	A	4.2	Use Table, page 111: Intermediate consumption at purchasers' prices
	Households	A	4.2	Use Table, page 111: Final consumption by households at purchasers' prices
	Government	A	4.2	Use Table, page 111: Final consumption by government at purchasers' prices
	Investments/ Stock changes	B	23.3	Gross domestic product, national income, net borrowing, page 628: Gross capital formation
	Rest of the World	A	4.2	Use Table, page 111: Exports of goods and services
Activities	Commodities	A	4.1	Supply Table, page 97: Total supply of goods and services
Labour	Activities	A	4.2	Use Table, page 111: Wages paid domestically
	Rest of the World	B	24.17	Income and Expenditure from and to the RoW, page 644: Wages received from the RoW
Capital	Activities	A	4.2	Use Table, page 111: Gross operating surplus + depreciation
	Rest of the World	B	24.17	Income and Expenditure from and to the RoW, page 644: Income on investments received from the RoW
Households	Labour	B	24.16	Income and savings of private households, page 643: Income to households from labour
	Capital	B	24.16	Income and savings of private households, page 643: Income to households from assets
	Government	B	24.16	Income and savings of private households, page 643: Income to households from social benefits paid by the government
	Enterprises	B	24.13	Enterprise profits, primary income of incorporated enterprises, page 640: Dividend distribution and transfer from reserves
	Rest of the World	B	24.17	Income and expenditure from and to the RoW, page 644: Transfers received from the RoW
Government	Capital	B	24.15	Income, expenditure and financial balance from the government, page 642: Income on investments
	Households	B	24.11	Main aggregates of the sectors, page 639: Received social security contribution
	Indirect taxes	B	24.15	Income, expenditure and financial balance from the government, page 642: Income and property taxes
	Direct taxes	B	24.15	Income, expenditure and financial balance from the government, page 642: Taxes on products and import duties

A = Federal Statistical Office (2010a): National Accounts. Input-Output accounting. Chapter 4: Base Tables
B = Federal Statistical Office (2008a): Statistical Yearbook 2008 for the Federal Republic of Germany. Chapter 24: National Accounts

Source: Own compilation

Underlying data sources of the German macro SAM for 2007 (Part B)

Row	Column	Source	Table	
Indirect taxes	Commodities	A	4.1	Supply Table, page 111: Taxes on products
	Activities	A	4.2	Use Table, page 111: Taxes on production
Direct taxes	Households	B	24.1	National Accounts, page 624: Income tax and taxes on assets
	Enterprises	B	24.11	Main aggregates of the sectors, page 639: Income tax and taxes on assets
Enterprises	Capital	B	24	National Accounts, page 621: Corporate and investment income
	Rest of the World	B	24.17	Income and expenditure from and to the RoW, page 644: Transfers received from the RoW
Investment/ Stock changes	Households	B	24.1	Nationals accounts, page 625: Changes in net assets plus depreciation
	Government	B	24.1	Nationals accounts, page 625: Changes in net assets plus depreciation
	Enterprises	B	24.1	Nationals accounts, page 625: Changes in net assets plus depreciation
	Rest of the World	B	24.1	Nationals accounts, page 625: Changes in net assets plus depreciation
Rest of the World	Commodities	A	4.1	Supply Table, page 111: Imports of goods and services
	Labour	B	24.17	Income and expenditure from and to the RoW, page 644: Wages paid to the RoW
	Capital	B	24.17	Income and expenditure from and to the RoW, page 644: Investment income paid to the RoW
	Households	B	24.17	Income and expenditure from and to the RoW, page 644: Transfers to the RoW
	Government	B	24.17	Income and expenditure from and to the RoW, page 644: Transfers to the RoW
	Enterprises	B	24.17	Income and expenditure from and to the RoW, page 644: Transfers to the RoW

A = Federal Statistical Office (2010a): National Accounts. Input-Output accounting. Chapter 4: Base Tables
B = Federal Statistical Office (2008a): Statistical Yearbook 2008 for the Federal Republic of Germany. Chapter 24: National Accounts

Source: Own compilation

4.4 Development of a detailed and disaggregated Social Accounting Matrix

4.4.1 Integration of Supply and Use Tables

Based on the compiled macro SAM that includes the main economic aggregates for Germany, the detailed and disaggregated SAM for Germany was developed. The next step was the implementation of the 2007 SUTs, provided by the Federal Statistical Office (Federal Statistical Office 2010a), into the framework of the macro SAM.

The SUTs for the year 2007 constitute the core of the basic German SAM and enlarge the production matrix of the macro SAM. The German SUTs for the year 2007 covers 71 commodities produced by 66 activities. As described in chapter 2.2.5, the supply table presents the supply of goods and services by product and industry, with a distinction between domestic industries and imports. Furthermore, this table includes trade and transport margins, taxes and subsidies on products. The use tables comprise the use of goods and services by product, split into intermediate consumption by industries, final consumption, gross capital formation and exports (Eurostat 2014).

The extended SUT-SAM was subsequently estimated and balanced under the application of the GCE method.

The next step in the compilation process of the German SAM was the disaggregation of the agricultural and energy sector that required the inclusion of various surveys alongside the national accounts. The steps done to disaggregate these two sectors are presented in the next two sections.

4.4.2 Disaggregation of the agricultural sector

The 2007 SUT presents the agricultural sector as a single industry that produces a single commodity. To have a deeper insight on the role of the agricultural sector in the frame of the energy policy, the commodities and activities are disaggregated as shown in Table 8. The single agricultural commodity presented in the SUT was split into 13 commodities. The activity agriculture was disaggregated on a regional base following the administrative units of the federal states (*Bundesländer*) of Germany[4]. The decision to present agricultural activities on this regional basis and not under the aspect of production specialisation underlies the fact that '*Bundesländer'* can be regarded as production units (farms) that produce multiple output, like farms do in most cases in reality. One agricultural activity – one federal state – in the SAM represents all farms in this region with the regional-specific multiple-output, i.e. focus on crops, livestock or biomass for biogas generation. This way of disaggregating the agricultural sector enables an analysis of regional differences in agricultural production within the

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[4] The agricultural sectors of the city states Hamburg and Bremen have been included into the activity 'Lower Saxony' and Berlins agriculture was added to 'Brandenburg'.

frame of a CGE application. STAGE_D is able to capture multi-product activities and allows for a more realistic picture of this sector than other CGE models based in IOTs.

Table 8: Disaggregation of the agricultural sector

Commodities		**Activities**	
	Agriculture		
cagric		**aagric**	
cwheat	Wheat	aSH	Schleswig-Holstein
cbarley	Barley	aNS	Lower Saxony
crye	Rye	aNR	Northrhine-Westphalia
cmaize	Maize	aHE	Hesse
cothgrain	other Grain	aRP	Rhineland Palatinate
coilseed	Oilseeds	aBW	Baden Wurttemberg
cbeet	Sugarbeet	aBA	Bavaria
cvegfruit	Vegetables and Fruits	aSL	Saarland
cothcrop	other Crops	aST	Saxony Anhalt
cdairy	Dairy	aBB	Brandenburg
cbeef	Beef and Sheep	aMV	Pomerania
cpig	Pigs	aSN	Saxony
cpoult	Poultry	aTH	Thuringia

Source: Own compilation

The disaggregation of the agricultural sector was done using data provided by the FARMIS Model, which is conducted by the Thünen Institute[5]. FARMIS is a comparative-static programming model for farm groups in Germany. The database builds on information from the Farm Accountancy Data Network (FADN) (Thünen Institute 2017). The FADN dataset comprises a sample of farm surveys collected each year in all member states of Europe. It includes accountancy data at farm level and has the objective to monitor the income and economic development of agricultural enterprises. The FADN database represents the only source of microeconomic data that follows harmonised bookkeeping principles (European Commission 2010).

The German agricultural sector is disaggregated as follows:

Agricultural production: The FARMIS database (FARMIS 2007) comprises detailed information on agricultural production at regional and product level in value terms. On this basis, the supply of agricultural commodities was distributed across the regional activities by calculating the shares of sales per region. The original value presented in the SUT provided the basis for the disaggregation of the agricultural production. On this base also regional production of commodities was determined.

Subsidies and taxes: The FARMIS database contains detailed information on subsidies: investment subsidies, subsidies for the production on less favoured area payments, single farm payments and other allocated subsidies are recorded by product and by activity. On the base of FARMIS data, the shares of subsidies by commodity and activity were calculated. The original figure in the base SAM

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[5] The Thünen Insitute is a German research institute doing research for the German Ministry of Agriculture (BMEL). It develops scientific foundations for decision-making of the German government.

was disaggregated on the basis of these calculated shares. Taxes are not recorded in the FARMIS database and therefore received from the Federal Statistical Office statistics and split by the shares of production by region (Federal Statistical Office 2012b).

Use of agricultural products: The use of agricultural products is distributed across the sectors on the base of the shares of sales recorded in the FARMIS database. The use of intermediate inputs by agricultural activities is calculated by means of the cost of production. Here, cost information for fertiliser, plant protections, energy, seed, repairs, services and other costs on regional and commodity level are available and have been used to split the totals of intermediate use for agricultural production. The use of agricultural commodities by households was disaggregated on the base of data concerning households' expenses for food products (Federal Statistical Office 2008c).

Intermediate use of agricultural commodities: The intermediate use of agricultural commodities was calculated on the base of sales shares by commodities reported in the FARMIS database. Additionally, data for intermediate use of agricultural commodities by the food industry and by households were derived from a special evaluation of the Federal Statistical Office (2010c). This special evaluation provided a higher disaggregation level of the food industry.

Stock changes: Stock changes of agricultural commodities were derived on the basis of sales shares by commodities reported in the FARMIS database.

Gross operating surplus: Depreciation of agricultural commodities, reported in the FARMIS database, was used to calculate the gross operating surplus in the German SAM.

Exports: Exports were disaggregated by the application of data reported in the export statistic survey of the German Ministry of Agriculture (BLE 2009).

Factor income: Disaggregated information about the use of factors by activity was derived from the FARMIS database. FARMIS includes detailed information about agricultural area split in arable and grass land, the shares of own and rented land as well as the rent prices. With regard to labour, the FARMIS database provides detailed information about wages and working hours. Furthermore, information about the value of own and rented capital is provided. This data was used to calculate labour and capital income.

With regard to the objective to capture the impact of the changing energy policy in Germany on the agricultural sector the production factor land was disaggregated. The capital account served as base account for this disaggregation. Data on regional land supply and use were derived from the FARMIS database. Here, information about the shares of arable and grass land, own or rented land and the rent prices was provided.

Production taxes: Production taxes paid by agricultural activities were distributed on the base of sales by industry.

Imports: Information about imports was derived from import statistics of the German Ministry of Agriculture (BLE 2009).

4.4.3 Disaggregation of the energy sector

To derive a SAM that captures energy generation in more detail, the energy sector, with special consideration of the electricity sector, was disaggregated as shown in Table 9. Here, the bold printed activities and commodities represent the original accounts derived from SUTs. The breakdown of these aggregated accounts is described below.

Table 9: Disaggregation of the energy sector

Commodities		**Activities**	
	Energy Sector		
ccoal	**Coal and Lignite**	**acoal**	**Mining coal**
cdark	Dark Coal	adark	Mining Dark Coal
cbrown	Brown Coal	abrown	Mining Brown Coal
coilgas	**Crude Petroleum and Natural Gas**	**acoke**	**Manufacture of Coke, Petroleum Products**
ccrudeoil	Crude Oil	acokeman	Coke Production
cnatgas	Natural Gas	apetro	Petroleum Production
		adiesel	Manufacture of Diesel Production
ccoke	**Coke, Refined Petroleum Products**	abiodie	Production of Biodiesel Production
ccok	Coke	abioeth	Bioethanol Production
cpetro	Petrol		
cdiesel	Mineral Diesel	**aelgaswat**	**Electricity, Gas, Steam and Hot Water supply**
cbiodiesel	Biodiesel	agas	Gas Supply
cbioethanol	Bioethanol	awater	Steam and Hot Water Supply
		aelblack	Electricity Generation Dark Coal
celectricity	**Electricity and District Heat**	aelbrown	Electricity Generation Brown Coal
cely	Electricity	aeloil	Electricity Generation Oil
cdist	District Heat	aelgas	Electricity Generation Gas
		aelnucl	Electricity Generation Nuclear Power
		aelwindsol	Electricity Generation Wind and Solar
		aelbio	Electricity Generation Biomass

Source: Own compilation

Compared to the agricultural sector that is part of the primary production in an economy, the energy sector comprises several parts of primary production like the extraction of energy resources, i.e. mining of dark and brown coal. But, the energy sector also includes various steps of processing raw materials (coal, crude oil etc.) into final products (electricity, petrol, bioethanol etc.). With regard to raw materials the scope of available resources expanded over the last years due to technological progress and the resulting implementation of renewable energy sources. Fossil fuels like petroleum or diesel nowadays can be substituted by bioethanol or biodiesel. Also new technologies like electricity generation based on wind and solar energy were introduced.

Several statistical databases were applied to disaggregate the energy sector recorded in the 2007 SUT. The Federal Statistical Office, the working group on renewable energy statistics (AGEE), the working group on energy balance (AGEB) and the energy database from the German Ministry of Economic Affairs and Energy (BMWi) represent the main providers of the databases applied for the disaggregation of the energy sector. The following part summarises shortly, which data was applied.

The German energy sector is disaggregated as follows:

Energy production: Information on domestic raw material extraction is based on data from the 'System of Integrated Environmental and Economic Accounting' provided by the Federal Statistical Office (Federal Statistical Office 2012a). The statistic was used to disaggregate brown and dark coal as well as natural gas and oil. Information about sales, based on data of the sales tax statistic, was applied to divide coke and petroleum production (Federal Statistical Office 2010f).

To capture the production of biodiesel and bioethanol, the activity 'petroleum production' was disaggregated into diesel and petroleum manufacturing on the base of data provided by the 'System of Integrated Environmental and Economic Accounting' of the Federal Statistical Office. Here, the information of the use of diesel and petroleum for the year 2005 offered the shares to calculate the supply of these fuels (Federal Statistical Office 2012a). Biodiesel and bioethanol were divided from diesel and petroleum on the base of production data from AGEE (2010) and BMWi (2010).

In the 2007 SUT electricity generation was included in the aggregate 'Electricity, Gas, steam and hot water supply'. To extract total electricity generation out of this aggregate, the shares of sales taxes of the different industries were applied (Federal Statistical Office 2010f).

To split the aggregate of electricity and district heat generation, the shares of sales were used too. The necessary information was provided by the industry statistic of the Federal Statistical Office (2010g).

To get a deeper insight into the different technological options for electricity generation, the supply of electricity was subdivided into electricity generation based on dark coal, brown coal, oil, gas, biomass, wind and solar. Production data from AGEB (2012) and BMWi (2012) provided the necessary information. Renewable electricity generation was disaggregated on the base of production data supplied by AGEE (2010).

Imports and Exports: Data about energy trade are derived from the evaluation tables of the energy balance of Germany provided by the 'System of Integrated Environmental and Economic Accounting' (Federal Statistical Office 2012a) and trade data derived from the working group on energy balance and the energy database from the German Ministry of Economic Affairs and Energy (AGEB 2012, BMWi 2012).

Energy use: The 'System of Integrated Environmental and Economic Accounting' offers detailed data about the use of energy by energy sources and industries (Federal Statistical Office 2012a). This database also builds the basis to disaggregate energy use by households, the government and the inter-sectoral energy use.

Stock changes: Stock changes of energy commodities are recorded in the 'System of Integrated Environmental and Economic Accounting' (Federal Statistical Office 2012a).

Production factors: The Federal Statistical Office offers data that captures the cost structure of industries (Federal Statistical Office 2010g). On the base of this information wages and the net operating surplus was derived.

Taxes and subsidies: Information about taxes and subsidies on products and production were provided from the tax statistic of the Federal Statistical Office (2010f).

4.4.4 Development of a satellite account for carbon emissions

Carbon emissions by activities and households represent an additional database for STAGE_D that was developed in terms of a satellite account. The SNA differentiates between two types of satellite accounts. The first type is the internal satellite account that follows all accounting rules of the SNA but is different in the standard classification system. The second type, applied in this study, for carbon emissions includes additional non-economic data that is not included in SUT framework. The satellite account is consistent with the SAM with regard to commodity, activity and households categories, but does not include monetary values. In the applied satellite account carbon emissions are recorded in tons, emitted by activities and households. The total carbon emissions by activities and households are derived from the 'System of Integrated Environmental and Economic Accounting' (Federal Statistical Office 2012a) and the Federal Ministry of Environment (UBA 2017). Because of the disaggregation of energy use on the level of separate energy commodities in the use matrix of the SAM, the shares of energy commodities used by activities and households are known. By means of these shares and the information about carbon emissions of energy units (tons of carbon dioxide per terrajoule), the carbon emissions of activities and households have been calculated.

4.5 Aggregation of the Social Accounting Matrix

Next to the disaggregated sections of the SAM, which were established with regard to the research question, a SAM also comprises accounts that are not relevant for the analysis. By using a too comprehensive database to calibrate the model, the model becomes too large and consequently the results become too detailed for practical analysis and interpretation. Furthermore, very small values of the detailed SAM can be avoided. Before using the SAM to calibrate STAGE_D, the SAM was therefore aggregated for practical purposes.

For the aggregation of the final SAM the Visual Basic Application (VBA) programme 'SAMgator' was applied. This programme was developed in the frame of the PROVIDE project (PROVIDE 2004b).

The SAMgator is implemented by using Microsoft Excel software, with the GAMS software in the background. For application the user declares the new aggregates for commodities, activities and the other accounts in an Excel template and declares the source and destination of the data input and output files. GAMS is activated directly from within Excel. The SAMgator generates all sets and mapping files and also checks whether all mappings are consistent before generating the GAMS programme file.

The main pillar of the SAMgator is a single GAMS equation that aggregates the database of the SAM in two dimensions like shown in the following equation:

$$\begin{aligned}\mathrm{NEWSAM(sp,spp)} &= SUM((ss,ssp) \\ &\$(MAPSAMAG(sp,ss) \\ &\$(MAPSAMAG(spp,ssp)),SAM(ss,ssp))\ ;\end{aligned} \qquad \text{(E 69)}$$

Here the parameter $SAM(ss,ssp)$ includes the disaggregated database, where ss is the set that defines the row and column labels of the SAM. The parameter $NEWSAM(sp,spp)$ includes the new aggregated database where s represents the set that defines row and column labels for the new SAM. The set $MAPSAMAG(sp,ss)$ captures the members of the set ss that aggregates into sp by the rows of $SAM(ss,ssp)$. The set $MAPSAMAG(spp,ssp)$ defines the members of the set ssp that aggregates into ssp by the columns of $SAM(ss,ssp)$ (McDonald 2013).

After the application of the SAMgator the final energy-agriculture SAM for calibrating STAGE_D comprises 35 commodities, 34 activities and factor accounts for land, labour and capital. Furthermore, it includes three tax accounts and respectively one account for the government, households, enterprises, stock changes, investments and savings as well as for the rest of the world.

4.6 Summary

The development of a detailed and disaggregated SAM for Germany can be regarded as one cornerstone of this research. The process of the development is imbedded in the accounting rules of the SNA and the requirements of STAGE_D. Starting point of the data work was the development of the macro SAM that constitutes the frame for the further composition of the SAM for Germany for the year 2007. In this framework SUT have been implemented and the agricultural and energy sector disaggregated. The construction of a SAM requires a comprehensive demand for data from various data sources, which are partly not consistent to each other. Another issue is the lack of data during the process of disaggregation. This applies especially to the cross-sectoral interrelations the further a SAM is disaggregated. The generalised cross entropy method is used to estimate missing data and to balance the SAM. The whole process of the development and disaggregation of a SAM can be regarded as a sequential approach with starting on macro level and finally finishing on a disaggregated meso-level, with the consequence that the disaggregated final SAM, with all accounts included, becomes very large. For practical purposes the SAM applied as database for STAGE_D was therefore reduced in a manner, in which the requirements for analysing the impacts of the energy policy and the special focus on the agricultural and energy sector are warranted. This aggregation was done by using the Visual Basic Application programme 'SAMgator'.

Next to the SAM, a satellite account capturing carbon emissions was developed to get the environmental view on the energy policy in Germany.

5 Development of the model STAGE_D – Own modifications

5.1 Introduction

This chapter presents the development of STAGE_D for the application to analyse the economic, environmental and social impact of the *Energiewende* on the German economy. The adaptions of the nested production function and the appropriate mathematical implementation in STAGE_D are presented in section 5.2. To enable the model also to capture environmental consequences, carbon emissions by commodity use of activities and households were implemented (see section 5.3). Section 5.4 introduces the underlying parameters of functional forms, which were applied for the analysis in the case study. This section closes with a short summary in section 5.5.

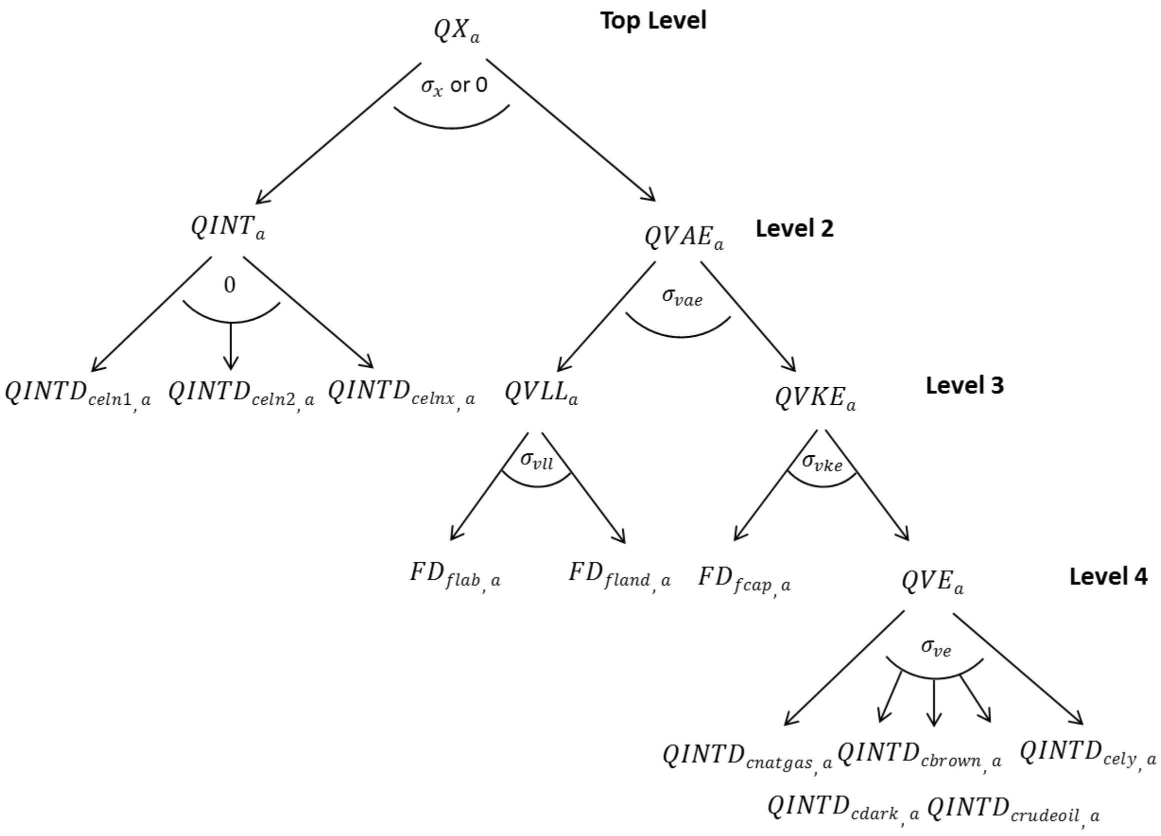
5.2 Modification of the nested production function

In the default version of the STAGE a two-stage production function is applied (see Figure 5). Because results depend significantly on substitution possibilities between primary inputs and energy inputs as well as on the substitution between energy inputs by itself, the structure of the nested production function was changed (Burniaux and Truong 2002).

To capture electricity generation and the impact of the German energy change policy in a more specific way in STAGE_D, the two-level nested production function applied in the default version of STAGE, was set up in STAGE_D as a four-level nest of production functions. The extension was done to allow the model to capture different production technologies of different power plants to produce the homogenous commodity electricity. The modified nested production function is presented in Figure 8 in quantity terms.

The production function of output by each activity at the **top level** (QX_a) of STAGE_D is a CES aggregate in the default version to combine intermediate inputs $(QINT_a)$ and the value added-energy aggregate $(QVAE_a)$. The top level can also be defined as a Leontief form, e.g. in the scenario calculation to model the nuclear phase-out. To allow for substitution possibilities between energy commodities in the production processes of an industry and to implement different production technologies, energy commodities have been shifted from the intermediate input aggregate $(QINT_a)$ into the value added aggregate (QVA_a), so that the value added – energy aggregate $(QVAE_a)$ was created. This was done by the establishment of the subset cel, that comprises the energy commodities dark coal, brown coal, crude oil, natural gas and electricity, and the subset $celn$ comprising all non-energy commodities. The applied elasticity of substitution (σ_x) of the CES function between the intermediate input aggregate and the value added-energy aggregate can differ between industries.

Figure 8: Modified nested production structure of STAGE_D



Source: Own compilation

The **second level** comprises two nests: a) the aggregate of intermediate inputs $(QINT_a)$ and b) the value added-energy aggregate $(QVAE_a)$. The aggregate of intermediate inputs is defined as a Leontief aggregation, which implies an elasticity of substitution of zero. Under this assumption inputs are combined in fixed proportions per unit of aggregate intermediate input $(QINT_a)$ and output (QX_a). The individual intermediate inputs are aggregated by the way that input-output coefficients $(ioqint_{a,celn})$ are defined in terms of input quantities relative to the aggregate intermediate input. The number of intermediate inputs depends on the one hand on the production technology but also on the level of disaggregation in the SAM. For a simplified presentation, Figure 8 only comprises three non-energy intermediate inputs $(QINTD_{celn,a})$.

The value added-energy nest $(QVAE_a)$ is defined as a two-argument CES function that combines the labour-land aggregate $(QVLL_a)$ and the capital-energy aggregate $(QVKE_a)$. The elasticity of substitution σ_{vae} between $QVLL_a$ and $QVKE_a$ can be different for each industry, but remains fix between these two aggregates.

The **third level** comprises two nests. The aggregate of the primary inputs labour and land $(QVLL_a)$ is defined by a two-argument CES aggregate over the factor labour $(FD_{flab,a})$ and the factor land $(FD_{fland,a})$ with σ_{vll} as appropriate elasticity of substitution.

The second nest on the **third level** comprises the capital-energy nest ($QVKE_a$), which offers the possibility to substitute between energy inputs (QVE_a) and capital ($FD_{fcap,a}$) by a defined elasticity of substitution σ_{vke} for this CES aggregation.

The **fourth level** of the nested production function offers the possibility to substitute energy inputs by the application of a n-argument CES function. This enables the substitution between electricity, dark coal, brown coal, natural gas and crude oil. The elasticity of substitution between these energy inputs is defined by σ_{ve}.

5.2.1.1 Mathematical implementation of the nested production structure into STAGE_D

The description of the mathematical implementation of the nested production structure into STAGE_D starts with a short excursion to modelling commodity output in STAGE. This part of the model was not changed in STAGE_D, but is presented here for a better understanding of how STAGE_D is generating multi-product output of an industry (see McDonald 2007). This part of the model illustrates why the activities of the agricultural sector can be represented on the regional base of the federal states (see section 4.4.2) as production units (farms) producing multiple output. The other way around comprises the assumption of multiple-output activities that a single commodity can be produced by multiple activities, i.e. electricity can be produced by different power plants that apply different technologies.

The total output of a commodity is the sum of the production of this commodity by each activity (E 70). Therefore, the domestic production of a commodity (QXC_c) is a CES aggregate of the quantities of this commodity produced by different activities ($QXAC_{a,c}$). Using a CES aggregation considers two practical aspects: *first*, quality differences of commodities can be included and *second*, a different ratio of commodities in a mixed production is captured. The assumption of imperfect substitution is implemented by a CES aggregation function with $adxc_c$ as the shift parameter, $\delta_{a,c}^{xc}$ as the share parameter and ρ_c^{xc} as the elasticity parameter. The first order condition for the optimal combination of commodity output is shown in (E 71). Here, $PXAC_{a,c}$ captures the prices of each commodity produced by each activity.

The model also includes an alternative specification for commodity aggregation where commodities can be produced by different activities as perfect substitutes (E 72). The matching price condition which requires that $PXAC_{a,c}$ equals PXC_c for the respective commodity-activity combination is shown in (E 73).

The particular assignment of commodities is controlled by the sets $cxac$ (commodities that are differentiated by activity) and $cxacn$ (commodities that are not differentiated by activity). This alternative specification is applied in this study to allow power plants to produce the homogeneous commodity electricity on the basis of different technologies, i.e. nuclear power or biomass.

Activities themselves produce commodities in activity specific fixed proportions. The activity output ($QXAC_{a,c}$) is a Leontief aggregate with fixed proportions of the output of each activity (QX_a) (E 74).

Production Block – Commodity Output

$$COMOUT_c \qquad QXC_c = adxc_c * \left[\sum_{a\$\delta_{a,c}^{xc}} \delta_{a,c}^{xc} * QXAC_{a,c}^{-\rho_c^{xc}}\right]^{-\frac{1}{\rho_c^{xc}}} \qquad \forall cx_c \quad \forall cxac_c \qquad \text{(E 70)}$$

$$COMOUTFOC_{a,c} \qquad PXAC_{a,c} = PXC_c * QXC_c \left[\sum_{a\$\delta_{a,c}^{xc}} \delta_{a,c}^{xc} * QXAC_{a,c}^{-\rho_c^{xc}}\right]^{-\left(\frac{1+\rho_c^{xc}}{\rho_c^{xc}}\right)} * \delta_{a,c}^{xc} * QXAC_{a,c}^{(-\rho_c^{xc}-1)} \qquad \forall cxac_c \qquad \text{(E 71)}$$

$$COMOUT_a \qquad QXC_c = \sum_a QXAC_{a,c} \qquad \forall cx_c \quad \forall cxacn_c \qquad \text{(E 72)}$$

$$COMOUTFOC_{a,c} \qquad PXAC_{a,c} = PXC_c \qquad \forall cxacn_c \qquad \text{(E 73)}$$

$$ACTIVOUT_{a,c} \qquad QXAC_{a,c} = ioqxacqx_{a,c} * QX_a \qquad \forall aqx_a \qquad \text{(E 74)}$$

After this short excursus in modelling commodity output, the following part of this section presents the mathematical implementation of the adapted nested production structure for STAGE_D for each level.

Nested Production Function - Top level

Industries are defined as multi-product activities that can produce combinations of commodity outputs for the composite price of activity output (PX_a). Like the STAGE model, STAGE_D includes the assumption that domestic activities produce commodities in fixed proportions ($ioqxacqx_{a,c}$) and these proportions provide a mapping between the supply prices of commodities and the weighted average activity prices (PXC_c) (E 75). The weights are derived from the supply matrix of the SAM.

The value of activity output is defined by the activity price less production taxes (TX_a) multiplied by the quantity of activity output (QX_a) (E 76). This value equals the sum of payments for value added and energy commodities ($PVAE_a$) times the quantitiy of value added – energy ($QVAE_a$) plus the quantity of non-energy intermediate inputs ($QINT_a$) times the price ($PINT_a$) for non-energy intermediate inputs.

To implement the possibility of energy substitution into the model, energy commodities have been shifted from the intermediate input aggregate $(QINT_a)$ into the value added aggregate (QVA_a), so that the value added-energy aggregate $(QVAE_a)$ was created. To achieve this, the sets cel and $celn$ were implemented into the model, were cel comprises energy commodities and $celn$ the non-energy commodities. With regard to prices required the shift of energy commodities into the value added aggregate the introduction of the variable $PQDDIST_{c,a}$ that ensures that also the sectoral proportions of energy commodity prices relate to the value added-energy aggregate. Simultaneously the intermediate input demand ($QINTD_{c,a}$) was made commodity and activity specific in STAGE_D.

The price of aggregate non-energy intermediate inputs $(PINT_a)$ is defined as the weighted average price of all non-energy intermediate inputs under the assumption of fixed proportions. The weights are determined by the input-output coefficients (E 77).

The aggregation on the top level can be defined by a CES or Leontief production function. In the default version, the top level production function is a CES aggregate of non-energy intermediate inputs and value added-energy inputs.

Under the assumption of a CES production function on the top level (E 79), the output of an activity (QX_a) is generated by the aggregated quantities of factors (value added) and energy inputs ($QVAE_a$) and the aggregate non-energy intermediate inputs ($QINT_a$). Here, δ_a^x is the share parameter, ρ_a^x the substitution parameter and AD_a^x the efficiency variable. The efficiency variables, also in the other nests, are defined as variables so that an adjustment possibility is provided (E 78). Here, $adxb_a$ is the base value, $dabadx_a$ is the absolute change in the base value, $DADX$ represents an additive adjustment factor and $adx01$ is a vector of zeros and non-zeros for scaling the additive adjustment factor.

Equation (E 80) presents the first order condition (FOC) that defines the optimal ratio of the value added-energy inputs to intermediate inputs. This can be expressed by the relative prices of the value added-energy inputs ($PVAE_a$) and the intermediate inputs ($PINT_a$).

The top level of the nested production function can also be defined as a Leontief function, where $QVAE_a$ and $QINT_a$ are combined in fixed proportions. Under the assumption of a Leontief aggregation on the top level, the aggregate quantities of production factors and energy ($QVAE_a$) and the intermediate inputs ($QINT_a$) are determined by the two equations (E 81) and (E 82). Here, $ioqvaeqx_a$ and $ioqint_a$ represent fixed volume shares in the output of an activity (QX_a). The decision about which functional form aggregates the output on the top level, is controlled by the membership of the set aqx, which includes activities with CES aggregation. The set $aqxn$ includes activities with a Leontief aggregation on the top level.

Top level – Implementation STAGE_D

$$PXDEF_a \qquad PX_a = \sum_{c} ioqxacqx_{a,c} * PXC_c$$ (E 75)

$$PX_a * (1 - TX_a) * QX_a = (PVAE_a * QVAE_a) + (PINT_a * QINT_a)$$ (E 76)

$$PINTDEF_a \qquad PINT_a = \sum_{celn} \left(ioqtdqd_{celn,a} * PQD_{celn} \right)$$ (E 77)

$$ADXEQ_a \qquad ADX_a = [(adxb_a + dabadx_a) * ADXADJ] + (DADX * adx01_a)$$ (E 78)

$$QXPRODFN_a \qquad QX_a = AD_a^x * \left(\delta_a^x * QVAE_a^{-\rho_a^x} + (1 - \delta_a^x) * QINT_a^{-\rho_a^x} \right)^{-\frac{1}{\rho_a^x}} \qquad \forall aqx_a$$ (E 79)

$$QXFOC_a \qquad \frac{QVAE_a}{QINT_a} = \left[\frac{PINT_a}{PVAE_a} * \frac{\delta_a^x}{(1 - \delta_a^x)} \right]^{\frac{1}{(1+\rho_a^x)}} \qquad \forall aqx_a$$ (E 80)

$$QVAEDEF_a \qquad QVAE_a = ioqvaeqx_a * QX_a \qquad \forall aqxn_a$$ (E 81)

$$QINTDEF_a \qquad QINT_a = ioqint_a * QX_a \qquad \forall aqxn_a$$ (E 82)

Level 2: Value added - energy aggregate and intermediate input aggregate

The second level comprises two production nests: the value added-energy aggregate ($QVAE_a$) and the aggregate of intermediate inputs ($QINT_a$).

The non-energy intermediate commodity demand by activity ($QINTD_{c,a}$) (E 83) is defined as the product of fixed (Leontief) input coefficients of the demand for commodity *c* by activity *a* ($ioqtdqd_{c,a}$) multiplied by the quantity of intermediate input by activity ($QINT_a$). As already mentioned the non-energy intermediate input ($QINTD_{c,a}$) is declared as commodity and activity specific.

The value added-energy aggregate ($QVAE_a$) is specified as a two argument CES function over the land-labour aggregate ($QVLL_a$) and the capital-energy aggregate ($QVKE_a$), where δ_a^{vae} represents the share parameter, ρ_a^{vae} the substitution parameter and AD_a^{vae} the efficiency variable (E 84).

In this nest, equation $ADVAEEQ_a$ (E 85) defines the efficiency variable $ADVAE_a$, where $advaeb_a$ is the base value, $dabadvae_a$ the absolute change in the base value and $DADVAE$ an additive adjustment factor. The parameter $advae01$ is a vector of zeros and non-zeros for scaling the additive adjustment factor.

The optimal ratio of aggregated $QVLL_a$ and $QVKE_a$ is defined by the first order condition for profit maximisation (E 86) that is determined by the respective relative prices of the capital-energy aggregate ($PVKE_a$) and the labour-land aggregate ($PVLL_a$).

Equation (E 87) determines the unit cost function for the activity price of the value added energy aggregate.

Level 2: Intermediate input aggregate – Implementation STAGE_D

$$QINTDEQ_{c,a} \qquad QINTD_{c,a} = \sum_{a} ioqtdqd_{c,a} * QINT_a \qquad \forall celn_c \qquad \text{(E 83)}$$

Level 2: Value added – energy aggregate – Implementation STAGE_D

$$QVAEPRODFN_a \qquad QVAE_a = AD_a^{vae} * \left[\delta_a^{vae} * QVLL_a^{-\rho_a^{vae}} + (1-\delta_a^{vae}) * QVKE_a^{-\sigma_a^{vae}}\right]^{-\frac{1}{\rho_a^{vae}}} \qquad \forall \delta_{vae} \qquad \text{(E 84)}$$

$$ADVAEEQ_a \qquad ADVAE_a = [(advaeb_a + dabadvae_a) * ADVAEADJ] + (DADVAE * advae01_a) \qquad \text{(E 85)}$$

$$QVAEFOC_a \qquad QVLL_a = QVKE_a * \left[\frac{PVKE_a}{PVLL_a} * \frac{\delta_a^{vae}}{(1-\delta_a^{vae})}\right]^{\frac{1}{(1+\rho_a^{vae})}} \qquad \forall \delta_{vae} \qquad \text{(E 86)}$$

$$PVAEDEF_a \qquad PVAE_a * QVAE_a = (PVLL_a * QVLL_a) + (PVKE_a * QVKE_a) \qquad \text{(E 87)}$$

Level 3: Labour-Land aggregate and Capital-Energy aggregate

The third level comprises two nests: The labour-land aggregate and the capital-energy aggregate.

Labour-Land aggregate

The labour-land aggregate is an aggregate over the primary inputs labour and land ($QVLL_a$) that is determined by a two-argument CES function over the factor labour ($FD_{flab,a}$) and the factor land ($FD_{fland,a}$) (E 88). Here δ_a^{vll} is the share parameter, ρ_a^{vll} the substitution parameter and AD_a^{vll} the efficiency variable.

The efficiency variable $ADVLL_a$ is defined by equation (E 89), where $advllb_a$ is the base value, $dabadvll_a$ the absolute change in the base value and $DADVLL$ an additive adjustment factor. The vector $advll01$ comprises zeros and non-zeros for scaling the additive adjustment factor.

To find the optimal allocation between labour and land, the first order condition $QVLLFOC_a$ is applied (E 90). The first order condition is determined by the respective relative prices for labour and land and the demand for labour by activity a ($FD_{flab,a}$). The price for land is defined as the product of the sectoral proportion of the land price ($WFDIST_{fland,a}$) multiplied by the price for land (WF_{fland}) and the taxes on land ($TF_{fland,a}$). The labour price is defined as the product of the sectoral proportion of the price for labour ($WFDIST_{flab,a}$) multiplied by the price for labour (WF_{flab}) and taxes on labour ($TF_{flab,a}$). The price for the labour-land aggregate is defined by equation (E 91).

Level 3: Labour-Land aggregate – Implementation STAGE_D

$QVLLPRODFN_a$

$$QVLL_a = AD_a^{vll} * \left(\delta_a^{vll} * FD_{fland,a}^{-\rho_a^{vll}} + \left(1-\delta_a^{vll}\right) * FD_{flab,a}^{-\rho_a^{vll}}\right)^{-\frac{1}{\rho_a^{vll}}} \qquad \forall\delta_{vll} \qquad \text{(E 88)}$$

$ADVLLEQ_a$

$$ADVLL_a = \left[\left(advllb_a + dabadvll_a\right) * ADVLLADJ\right] + \left(DADVLL * advll01_a\right) \qquad \text{(E 89)}$$

$QVLLFOC_a$

$$FD_{fland,a} = FD_{flab,a}\left[\frac{\left(WFDIST_{flab,a} * WF_{flab} * \left(1 + TF_{flab,a}\right)\right)}{\left(WFDIST_{fland,a} * WF_{fland} * \left(1 + TF_{fland,a}\right)\right)} * \frac{\delta_a^{vll}}{\left(1-\delta_a^{vll}\right)}\right]^{\frac{1}{\left(1+\rho_a^{vll}\right)}} \qquad \forall\delta_{vll} \qquad \text{(E 90)}$$

$PVLLDEF_a$

$$PVLL_a * QVLL_a = \left(WF_{fland} * WFDIST_{fland,a} * \left(1 + TF_{fland,a}\right) * FD_{fland,a}\right) + \left(WF_{flab} * WFDIST_{flab,a} * \left(1 + TF_{flab,a}\right) * FD_{flab,a}\right) \qquad \forall\delta_{vll} \qquad \text{(E 91)}$$

Capital-Energy aggregate

The second nest on the third level is the capital-energy aggregate that offers a substitution possibility between capital and energy inputs in the production process of an activity. The capital-energy aggregate is defined as a two-argument CES function over the factor capital ($FD_{fcap,a}$) and the energy aggregate (QVE_a) (E 92) in which δ_a^{vke} is the share parameter, ρ_a^{vke} the substitution parameter and AD_a^{vke} the efficiency variable.

The efficiency variable $ADVKE_a$ is defined by equation (E 93), where $advkeb_a$ is the base value, $dabadvke_a$ the absolute change in the base value, $DADVKE$ the additive adjustment factor and $advke01$ a vector of zeros and non-zeros for scaling the additive adjustment factor.

For the optimal allocation for capital and energy inputs, the first order condition ($QVKEFOC_a$) is defined by equation (E 94).

Equation (E 95) shows the price definition of the capital-energy aggregate, where $WFDIST_{fcap,a}$ represents the sectoral proportion of the capital price, WF_{fcap} the price for capital, $TF_{fcap,a}$ specifies the tax rate for capital use by activity and $FD_{fcap,a}$ the capital demand by activity. PVE_a is the price for the energy aggregate and QVE_a the respective quantity.

Level 3: Capital-Energy aggregate – Implementation STAGE_D

$QVKEPRODFN$

$$QVKE_a = AD_a^{vke} * \left(\delta_a^{vke} * FD_{fcap,a}^{-\rho_a^{vke}} + \left(1 - \delta_a^{vke}\right) * QVE_a^{-\rho_a^{vke}}\right)^{-\frac{1}{\rho_a^{vke}}} \qquad \forall \delta_{vke} \tag{E 92}$$

$ADVKEEQ_a$

$$ADVKE_a = [(advkeb_a + dabadvke_a) * ADVKEADJ] + (DADVKE * advke01_a) \tag{E 93}$$

$QVKEFOC_a$

$$FD_{fcap,a} = QVE_a * \left[\frac{PVE_a}{\left(WFDIST_{fcap,a} * WF_{fcap} * \left(1 + TF_{fcap,a}\right)\right)} * \frac{\delta_a^{vke}}{\left(1 - \delta_a^{vke}\right)}\right]^{\frac{1}{\left(1+\rho_a^{vke}\right)}} \qquad \forall \delta_{vke} \tag{E 94}$$

$PVKEDEF_a$

$$PVKE_a * QVKE_a = (WFDIST_{fcap,a} * WF_{fcap} * \left(1 + TF_{fcap,a}\right) * FD_{fcap,a} + PVE_a * QVE_a) \qquad \forall \delta_{vke} \tag{E 95}$$

Level 4: Energy aggregate

Level four comprises the energy aggregate (QVE_a) which is determined by a multi argument CES function. The aggregate includes the energy commodities natural gas ($QINTD_{cnatgas,a}$), electricity ($QINTD_{cely,a}$), crude oil ($QINTD_{ccrudeoil,a}$), brown coal ($QINTD_{cbrown,a}$) and dark coal ($QINTD_{cdark\ ,a}$).

In the related production function ($QVEPRODFN_a$) (E 96), δ_a^{ve} is the share parameter, ρ_a^{ve} the substitution parameter and AD_a^{ve} represents the efficiency variable.

The efficiency variable $ADVE_a$ is defined by equation (E 97), where $adveb_a$ is the base value, $dabadve_a$ the absolute change in the base value, $DADVE$ an additive adjustment factor and $adve01$ a vector of zeros and non-zeros for scaling the additive adjustment factor.

The associated first order condition for profit maximisation ($QVEFOC_a$) (E 98) determines the price of energy inputs (PQD_{cel}). Here, the sectoral proportion of energy commodity prices by activity ($PQDDIST_{cel,a}$) and the tax rates on energy commodity use by activity ($TCE_{c,a}$) are included.

The first order condition for profit maximisation is derived by the equality between the payments for each energy commodity by each activity and the values of the marginal products of those energy commodities by each activity.

The price for the energy commodities (PVE_a) is defined as the product of the sectoral proportion of the energy price ($PQDDIST_{cel,a}$) multiplied by the energy price (PQD_{cel}), the taxes on energy ($TCE_{cel,a}$) and the energy demand by activity $\left(QINTD_{cel,a}\right)$ (E 99).

Level 4: Energy aggregate – Implementation STAGE_D

$QVEPRODFN_a$

$$QVE_a = AD_a^{ve}\left[\sum_{cel\$\delta_{cel,a}^{ve}} \delta_{cel,a}^{ve} * QINTD_{cel,a}^{-\rho_a^{ve}}\right]^{-\frac{1}{\rho_a^{ve}}} \qquad \forall \sum_{cel} \delta_{cel,a}$$

(E 96)

$ADVEEQ_a$

$$ADVE_a = [(adveb_a + dabadve_a) * ADVEADJ] + (DADVE * adve01_a)$$

(E 97)

$QVEFOC_a$

$$PQD_{cel} * PQDDIST_{cel,a} * \left(1 + TCE_{cel,a}\right) = PVE_a * QVE_a * \left[\sum_{cel\$\delta_{cel,a}^{ve}} \delta_{cel,a}^{ve} * QINTD_{cel,a}^{-\rho_a^{ve}}\right]^{-1} * \delta_{cel,a}^{ve} * QINTD_{cel,a}^{(-\rho_a^{ve}-1)} \qquad \forall \delta_{cel,a}$$

(E 98)

$PVEDEF_{cel,a}$

$$PVE_a * QVE_a = \left(PQD_{cel} * PQDDIST_{cel,a} * \left(1 + TCE_{cel,a}\right)\right) * QINTD_{cel,a})$$

(E 99)

5.3 Implementation of carbon emissions

Based on the code of the global energy model GLOBE_EN that was developed by Scott McDonald and Karen Thierfelder (2008), also carbon emissions are implemented into STAGE_D. Here, carbon emissions are divided into emissions caused by the use of energy commodities ($QINTD_{c,a}$) by activities ($CO2EMISS_{c,a}$) (E 100) and households ($CO2EMISS_{c,h}$) (E 101) multiplied by the carbon emission coefficients (co2co). The total amount of carbon emissions ($CO2EMISSTOT$) is a sum over emissions arising from industries and the households (E 102).

$$CO2EMISS_{c,a} = QINTD_{c,a} * co2co_{c,a} \qquad \forall cel \qquad \text{(E 100)}$$

$$CO2EMISS_{c,h} = QINTD_{c,h} * co2co_{c,h} \qquad \forall cel \qquad \text{(E 101)}$$

$$CO2EMISSTOT = \sum_{c,a} CO2EMISS_{c,a} + \sum_{c,h} CO2EMISS_{c,h} \qquad \text{(E 102)}$$

5.4 Parameters of functional forms

Elasticities of substitution are important drivers of model results (Sancho 2010). Elasticity parameters describe the responsiveness of producers and consumers to relative price changes and are necessary to calibrate a CGE model. Next to the information of the SAM, elasticities represent an important data source. One issue of elasticities is their availability.

The model extension and the more detailed specification of production technologies increase the requirements for elasticities of substitution. Furthermore, the higher disaggregation level of the SAM requires more specific elasticities for single commodities or activities.

Table 10 presents the elasticities of substitution between imported and domestically produced commodities (Armington elasticity) and the elasticity of transformation between export and domestic supply (CET elasticity) applied in STAGE_D. The Armington elasticities are based on the elasticities provided in the GTAP database and borrowed from Orlov (2012). These elasticities are not country specific, but due to the lack of specific data for Germany, applied in STAGE_D for this research.

The applied CET elasticities are based on CET elasticities used in other CGE models (Wiebelt 1996, Banse 1997, Weyerbrock 1998, Orlov 2012) and comprise values of 2.9 for energy commodities, 2.0 for industrial commodities and 1.5 for food, feed and agricultural commodities.

Table 10: Armington and CET elasticities

Commodity	Armington Elasticity	CET Elasticity
Dark coal	1.52	2.90
Brown coal	0.90	2.90
Crude oil	2.60	2.90
Natural gas	8.60	2.90
Electricity	1.40	2.90
Light manufacturing	2.65	2.00
Heavy manufacturing	1.87	2.00
Construction	2.53	2.00
Transport	0.95	2.00
Service	0.59	2.00
Agricultural products	1.45	1.50
Food and feed products	1.45	1.50

Source: Own compilation

Table 11 shows the elasticity values for production and consumption in the adjusted STAGE_D model. Contrary to homogeneous commodities like electricity in this study, commodities are differentiated depending on the activity that produces this commodity. The domestic output of this commodity is a CES aggregate with an elasticity of 4, like in the STAGE base model.

The modified STAGE_D model comprises a four level nested CES production function (see section 5.2). Activity output at the top level is defined by the production elasticity (σ_x) that relates to the substitution between the value added-energy aggregate and the non-energy intermediate input aggregate. The elasticity of substitution on the top-level is 1.2 for all activities.

At the second level the value added-energy elasticity (σ_{vae}) defines the substitution between the labour-land aggregate and the capital-energy aggregate and takes various values between 0.2 and 1.6.

Level three comprises two nests and two elasticities for the labour-land aggregate and the capital-energy aggregate. The elasticity between labour and land (σ_{vll}) comprises values between 0.4 and 0.8. The elasticity between capital and the energy aggregate (σ_{vke}) is 2 for all activities.

The elasticity of substitution between energy inputs on level 4 (σ_{ve}) is 0.5 for all activities. There are exceptions that comprise electricity generating activities and mining of dark coal. The elasticity of substitution between the capital and the energy nest (σ_{vke}) is 0.1 at this point and for wind and solar this elasticity is 5. These elasticities are user defined.

Table 11: Elasticity values for production and consumption in the adjusted STAGE_D model

	Functional Form	Set	Value
Production	CES on product aggregation from different industries	Commodities	4
	CES on value added-energy and intermediate inputs	Activity	1.2
	CES on labour-land aggregate and capital-energy aggregate	Activity	0.2 to 1.6
	CES on labour-land aggregate	Activity	0.4 to 0.8
	CES on capital-energy aggregate	Activity	2
	CES energy aggregate	Activity	0.5
Consumption	LES income elasticity	Household	1
	LES Frisch parameter	Household	-1

Source: Own compilation

With regard to households the LES income elasticity was set to 1 and the LES Frisch paramenter to -1. These elasticites are equal to the values in the STAGE base model.

Pyatt (1988) mentions that the elasticities applied in a GCE model are one of the weaknesses of CGE models, because they are received from outside the SAM framework. One way to proof the reaction of a model to the applied elasticities is the sensitivity analysis. The sensitivity analysis for the applied elasticities in STAGE_D is presented in section 7.5.

5.5 Summary

This chapter presents the modifications of the model STAGE_D. The two-level production function of the basic version of STAGE was set up as a four-level nest of production functions and implemented into the model. Furthermore, a set of equations was included to capture carbon emissions by activities and households. This section additionally introduces the parameters of functional forms applied in STAGE_D to analyse the impact of the exit from nuclear and fossil-fuel energy on the German economy, presented in the next chapter.

6 Case study – Impact of the *Energiewende* on the German economy

6.1 Introduction

In September 2010 the German government decided on the establishment of an energy change strategy, the *Energy Concept*, which required a fundamental long-term restructuring of the German energy supply system during the period until 2050. The main objective of the so-called *Energiewende* is a comprehensive replacement of fossil energy by renewable energy sources to ensure climate protection. At the same time, affordable energy prices for consumers, a high level of economic competitiveness and development and the reduction of the import dependency on energy commodities have to be maintained (BMWi 2010, BMBU 2012).

One aspect of the implementation of the *Energy Concept* was the extension of the operating lifetime of German nuclear power plants by an average of 12 years to reach the environmental goal to reduce carbon emissions. But, the nuclear accident in Fukushima, in March 2011, changed the government's energy strategy to include the elimination of nuclear power by the year 2022, starting with the immediate closure of the eight oldest plants. This decision was enacted by the government in the frame of the *Energy Package* in July 2011 (BMWi 2012).

These changes are being implemented alongside major changes in the coal policies. The European Council of Ministers introduced (stepwise) reductions in dark coal subsidies from 2011 to 2018 that are expected to end German dark coal production. Additionally electricity generation using brown coal has to be reduced. In 2015, the government decided to close 2.7 GW of brown coal power plants capacity, comprising 13 %, by 2020. The combined impact of the nuclear and coal policies and the increase of renewable energy as an objective of the *Energiewende* is that around 50 % of established energy sources have to be replaced by renewable energy sources, by 2030 (BMWi 2013a, BMWi 2017).

The objective of this case study is the presentation and analysis of the impact of the exit from nuclear and fossil-fuel energy and the increasing use of renewable energy sources for electricity generation on the German economy. A special emphasis is laid on the agricultural sector, because the agricultural sector is concerned with the energy policy in two ways: 1) agriculture became a 'new player' on the electricity market due to the possibility to generate electricity based on biogas and 2.) agriculture is an intensive user of electricity and directly concerned by the total economic effects of the implementation of the *Energiewende* in the German economy.

The case study comprises two parts. In the first part, presented in this chapter, the framework conditions and specifics of the German electricity sector are presented with the aim to provide a better understanding of how electricity is supplied and used in the German economy and how the development process of the *Energiewende* was involved over the last years. This background information complements the information that is captured in the German SAM (see chapter 4), because a SAM shows a static picture of the German economy and electricity sector.

In the second part of the case study, presented in the following chapter 7, the model STAGE_D is applied. This analytical part of the case study comprises the introduction of the scenarios and model closures as well as the presentation and analysis of the results.

This descriptive chapter is structured as follows. Starting point is the presentation of the political background. This comprises the *Energy Concept* and the *Energy Package* as well as a short introduction of the coal policy and the Renewable Energy Act in section 6.2. The following section 6.3 gives an overview of electricity generation by energy sources and gross domestic electricity generation in Germany. In this context, section 6.4 has a closer look at the development of electricity generation based on renewable energy sources, with a special treatment of electricity generation based on biomass and the substrate provision by the agricultural sector. Additionally to the supply, section 6.5 shows the use of electricity by industries and households. Information about the domestic provision of energy resources and the dependence on imports of the German economy are captured in section 6.6. Section 6.7 contains the presentation of some specifics of the German electricity market. The development of electricity prices with a more detailed consideration of the components that add up to the consumer prices for households and industries is presented in section 6.8. Electricity trade is the focus of section 6.9. This chapter closes with a consideration of the impact of electricity generation based on renewable energy sources on carbon emissions in section 6.10. A summary of the descriptive chapter is given in section 6.11.

6.2 Energy policy in Germany

The changes on the German energy markets, observable over the last years, are consequence of a comprehensive restructuring programme initiated by the German government. The legal foundation of this process can be seen in the implementation of the *Energy Concept* and the *Energy Package*, which are presented here in more detail. Furthermore, a short introduction of the Renewable Energy Act, the Dark Coal Financing Act and energy taxation is given.

The Energy Concept 2010

The *Energy concept* can be regarded as an extension of the *Integrated Energy and Climate Program* of the German government, implemented in December 2007, on the basis of the decisions of the cabinet meeting in Meseberg. With the *Energy Concept*, determined on 28 September 2010, the government established a long-term strategy for a transformation process of the German energy system until the year 2050. This process, known as *Energiewende* (Energy Shift), relates to all areas of energy supply and use (electricity, heat and mobility) (BMWi 2010).

Central point of this policy measure is the extension of renewable energies to the main pillar in the German energy-mix. In the electricity sector wind, solar and biomass will serve as alternative resources for fossil fuels (oil, coal, natural gas) and nuclear energy. In the framework of the *Energy Concept* nuclear power got a role as bridge technology to secure electricity supply during this transition process. Therefore, an average of 12-year extension of the run-time to nuclear power plants was granted.

Table 12 presents the long-term objectives of the German energy policy determined in the *Energy Concept*.

Table 12: Objectives of the German energy policy

	2020	2030	2040	2050
		%		
Reduction of greenhouse gases (base: 1990)	-40	-55	-70	-80
Share of renewable energies in total final energy consumption	18	30	45	60
Share of renewable energies in electricity consumption	35	50	65	80
Reduction of primary energy consumption (base: 2008)	-20			-50
Reduction of electricity consumption (base: 2008)	-10			-25
Reduction of final energy consumption in transport sector (base: 2008)	-10			-40

Source: BMU (2012)

Altogether, a reduction of energy use and an increase of renewable energy sources are on focus of the implementation. With regard to the electricity sector the share of renewable energy in electricity consumption is intended to increase by 35 % in 2020, 50 % in 2030, 65 % in 2040 and 80 % in the year

2050 compared to the year 2008. The consumption of electricity shall be reduced by -10 % in 2020 and -25 % in 2050. This reduction shall be achieved by an increase of efficiency in electricity use.

Furthermore, the implementation of the *Energy Concept* occurs on the background to increase climate protection. It is intended to achieve a reduction of greenhouse gases by -40 % in 2020 and -80 % in 2050 compared to the year 1990.

The achievements of the objectives in the energy sector, presented in Table 12, are implemented under the consideration of the development of industries, households and trade. During the comprehensive transformation process in the energy sector the competitiveness and development of domestic industries shall be maintained. In addition, competitive prices shall be ensured for the industries as well as affordable prices for households.

The objective to reduce energy use and to switch from a fossil to a renewable base also occurs under the aspect to reduce the import demand for energy commodities. Germany, characterised as a resource poor country, strongly depends on imports of oil and gas. For the future, the German government expects higher energy prices due to the increasing global demand for energy resources. Therefore, the reduction of import dependency is a further objective in the frame of the *Energiewende*.

Consequently, the *Energiewende* can be regarded as an integrated overall approach with an impact on all actors in the economy (BMWi 2010).

The Energy Package 2011

As a consequence of the Fukushima Daiichi (Japan) nuclear accident in March 2011, the federal government reconsidered the long-term role of nuclear power, with the result to phase-out the use of nuclear power for commercial electricity generation at the earliest possible time. On 30 June 2011, the *Bundestag* passed the Thirteenth Act amending the Atomic Energy Law (*Dreizehntes Gesetz zur Änderung des Atomgesetzes*). This act entered into force on August 6, 2011. One important decision was to ensure that the nuclear phase-out could proceed as quickly as possible with the eight oldest nuclear power plants not being reconnected to the grid.

In order to phase-out nuclear power more quickly, the process of reorganising the German energy supply system at a fundamental level needed to be substantially accelerated. So the Federal Cabinet, the *Bundestag* and the *Bundesrat* enacted a comprehensive so-called *Energy Package*, in July 2011. This *Energy Package* consists of seven acts and one ordinance, *e.g.* on expanding renewables, expanding the grid, energy efficiency and on the funding of the reforms. The *Energy Package* marked the second significant step by the federal government towards the restructuring of the energy supply (Hübner et al. 2012, BMWi 2012).

The Renewable Energy Act

The Renewable Energy Act (EEG) presents the legal foundation for the promotion of renewable energy sources for electricity generation and builds up on the 'Energy Feed-in Law', introduced in the year 1991. The Renewable Energy Act was established in the year 2000 (EEG 2000). At this time the main objective of the EEG was the development and support of new technologies for electricity generation, such as wind, solar and biomass energy. In the framework of the EEG the market entry of these new technologies was regulated and supported by fixed remunerations and guaranteed purchase of this electricity. Due to technological progress of renewable-based power plants, the increasing provision of renewable-based electricity and changing political sub-ordinate targets, the EEG has been amended several times (EEG 2004, EEG 2009, EEG 2012, EEG 2014, EEG 2017) (FNR 2017).

Due to the positive development of renewables energies (see section 6.4), the EEG 2017 introduced a paradigm shift: since 2017, the remuneration of renewable energy is no longer determined by the state. Until this year prices for renewable electricity were determined by calls for tenders on the electricity market because renewable energies became competitive against fossil energies (BMWi 2017).

The Dark Coal Financing Act

The extraction of dark coal in Germany is not competitive in the international context; therefore dark coal extraction has been subsidised since 1974. In February 2007, a coal policy agreement was decided between the government, the dark coal industry and the coal-mining states (*Bundesländer*). The agreement of 'Terminating subsidised dark coal production in Germany in a socially acceptable manner' describes the details of the phase-out process of dark coal until the year 2018. The corresponding act 'The Act to Finance the Termination of Subsidised Dark Coal Production by the Year 2018' (Dark Coal Financing Act, *Steinkohlefinanzierungsgesetz*), entered into force on December 28, 2007. On this legal basis subsidies are reduced annually. Appropriate to the agreement, the government and the coal-mining states grant the financial support for sales, mine closures and liabilities needed in the period between 2009 and 2019. The coal mining industry has to contribute to the costs from 2012 onwards.

Beyond the German act, operational aid of dark coal extraction from 2018 onwards is permitted by a European Council Regulation, which came in force in January 2011 (BMWi 2007, IAE 2013).

Electricity taxation in Germany

Governments tax revenues based on electricity taxes comprised 6.6 Billion (bn) Euro (€) in the year 2015. This corresponds to a share of around 7.7 % of Germanys total tax revenues in this year

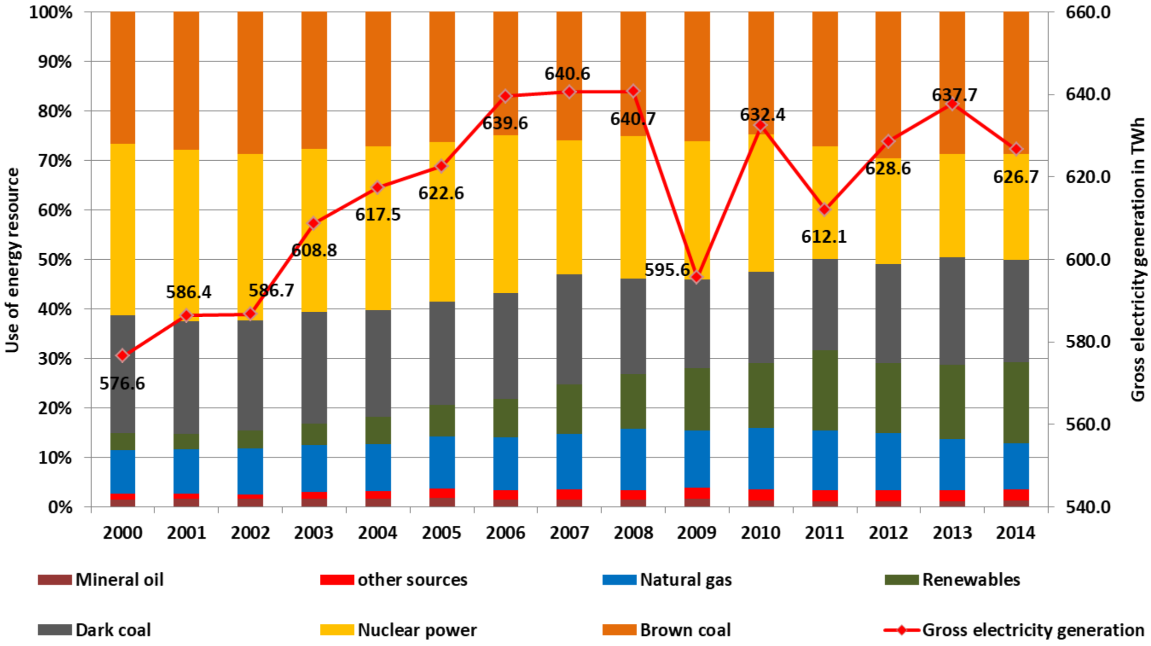
(Federal Statistical Office 2017). The Electricity Tax Act (StromStG 1999) regulates the taxation of electricity consumption and has been introduced in Germany in April 1999 within the framework of the ecological tax reform. The electricity tax is an indirect excise tax, accrued by the electricity supplier, if electricity is used by the final consumer. This tax is passed directly to the consumer by electricity prices. Since 2003 the electricity tax rate comprises 2.05 Cent/kWh (Ministry of Justice and Consumer Protection 2000).

6.3 Electricity generation in Germany

In 2014, German power plants generated 626.7 terawatt hours (TWh) of electricity (BMWi 2017b). Within the EU, Germany is the biggest producer of electricity with a share of 19.5 % of the total EU gross domestic electricity generation (Eurostat 2016a).

Figure 9 presents development of gross electricity generation and the appropriate shares of energy resources used for electricity generation in Germany between the years 2000 and 2014. Gross electricity generation increased from 576.6 TWh in 2000 up to 640.6 TWh in the year 2007 and 626.7 TWh in 2014 (AGEB 2016, BMWi 2017) but shows a volatile development.

Figure 9: Gross domestic electricity generation (in TWh) and electricity generation by energy source (in percent) between 2000 and 2014



Source: AGEB (2016), BMWi (2017)

Background of the increasing electricity generation is the rise of electricity generation based on renewable energies due to the guaranteed purchase of this electricity determined in the EEG (see section 6.2).

The intensified volatility is caused by two facts: 1) One characteristic of electricity generation on the basis of the renewable energies wind and solar is the volatile feed-in because these types of electricity supply strongly depend on weather conditions. 2) On the other hand the volatile electricity generation is a consequence of the inflexibility of the production processes of power plants on the base of coal and nuclear power to react on the unsteady electricity supply, based on renewable resources. For technological reasons coal- and nuclear-based power plants are not able to adapt to current demand situations for electricity (AEE 2013).

Next to direct influences of the electricity market on electricity generation, also other economic impacts influence the supply of electricity. This becomes evident in the years 2008 and 2009 with a decline of electricity generation down to 595.6 TWh in 2009 (BMWi 2017). This decline was caused by the global economic slowdown as a result of the economic and financial crisis. The second drop in the year 2011 is the resulting effect of the immediate shut down of the eight oldest nuclear power plants as a consequence of the Fukushima accident, decided in the *Energy Package* by the government (see section 6.2).

A consideration of the importance of particular energy resources used for electricity generation (see Figure 9) already shows the progress of the restructuring process from a fossil-based electricity supply system to a renewable based system. At the starting point of the implementation of the EEG in the year 2000, nuclear energy, brown and dark coal, with shares of 34.7 %, 26.6 % and 23.8 % respectively, have been the foundation of the German electricity supply system. Even in the year 2014 brown and dark coal represented the most important sources for electricity production with shares of 28.8 % and 20.7 %, respectively. Since the political decision to reduce subsidies for dark coal extraction in Germany (see section 6.2) the use of dark coal for electricity generation has been reduced slightly. Nevertheless, the share of dark coal on gross electricity production is relatively stable, because of the fulfilment of the demand of dark coal power plants by imports (see section 6.6) (AGEB 2016).

Brown coal does not depend on subsidies and is available in sufficient quantities as a natural resource. Germany is the biggest extractor of brown coal worldwide. In 2012, two new power plants were put into operation with a capacity of 2,875 megawatt (MW) (AGEB 2014). Electricity generation based on brown coal increased by 2 % between 2000 and 2014.

Against the background of the Fukushima accident and the political decision of the immediate shutdown of the eight oldest nuclear power plants in 2011 (see section 6.2), electricity generation based on nuclear power decreased by a share of 13.4 % down to 21.0 % in 2014. Primarily, coal replaced nuclear power in the German electricity supply system (BMWi 2017b).

Due to the support system, established in the EEG (see section 6.2), the use of renewable energy resources increased from a share of 3.4 % in 2000 up to 16.3 % in the year 2014. The most important developments could be observed in the use of wind power, solar energy and biomass.

Natural gas as a resource for electricity generation comprised a share of 8.8 % in 2000 and increased slightly to 9.3 % in 2014. Gas power plants are characterised by high cost of production. But due to their flexibility to adapt to fluctuations of renewable electricity supply, they may become more important in the future (AEE 2013).

The development of gross electricity generation and the changes in the resource mix show that a) political conditions, b) the availability of domestic natural resources, c) technological progress, d) the structure and economic development of the national economy, but also e) global developments have impacts on the German electricity supply system.

6.4 Development of electricity generation based on renewable energy sources

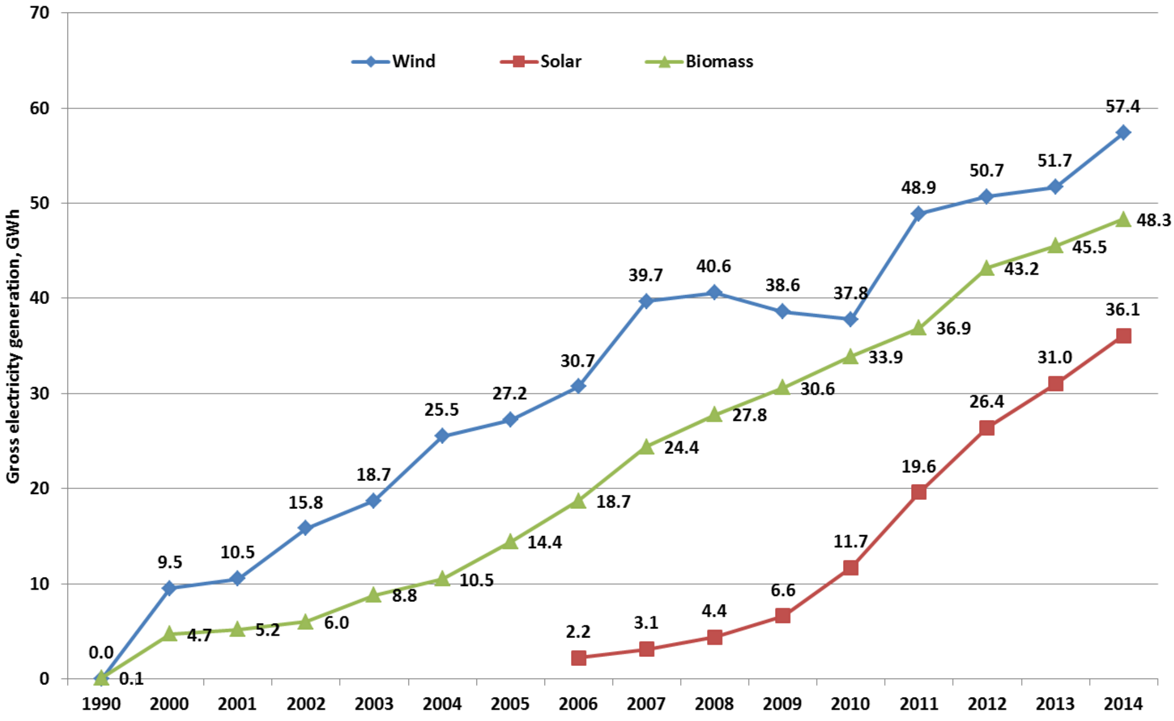
As already mentioned in section 6.3 the importance of electricity generation based on renewable energy sources increased steadily over the last years. In 2014, gross electricity consumption based on renewable energy resources comprised a share of 27.3 %, starting from 6.2 % in 2000 (AGEE 2016).

Figure 10 presents the development of renewable electricity generation based on wind, solar and biomass between 1990 and 2014.

In the early stages, these new technologies were characterised by high production costs. Due to the political support program (EEG) and technical progress, renewables developed to an important cornerstone of the German electricity supply system.

Wind energy as source for electricity generation became the main pillar over the last years. In the year 2014, around 12 % or 57.4 gigawatt hours (GWh) of German electricity was produced by onshore and offshore wind plants. In addition to the expansion of suitable land sites and the replacement of old, smaller plants by modern and more powerful systems - the so-called ‘repowering’ - the expansion of wind energy at sea (offshore wind energy) is becoming increasingly important (BMWi 2017, AGEE 2016).

Figure 10: Gross electricity generation based renewable resources between 1990 and 2014 (in GWh)



Source: AGEE (2016)

Electricity generation based on solar panels has been the most costly renewable technology for electricity generation in the past. Therefore, compared to other renewable energy sources, the comprehensive electricity generation based on solar started relatively late in the year 2006. Due to technological developments, solar based electricity increased to a share of 6.1 % on total renewable energies in 2014 with an electricity generation of 36.1 GWh (AGEE 2016, BMWi 2017).

Resources for electricity generation based on biomass are numerous and comprise solid and liquid fuels, biogenic waste, landfill gas, gas from purification plants and biogas. Due to the support in the framework of the EEG, electricity based on biomass comprised 8.2 % on total renewable electricity generation in 2014. This corresponds to an electricity generation by 48.3 GWh. Biogas is the most important source of biomass. In 2014, around 5 % of electricity was generated on the base of this source (AGEE 2016).

The next chapter presents a more detailed view to the use of biomass for biogas generation in the agricultural sector.

6.4.1.1 Biomass as resource for electricity generation

This section focuses on the production of biomass for biogas generation in the framework of agricultural production.

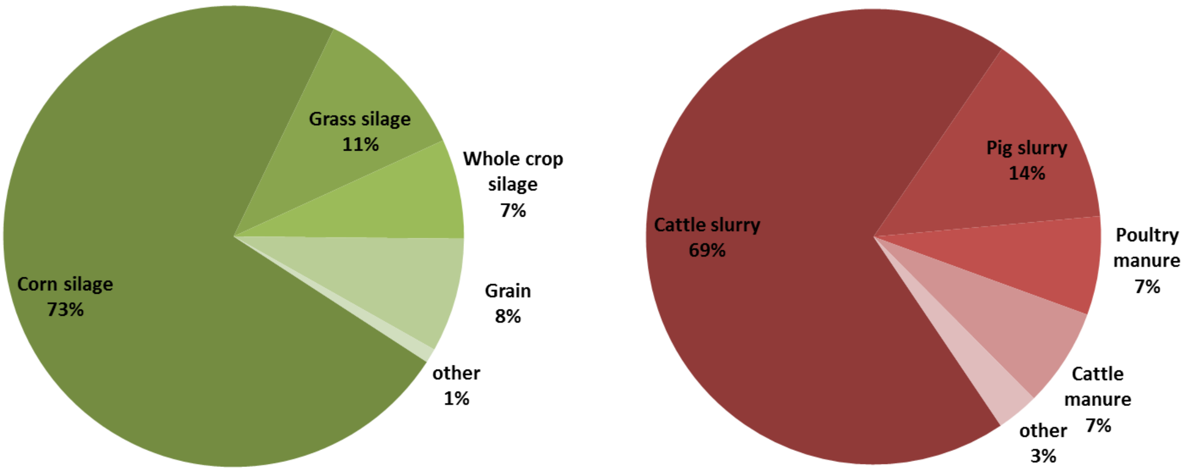
Compared to wind and solar energy, which represent free natural resources, the production of biomass generates costs and furthermore a competition for production factors (indirect competition) and the final use (direct competition). Direct competition occurs when agricultural raw materials are used for more than one purpose. For example, wheat can be used for food production, feed, as a substrate for biogas and biofuel production, or as a basic material for starch production in the chemical industry. Indirect competition occurs when biomass production requires the same production factors and especially the scarce factor land. This means for example, that the production of energy crops, which are initially not grown for food or feed purposes or material re-use are competing with these use alternatives because they are grown on the same limited cultivation areas (Hermeling & Wölfing 2011, Bringezu et al. 2008, Faulstich 2012).

Biogas can be produced on the basis of crop and livestock substrates. Figure 11 presents the substrate usage for biogas generation in the year 2012 divided by crop- and livestock-based substrates. The use of crop-based substrates dominates with a relation between crop- and livestock-based substrates by 63 % to 27 % (DBFZ 2014).

In the field of crop-based substrates maize and grass silage, whole plant silage and cereal grain represent the most important substrates. Maize and grass silage are by far the most important crop substrates with shares of 55.7% and 35.7% of total crop-based substrates. With a significantly lower share, whole plant silage with 6.1 % and cereal grain with 1.1 % rank third and fourth place. The total of these four main substrates sums up to 98.6 % of all crop-based substrates used for biogas generation.

In the field of livestock-based substrates cattle slurry, with a share of 69.0 %, pig slurry with 14.0 %, poultry and cattle manure with 7.0 % and 3.0 % represent main substrates. Together, these substrates comprise 97.0 % of the livestock-based substrate use (ibid).

Figure 11: Crop and livestock based substrate use for biogas generation (2012)

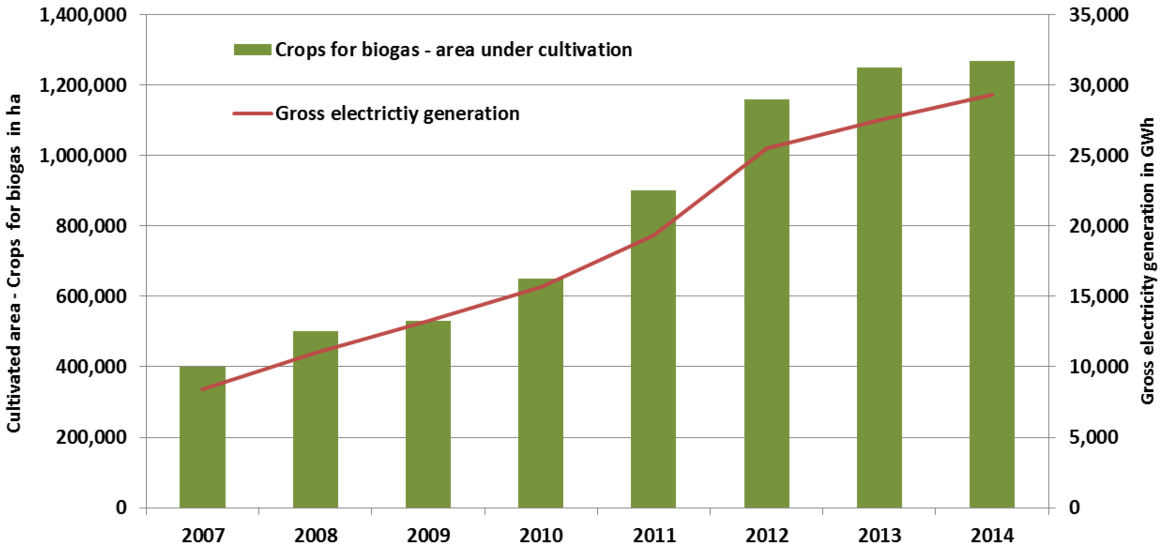


Source: DBFZ (2014)

Next to technological and biochemical requirement of biogas generation, especially the government subsidies in the framework of the EEG influenced the development biogas generation and the composition of substrate inputs (Becker 2016).

While livestock based substrates can be seen as by-product of livestock production, crop based substrates indirectly compete for the factor land (Theuvsen et al. 2010). Figure 12 shows the development of land used for crops for biogas generation and the gross electricity generation based on biogas. Gross electricity generation based on biogas represents the most important source of renewable electricity generation based on biomass. From the year 2000 onward, biogas produced an increasing amount of renewable-based electricity, which comprised 29.3 GWh in 2014, representing a share of 5.0 % of renewable electricity. The development of the cultivated area for crops used for biogas production has more than tripled since the year 2007 and comprised 1,268,000 hectare (ha) in the year 2014 (FNR 2016).

Figure 12: Biogas - Development of gross electricity generation (in GWh) and land use (in hectare)



* from 2008 Biogas and Biomethan

Source: FNR (annual publications), AGEE (2016)

In the framework of the EEG fixed output prices for electricity for 20 years after the construction of a biogas plant are determined (FNR 2017). Therefore, electricity generation of biogas plants does not depend on electricity prices, but on the alternative prices for crops and livestock (Becker 2016).

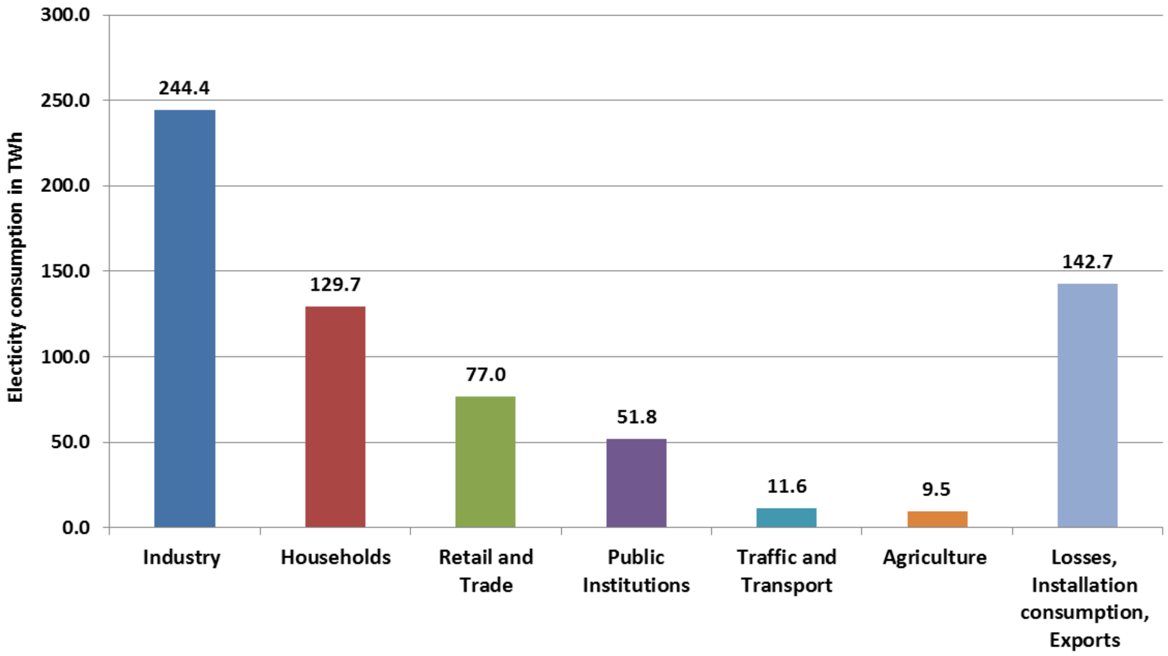
6.5 Electricity use in Germany

Within the EU, Germany is the biggest user of energy with a gross domestic energy consumption of 313 million tons of oil equivalent in 2014 (Eurostat 2016b). This related to 19.5 % of the total European gross energy consumption. The high energy demand is caused by the fact that Germany represents one of largest countries within the EU in terms of population and energy intensive industries. Domestically, about 50 % of energy is used for heat, 30 % for transport and 20 % for electricity generation (UBA 2013).

Figure 13 presents the electricity consumption by consumer groups in the year 2014. The total gross electricity consumption, including losses, installation consumption and exports, comprehended 666.7 TWh. The biggest user of electricity in Germany is the industry, which includes the mining and manufacturing sectors, with 244.4 TWh. This corresponds to 36.7 % of the total consumption. The amount of 129.37 TWh (19.5 %) of electricity is used by private households. Retail and trade (11.5 %), public institutions (7.8 %) and the transport sector (1.7 %) also represent big users of electricity (BMWi 2017).

Although the agricultural sector is a small sector within the German economy with a share of 0.63 % on total GDP in the year 2014 (Statista 2017), agricultural production is characterised by a high electricity demand. In the year 2014 this sector used 9.5 TWh of electricity, an amount with a share of 1.4 % on total gross electricity consumption.

Figure 13: Gross electricity use by consumer groups in Germany in the year 2014 in TWh



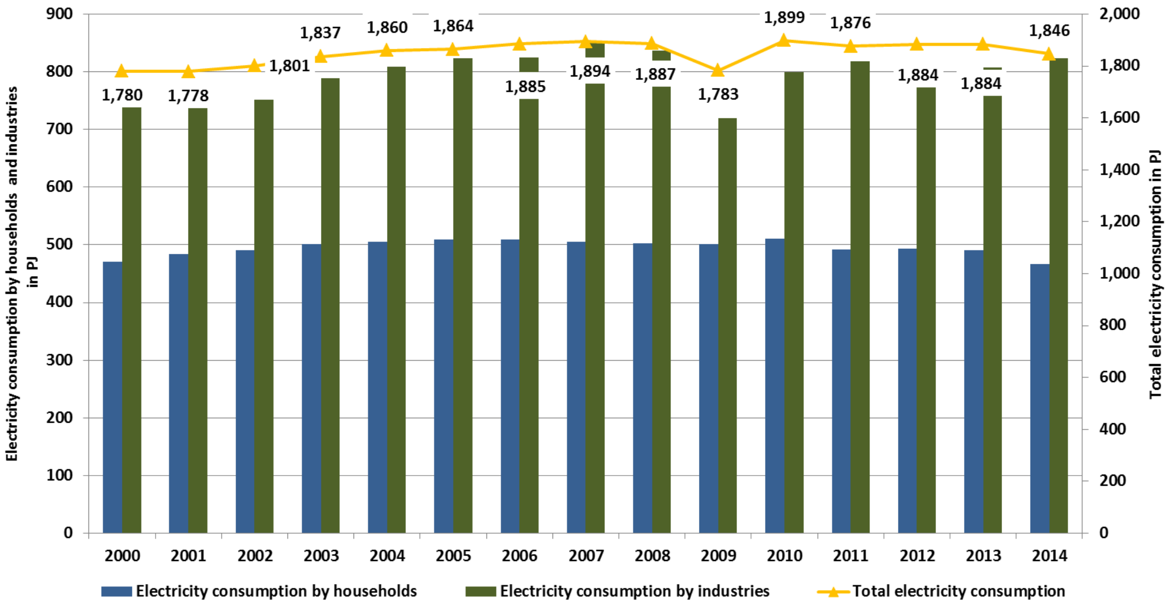
Source: BMWi (2016)

Figure 14 presents the development of the total electricity consumption in Germany with a separate view on the biggest users of electricity: households (blue bars) and the industry (green bars). The total electricity consumption in Germany increased steadily from the year 2000 until the year 2007/2008 from 1,780 Petajoule (PJ) up to 1,894 PJ. The sharp decline in 2009 is caused by the global economic and financial crisis, which caused a lower demand on domestic and global level. Compared to the development between 2000 and 2008 the trend of increasing consumption of electricity changed since 2011. Electricity use remained almost stable in 2011, 2012 and 2013 and declined down to 1,846 PJ in 2014 (AGEB 2016, BDEW 2015a).

Electricity consumption by households increased steadily until 2006 from 470 PJ up to 509 PJ. Since 2006 electricity consumption decreased and accounted for 467 PJ in 2014. The increase in 2010 was caused by cold weather conditions (BDEW 2015a).

The consumption of electricity by the industry increased from 748 PJ in 2000 to 824 PJ in 2014 but also shows stagnation since 2010.

Figure 14: Development of electricity consumption (in Petajoule)



Source: AGEB (2016)

A closer view at the development of electricity consumption by households and the industry shows that there are different influencing factors. A study of the *Bundesverband der Energie- und Wasserwirtschaft* (BDEW 2015a) analysed the influencing factors of electricity use over time. The following trends and factors for an increasing or decreasing electricity use were identified:

<u>Increase of efficiency:</u> Over the last years, efficiency in electricity use increased due to technological progress. The improved efficiency was caused by two effects: a) On the one hand, the use of electricity decreases because of a lower demand of production processes and technical devices, which cause lower costs for electricity input. b) But on the other hand, in some cases these lower costs caused an increasing use of electricity. This relation is called ‘rebound effect’ and can appear in industries and households.

<u>Industry:</u> Energy intensive production processes have been transferred into foreign countries as a consequence of increasing prices for energy in Germany (see Figure 16). Furthermore, a declining share of energy intensive production on the total value added of the German economy, lead to reduction of electricity use. Nevertheless, the use of electricity in industry increased because electricity is often the chosen energy source for new plants.

<u>Substitution effects:</u> In the past, electricity was used in a large amount for heat generation in households. In the last years, electricity lost market shares because of an increasing use of gas and renewable energies for heating.

Next to substitution effects that replace electricity, also reverse effects can be observed. In the automotive industry electric cars are becoming more important. Also, an increasing use of electric heat pumps in the industry can be observed.

Demographic development: The development of the amount of electricity used in households in Germany is influenced by two factors: a) the trend for more households with fewer members but more living space and b) the increase of efficiency of energy use (UBA 2017). Another factor is the increasing number of technical devices in households.

Consumer behaviour: Increasing prices for electricity and higher awareness of consumers for environmental protection caused a declined demand for electricity in German households. This was achieved by a more economical and more efficient use of electricity.

Next to the referred long-term aspects that influence electricity consumption, also cyclical factors have an impact on electricity demand. These factors comprise the domestic and global economic development, political framework conditions - like the EEG - and weather conditions, which especially influence the use of electricity for heat generation.

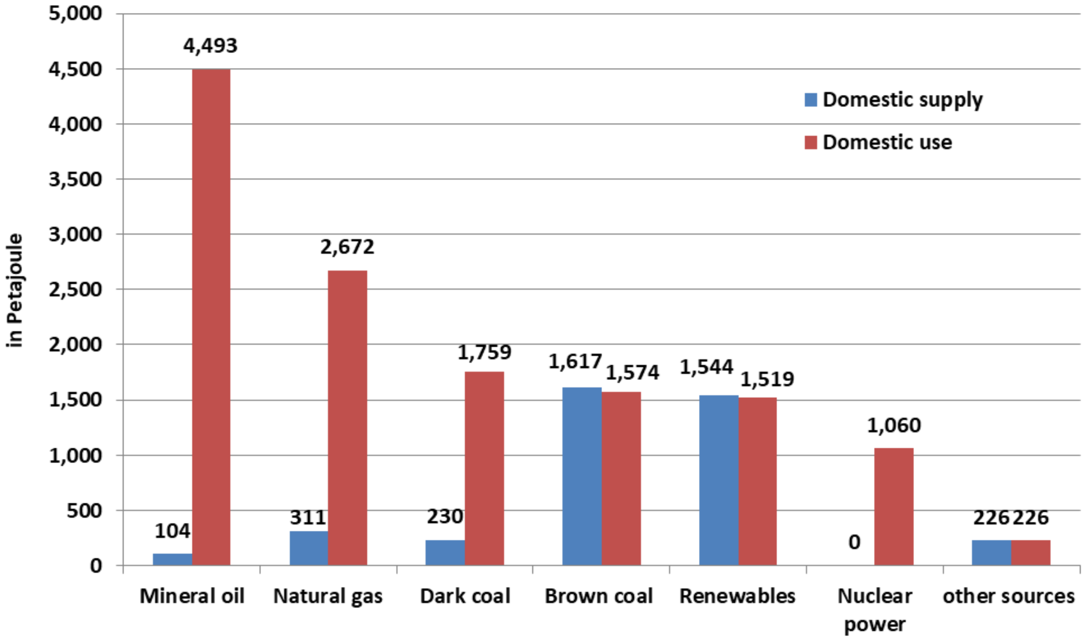
6.6 Import dependency on energy resources of the German economy

Germany is characterised as a resource poor country. Figure 15 shows the domestic supply and use of primary energy resources in the year 2014. The figure illustrates, that domestic demand for energy resources considerably exceeds the domestic supply. Therefore, Germany depends highly on imports of energy resources.

In Germany only 4,033 PJ, what corresponds to 31 % of the total energy use of 13,180 PJ, are produced on the basis of domestic energy resources. This means that around 69 % of domestically used energy resources have to be imported (AGEB 2016).
Germany has small deposits of mineral oil and natural gas, which deliver 104 PJ or 311 PJ, respectively. Around 98 % of mineral oil and 87 % of natural gas have to be imported. The use of energy is dominated by mineral oil, with 4,493 PJ, which comprised a share of 34 % on total energy demand in 2014. Until today, oil-based products cover almost the total requirements in the transport sector, but also in the chemical industry.

Natural gas is used at an amount of 2,672 PJ, representing 20 % of the total energy demand, and is mostly used for heat generation.

Figure 15: Domestic supply and imports of primary energy resources in Germany in 2014 (in Petajoule)



Source: AGEB (2016)

Germany possesses large dark coal deposits. Although dark coal extraction already declines as a consequence of the abolition of subsidies for dark coal extraction (see section 6.2), Germany extracted dark coal by an amount of 230 PJ in 2014. The high import demand for dark coal shows that although dark coal extraction is state-funded in Germany, imports by a share of 87 % are necessary to cover the domestic demand. Overall dark coal captures 13 % of the total energy demand and is mostly used for electricity generation.

Brown coal represents the most important domestic energy resource. In 2014, brown coal with an energy content of 1,617 PJ was extracted domestically. 1,574 PJ were predominantly used for domestic electricity generation. Brown coal provides 12 % of the domestic energy demand. Due to a low energy content only around 3 % of brown coal has been exported.

Nuclear energy is produced continuously over years from nuclear fuel rods. These fuel rods have to be imported (AGEB 2016). Therefore, the domestic supply of this energy resource is shown as zero. Altogether, nuclear energy by an amount of 1,060 PJ is used domestically for electricity generation. The share of nuclear power on primary energy use comprised 8 % in 2014.

A view on the importance of renewable energy sources in the year 2014 shows that renewables already became increasingly important as a domestic energy resource in the framework of the *Energiewende*. Wind power, in addition to the use of solar energy and biomass produced together 1,544 PJ of energy, what comprised around 12 % of the domestic energy use in 2014 (AGEB 2016). Renewable energy is used for heat generation, the generation of biofuels for transport and electricity generation. Figure 15 shows that the domestic supply of renewable energy exceeds the domestic use. This fact is caused by the warranted feed-in of renewable electricity in the grid due to the regulations of the EEG (see section 6.2) and the maintenance of the system voltage of the grid. The specifics of German electricity markets will be considered in the next section.

6.7 Specifics of the German electricity market

Until 1998, the German electricity market was state-controlled. Following the Directive 96/92/EC of the European Commission of the year 1997, the German electricity market was liberalised in 1998. The liberalisation process comprised the generation, the transport and distribution of electricity and the establishment of an electricity stock exchange.

In the late Nineties, while the liberalisation process took place, the development of renewable energies was negligible and therefore the liberalisation and resulting structure of the electricity market was constructed under the technological conditions of fossil and nuclear electricity generation. The focus was on the introduction of competition and marketing to offer electricity for appropriate prices (Connect 2015).

As a result of this liberalisation process, producers of electricity sell their product primarily on the wholesale market. The *first* option for producers, which is often used for long-term contracts, is the so-called ‘Over-the-counter’ (OTC) contract. The *second* possibility is the trade of electricity over the ‘European Energy Exchange’ (EEX), which was established in the framework of the liberalisation process (BMWi 2016). The prices for electricity are daily determined on the electricity exchange and represent the orientation for the OTC-trade.

Prices on the exchange are determined on the base of the order of marginal costs of the different types of power plants, the so-called ‘merit order’. The last and most expensive power plant, which is still necessary to satisfy the demand is called ‘marginal power station’. This ‘marginal power station’ determines the unit price for all power plants and therefore the market clearing price on the electricity exchange (AEE 2013). Due to this process of price formation on the electricity exchange, electricity prices are based on short-term marginal cost of power plants. The prices are determined by the costs of energy input, but not by long-term capital and financing costs of power plants. So only the price for electricity is compensated, but not the price for the provision of performance (so-called ‘energy only market’). Hence, the economic efficiency of power plants depends on the generation of marginal income. In the long-term economic perspective of a power-plant, the prices for electricity have to be over the marginal costs to cover fix and operating costs and to take profit (AGE 2013, Connect 2015).

At this point the role of the newly established renewable energies becomes important. Electricity remunerated according to the EEG, is traded on a large scale on the spot market of the EEX. The characteristic of renewable energy, with the exception of biomass, is the amount of marginal costs, which tend to be zero for wind and solar power plants. Additionally, electricity traded under the conditions of the EEG has to be traded preferentially. As a consequence, the 'merit order' of power plants changes in times when renewable-based electricity is available. The most expensive power plants, which are fossil-based power plants and especially gas power plants, are displaced by renewables power plants and cost-efficient power plants. As a result, the prices on the electricity exchange decline. Therefore, fossil and nuclear power plants more often do not achieve marginal returns and consequently increase their depreciations (INSM 2016).

The domestic demand for electricity depends on the time of day as well as on the season and fluctuates daily between 40 and 80 Gigawatt. In times of low load, under the requirement of the existence of wind and sunshine, renewable energies are already able to cover a large part of the domestic electricity demand. In these periods, only a few conventional fossil power plants are used to cover the remaining demand. But because of technical and economic reasons, coal- and nuclear-based power plants are not able to reduce their production during this time. That means that an oversupply of electricity is generated during these periods (see section 6.4) and the prices for electricity decrease and even can become negative on the EEX (AEE 2013).

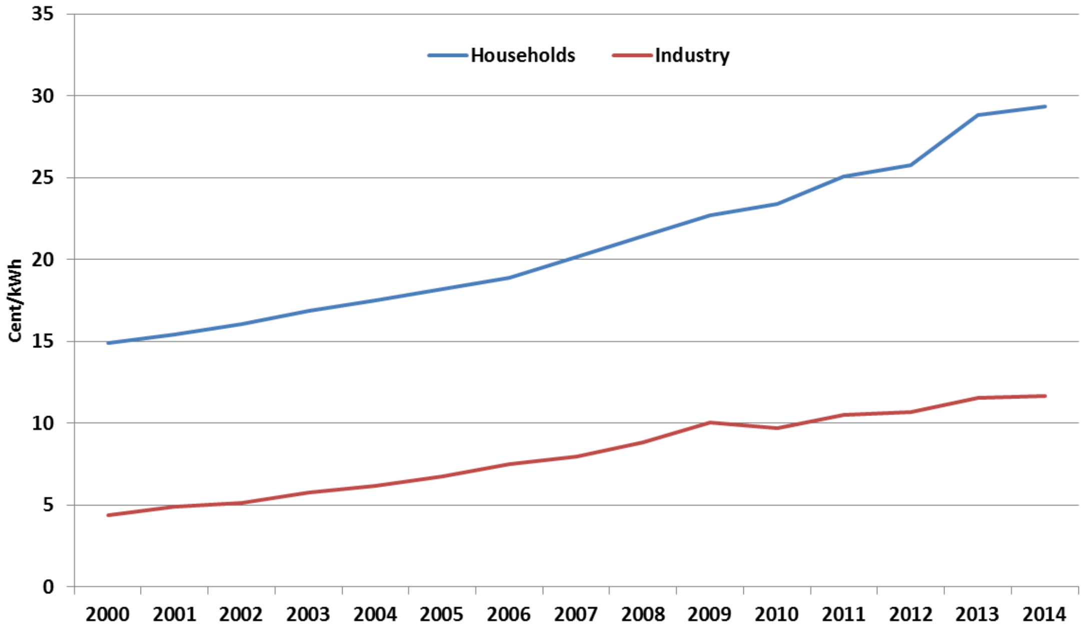
The reasons for the inflexibility of fossil power plants are manifold. Several fossil power plants are used to guarantee the supply of control energy for the grid and have to generate electricity. But fossil and nuclear power plants are also inflexible. Starting up and down these types of power plants is often inefficient from an economic and technological perspective. Gas power plants, which could be flexible in their operation, are characterised by high marginal costs. Consequently, not flexible gas power plants generate electricity to secure the base load in the grid, but coal and nuclear based power plants that are characterised by the described technological and economic inflexibility. Electricity that is not used in Germany is exported to foreign countries. The resulting development of electricity trade is presented in section 6.9.

6.8 Development of electricity prices in Germany

This section focusses on the development and price formation for electricity in Germany. Electricity generated on the basis of renewable energy, which is not sold directly in the framework of green electricity tariffs that are defined in the EEG, is sold on the EEX by transmission system operators. The difference between the guaranteed EEG-price for electricity fed into the grid for operators of renewable energy plants and the particular current price, which is achieved on the electricity exchange is passed on the consumer in terms of the so-called EEG-levy. Due to the increasing provision of renewables in the energy mix for electricity generation, the price for electricity on the EEX decreased over the last years. This decrease is a consequence of changes in the 'merit-order' of power plants and the low marginal costs of renewable energy sources wind and solar (see section 6.7). As a consequence, the EEG-levy increased and caused higher prices for consumers (AEE 2013).

Figure 16 shows the development of electricity prices for households and the industry in Germany. Although the prices on the EEX declined as a consequence of an increasing supply of renewable-based electricity and the resulting change of the 'merit order' of power plants, prices for electricity consumed by households and the industry increased continuously over the last years. In the year 2000, representing the starting year of the EEG and the related support of renewable energies, the price for electricity comprised 14.92 Cent/kWh for households and 4.40 Cent/kWh for the industry. In the year 2014, electricity prices for households almost doubled up to 29.37 Cent/kWh. The prices for industries increased by around 62 % up to 11.66 Cent/kWh (BMWi 2017). The reason for the growing electricity prices can be found in the composition of the final electricity price for consumers, which also explains the difference between the electricity price for households and the industry.

Figure 16: Development of electricity prices for households and the industry in Germany (in Cent per kWh)

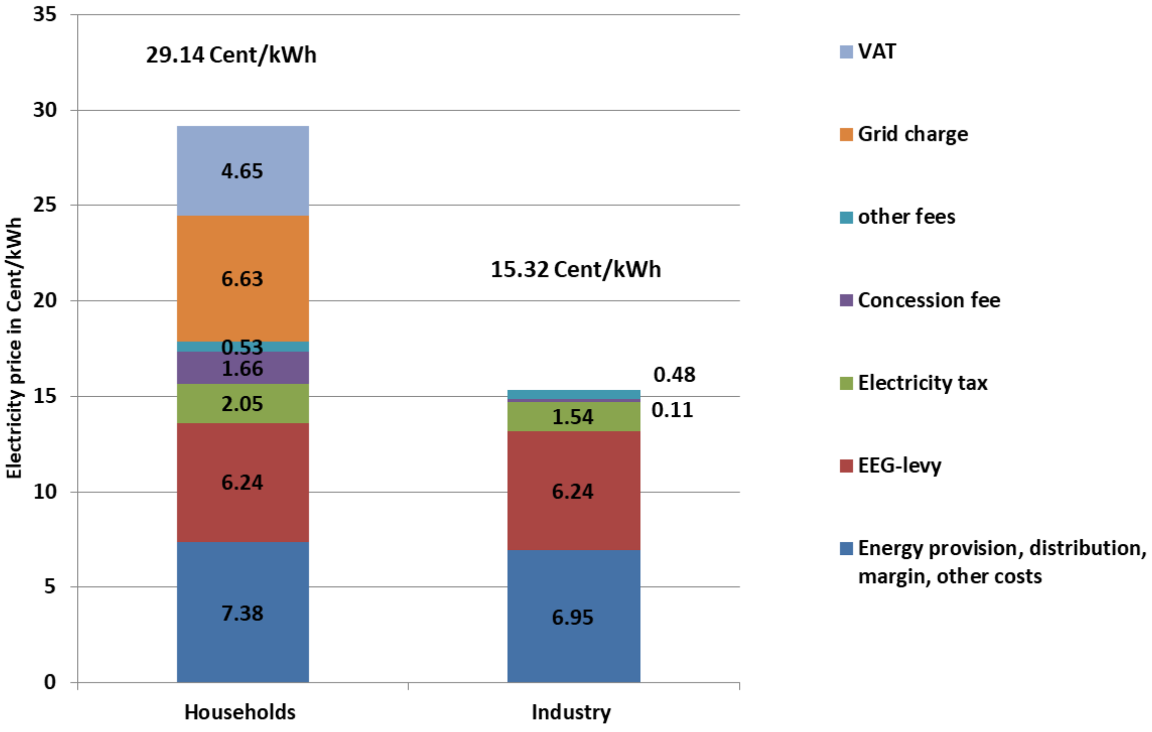


Source: BMWi (2017)

Figure 17 presents the components of the electricity prices for households and the industry. Pictured are the cost items of the average electricity price for an exemplary household with an annual electricity consumption of 3,500 kWh and an exemplary industrial enterprise with an annual consumption between 160 MWh and 20 GWh.

Altogether, the cost elements that influence the price for electricity for households and industrial firms, can be summarised into three categories. These categories comprise a) costs for procurement and distribution, b) grid charges and c) taxes and levies. Figure 17 illustrates that the composition of these three components is different between households and industrial firms and finally result in different prices for electricity. Overall, the average price for electricity for households comprised 29.14 Cent/kWh and 15.32 Cent/kWh for the industrial enterprise. Some of the cost factors are equal between industry and households, but there are also differences in the cost factors.

Figure 17: Composition of the average electricity price for households and industry in 2014 (in Cent per kWh)



Source: BDEW (2015b, 2016)

The price forming factors for households include costs for energy provision, distribution and margins with an amount of 7.38 Cent/kWh. For the industry, these costs components together comprise 6.95 Cent/kWh. This cost position includes the actual costs of production for electricity, the costs for the use of supply networks and the administrative costs of the provider. The lower price share for the industry is justified by staggered prices of electricity suppliers. For higher purchase quantities of electricity, supplier offer lower prices per kWh (BDEW 2016, 2015b).

The EEG-levy comprises an amount of 6.24 Cent/kWh and is equal for households and industry. This levy balances the difference between the guaranteed EEG-price for electricity based on renewable energy and the particular current price, which is achieved on the EEX (see section 6.7).

A further component of electricity prices is the electricity tax (see section 6.2). The regular tax rate comprises 2.05 Cent/kWh. The Electricity tax is an indirect tax, which is incurred by the electricity supplier when electricity is taken from the grid for final consumption. Electricity suppliers pass on the electricity tax to the final consumer. The lower tax rate for the industry, with an average amount of 1.54 Cent/kWh, is a result of tax benefits. These benefits were introduced by the government with regard to maintain the international competitiveness of the German manufacturing industry (Ministry of Justice and Consumer Protection 2000).

The concession fee is a charge for granting the right to use public routes for the installation and operation of pipelines intended for the direct supply of final consumers with electricity and gas (BDEW 2010). The amount of the fee depends on the population of a community. In the year 2014 households had to pay an average fee of 1.66 Cent/kWh and the industry 0.11 Cent/kWh.

The position 'other fees' comprise the KWK-levy, which is used to promote combined heat and power plants. The fee also includes grid charges of energy intensive enterprises (§19-levy) that are released from these charges. Next to this, 'other fees' include the offshore-levy, which balances lost revenues of offshore wind parks as a result of delayed connection to the power grid. Overall, these 'other fees' sum up to 0.53 Cent/kWh for households and 0.48 Cent/kWh for the industry.

Compared to the industry, households also have to pay grid charges in the amount of 6.63 Cent/kWh and value-added tax, which comprises 4.65 Cent/kWh.

In the result around 52 % of the electricity price comprises taxes and levies, 23 % have to be paid for the use of the grid and around 25 % serve for the actual provision of electricity (BDEW 2015a).

The development of the electricity prices show that households and the industry have to struggle with increasing electricity prices due to the shifting of the EEG-levy to the final consumer. Especially households, which contrarily do not have the option to pay reduced electricity tax rates compared to the industry, have to pay for the replacement of fossil/ nuclear by renewable energies.

6.9 Development of electricity trade

Electricity trade is also characterised by some specifics. Because of technological characteristics of the grid, the German physical electricity market is not country-specific. In fact, it is a complex market and grid system between ten European countries[6]. The objective of this connected market is the synchronisation of supply and demand of electricity and the maintenance of electric tension in the grid during phases of high and low demand. Therefore, the amount of German imports and exports of electricity, shown in Figure 18, is primarily a consequence of electricity exchange due to

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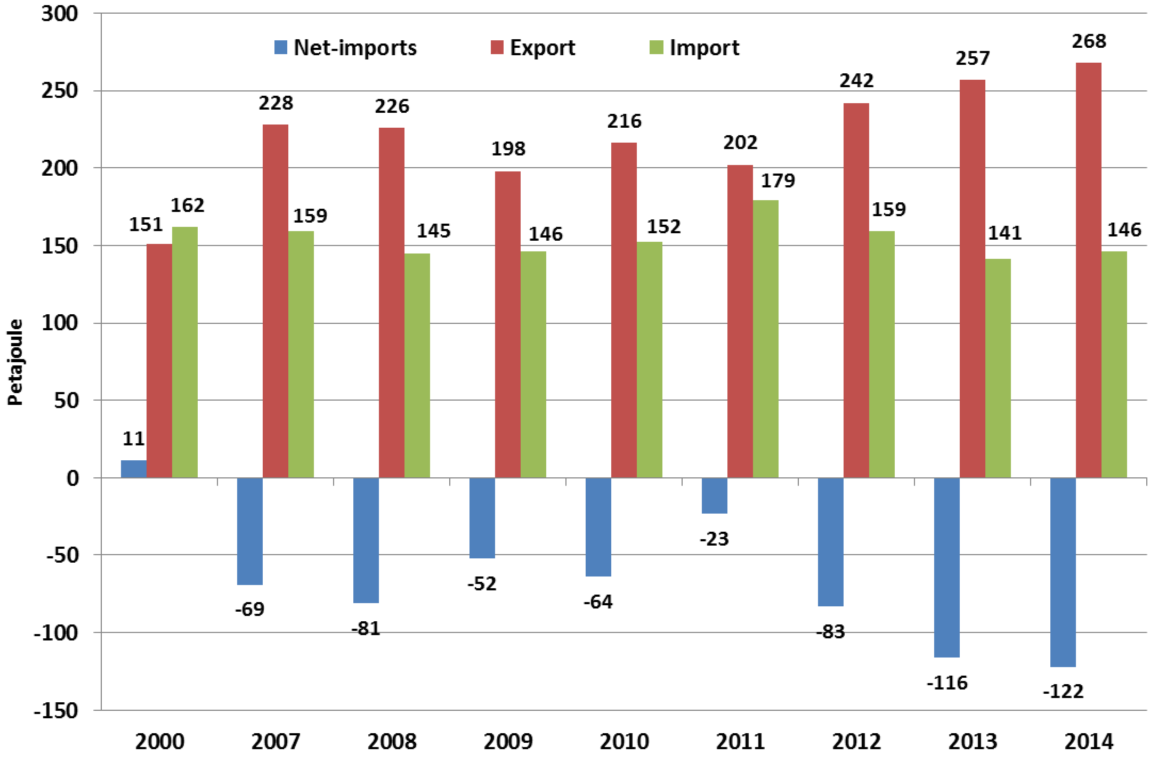
[6] Denmark, the Netherlands, Luxembourg, France, Switzerland, Austria, Czech Republic, Poland, Sweden, Germany

technological conditions in the grid. Relevant for conclusions about electricity trade are the numbers of net-imports (BMWi 2017).

Figure 18: Development of electricity trade in Germany between 2000 and 2014 (in Petajoule)



Source: AGEB (2016)

For purposes of clarity, Figure 18 shows the development of electricity trade from 2007 onwards. The information for the year 2000, the year of the implementation of the EEG, serves for a better placement of the development.

In 2000, Germany has been a net-importer of electricity with an amount of 11 PJ. Due to a) the increase of electricity generation based on renewable energies (see Figure 10) and the preferred feed-in into the grid under the conditions of the EEG, but also because of b) the inflexibility of electricity production regulation of fossil and nuclear power plants (see section 6.7), domestic electricity generation increased to a level that exceeds domestic demand. Thus, Germany became a net-exporter of electricity and net-imports became negative. In the year 2014, exports exceeded imports by an amount of -122 PJ (AGEB 2016).

Furthermore, Figure 18 shows a volatile picture of the development of imports and exports of electricity. The considerable influences on the amount of electricity imports and exports can be summarised as follows:

Technological conditions: As described in section 6.7, the current composition of fossil and nuclear power plants is characterised by inflexibility with regard to modifications of electricity supply to the actual demand of electricity. Due to the constant electricity generation by these power plants, exports of electricity increase in times when renewable power plants deliver a high amount of electricity to the grid.

Renewable Energy Act: The Renewable Energy Act (see section 6.2) ensures a guaranteed and preferred feed-in of renewable-based electricity into the grid. In years, characterised by optimal weather conditions for electricity generation based on wind and solar energy, this renewable-based electricity is available in the grid, independent of the demand. Furthermore, the EEG caused an extension of electricity generation based on wind, solar and biomass (see section 6.4), with the consequence that the provided amount of renewable and preferred electricity increased. The volatile development of electricity exports is a consequence of the dependence on weather conditions of renewable electricity generation.

Energy Package: Due to the immediate shutdown of the eight oldest nuclear power plants in the year 2011 and the abolition of electricity supply, imports of electricity increased.

Increase of efficiency: The increase of efficiency in electricity use due to technological progress causes a decrease of electricity demand.

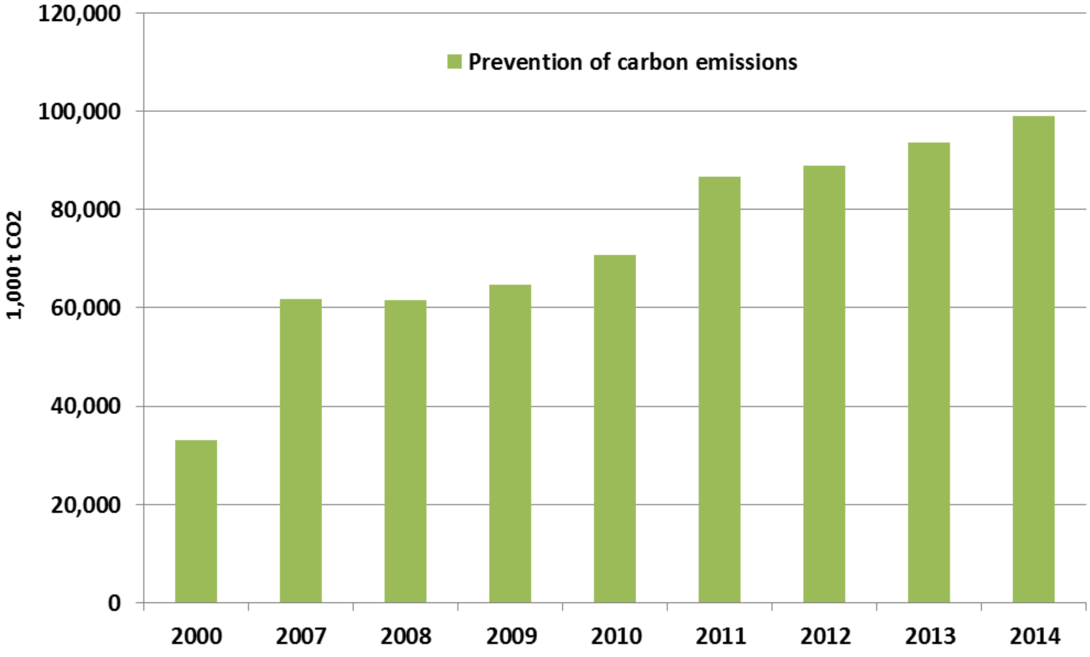
Consumer behaviour: Increasing prices for electricity (see section 6.8) and the awareness of consumers for environmental protection caused a decline in electricity demand and electricity imports.

Export supply and import demand for electricity depend furthermore on the domestic and global economic development (BDEW 2015).

6.10 Impact of renewable energy sources on the prevention of carbon emissions

One environmental objective of the *Energiewende* is the reduction of carbon emissions by replacing fossil by renewable energy sources (see Table 12). Figure 19 shows the development of the prevention of carbon emissions as a consequence of the increased use of renewable energies for electricity generation between the years 2000 and 2014.

Figure 19: Prevention of carbon emissions by renewable energy sources for electricity generation (in 1,000 tons)



Source: BMWi (2017)

The figures show that the increasing use of bio-based resources caused an increase in the prevention of carbon emissions from 33 million tons in the year 2000 up to 99 million tons in 2014 (BMWi 2017). The development of carbon emission prevention is conditioned on the development of electricity generation based on renewable energies shown in Figure 10 and illustrates one characteristic of renewables: In the years 2008, 2009 and 2010 electricity generation based on wind energy declined, due to windless weather. Therefore, also the prevention of carbon emissions remained almost on the same level. The use of biomass and solar energy for electricity generation increased during this time and absorbed the missing wind energy (see section 6.4). But nevertheless, the stagnation in the prevention of carbon emissions shows the dependence of renewable energies sources on weather conditions to achieve the political determined targets to reduce carbon emissions (see section 6.2).

6.11 Summary

The political objectives for the energy sector, determined by the *Energy Concept*, the *Energy Package* and the Renewable Energy Source Act, currently cause a restructuring process of the German electricity supply system.

The consideration of electricity generation shows a switch from a fossil- and nuclear-base to a renewable-based supply system. Especially electricity generation based on wind, solar and biomass experienced a considerable increase. Biomass-based electricity generation comprises a special role in the frame of renewable energies. While the provision of wind and solar energy is characterised by marginal costs that tend to be zero, the supply of biomass is characterised by the existence of higher costs and furthermore by a competition for production factors as well as for the final use of agricultural commodities. Here, the new possibility to use agricultural products for electricity generation competes with the usage as feed and food.

Industries and households represent the biggest users of electricity. Over the years, electricity consumption showed stagnation with a declining tendency. On the one hand, these effects are caused by an increasing efficiency of electricity use. On the other hand, manifold influencing factors like the economic development, substitution effects, changes of consumer behaviour or increasing prices for electricity have an impact on electricity use.

Germany is a resource-poor country and strongly depends on energy imports. With regard to energy resources used for electricity generation, there is a high import demand for natural gas and dark coal. Brown coal and renewable resources are available domestically.

The German electricity sector and the transformation process is characterised by various specifics. Old established power plants, like the remaining nuclear power plants and coal power plants are inflexible with regard to adapting their electricity supply on changing framework conditions. But they are necessary to ensure a sufficient electricity supply in times of high demand. Gas power plants provide this flexibility but have too high marginal costs for being competitive with coal or nuclear power plants. At the same time, electricity on the basis of wind and solar energy is generated under the preferred conditions of the EEG. As a consequence electricity supply based on renewable energy resources increased over the last years.

In the framework of the liberalisation of the electricity market an energy exchange was established. Here, the prices for electricity are determined on the basis of the order of marginal costs of power plants, the so-called 'merit order'. The most expensive power plants, which are fossil-based power plants and especially gas power plants are displaced by renewable power plants and cost-efficient power plants. As a consequence, the prices on the electricity exchange decline and fossil and nuclear power plants more often do not achieve marginal returns.

Although prices for electricity achieved by generating companies tend to decrease, electricity prices for households and industries increase. The reasons for these increasing prices are on the one hand the increase of the EEG-levy, which balances the difference between the EEG guaranteed price for electricity fed into the grid for operators of renewable energy plants and the particular current electricity price and on the other hand the composition of the final electricity price for consumers. Especially households, which do not have the option to pay reduced electricity tax rates compared to the industry, have to pay for the replacement of fossil fuel with renewable energies.

Changes of the domestic supply and use of electricity have an impact on electricity trade. As a consequence of the increased supply of electricity based on renewable energy sources, Germany changed from a net-importer to net-exporter of electricity.

One objective of the *Energiewende* is climate protection and, in this context, the reduction of greenhouse gases. The emissions of carbon dioxide caused by electricity generation show a declining but volatile tendency as a consequence of the increasing use of renewable energies.

7 Case study – Scenario description, Model closures and Results

7.1 Introduction

In the case study, the comparative-static model STAGE_D is applied, to analyse the impacts of the transformation from a nuclear and fossil-based to a renewable based electricity supply system on the German economy, with special consideration of the agricultural sector. This chapter presents the description of the considered scenarios, the simulation results and their analyses.

The model STAGE_D as well as the underlying SAM have been developed in the framework of this research (see chapters 4 and 5). The SAM, applied in this case study, comprises detailed and disaggregated information of the electricity and agricultural sector.

The model STAGE_D allows multiple production technologies for electricity generation that comprise existing technologies (nuclear, dark coal, brown coal, oil and gas) and new technologies (wind, solar, biomass) with different cost structures. Electricity is implemented in the model as a homogenous product being produced by these different technologies with different cost structures.

The agricultural sector is captured in STAGE_D as a multi-product sector. Agricultural activities are distinguished at the regional level of the German states (*Bundesländer*). That means that a given agricultural activity - one state - represents all farms of that region and that this agricultural activity is able to produce multiple output, i.e. crops, livestock as well as biomass for biogas generation. This consideration enables the model to capture regional differences in the production structure.
Furthermore the model also provides an accounting for the carbon emissions resulting from the use of energy inputs by sectors and households. The database is provided in form of a satellite account (see section 4.4.4).

This chapter starts with the presentation of the scenarios, considered in this case study, in section 7.2 and the underlying model closures in section 7.3.

Scenario results are presented and analysed in section 7.4, starting with the analysis of the macroeconomic impact. The presented changes in GDP, see section 7.4.1, can be interpreted as an indicator for the total economic development.

Because a CGE model captures the circular flow of an economy, changes in commodity and factor demands in the electricity sector (see section 2.3.1) affect the whole economy and its actors. Due to the complexity of the driving factors of economic adaptions, as a reaction on the changes in the electricity sector, the results are presented stepwise.

The electricity sector, as the triggering sector for economic changes, is the starting point of the analysis in section 7.4.2. Here, the changes in the composition of nuclear, fossil and renewable resources used for electricity generation are presented. One consequence of the modified resource use and application of new technologies is a change in the cost structure of electricity generation. Therefore this section additionally presents the impact of the application of new technologies on electricity prices under the new equilibrium situations in the three scenarios.

The impact of the restructuring process of the electricity sector on other sectors of the economy is presented subsequently in section 7.4.3. A closer examination of the impacts on factor income and factor prices is given in section 7.4.4. Changes in factor income have a direct impact on the income and consumption of households. The way how households are concerned in the different scenarios is presented in section 7.4.5. Next to adjustments of the domestic economy, the *Energiewende* also has impacts on international trade. Section 7.4.6 captures the trade effects with regard to electricity and commodities used for electricity generation, but also the changes of import and exports of commodities produced in other sectors.

The nuclear phase-out and the substitution of fossil by renewable energies have also environmental impacts. One objective of the German government is the long-term reduction of greenhouse gas emissions. The changes of carbon emissions as a consequence of the implementation of energy change policy are outlined in section 7.4.7.

The presentation of the results completes with a special focus on the agricultural sector in section 7.4.8. The agricultural sector gets particular attention in this consideration due to its special role as a sector characterised by a high level of energy and electricity use but also as a ‘new’ actor for providing electricity based on biogas. Therefore, the impact of the changes in the electricity sector on agricultural production and prices as well as on trade is analysed in this section.

The chapter closes with a summary of the model results, conclusions and recommendations for further research, presented in section 7.6.

7.2 Scenario description

The impact of the exit from nuclear and fossil-fuel energy and the concurrent increase of renewable energy on the German economy are captured through three related scenarios, which are presented here with regard to their objective and the implementation into STAGE_D.

Objectives of the scenarios

Scenario 'Phase_out': Impact of the nuclear phase-out on the German economy

The political and social acceptance of the use of nuclear power for electricity generation in Germany changed over the last years. At the beginning of the comprehensive conversion of the German electricity supply system in the framework of the *Energy Concept* in 2010*,* the German government decided the extension of the operating lifetime of nuclear power plants. Nuclear power was intended to be a bridge technology until renewable-based electricity generation would be developed to supply electricity in a sufficient extent because nuclear power offers environmental advantages due to low carbon emissions and a low import demand.

But as a consequence of the nuclear accident in Fukushima in the year 2011, the government changed its strategy for the transformation process of the electricity supply system with an immediate closure of the eight oldest nuclear power plants and the decision of the complete nuclear phase-out in the year 2022 in the framework of the *Energy Package* (see section 6.2).

The underlying object of the scenario 'Phase_out' is the analysis of the economic, environmental and social impact of the nuclear phase-out in Germany under the assumption of a complete phase-out.

Scenario 'Complete': Increase of the importance of renewable energies in the electricity sector

One main objective of the German *Energiewende* is the transformation of the electricity supply system away from the old established fossil and nuclear basis towards a renewable based system (BMWi 2010).

The second scenario 'Complete' focusses on the impacts of the substitution of fossil by renewable energies for electricity generation based on the objective of the *Energiewende* to extend renewable energies to the main source for electricity supply. With regard to fossil-based electricity generation in this scenario the assumption was made that electricity generation based on coal mostly is replaced by gas. Background of this decision is the technological flexibility of gas-based electricity generation to balance the fluctuating supply of wind and solar based electricity generation, because of varying weather conditions (see section 6.4).

Furthermore, this scenario includes the abolition of domestic dark coal extraction as a consequence of the cancelled dark coal subsidies in 2018 (BMWi 2007, IAE 2013) as well as the nuclear phase-out.

Scenario 'Biomass': Analysing the role of biomass in the framework of the *Energiewende*

The agricultural sector comprises a special role in the transformation process of the energy supply system. Agriculture is an energy intensive sector with a high use of electricity and other energy inputs. Furthermore, the agricultural sector became a provider of electricity due to the technological possibility to generate electricity based on biogas as a consequence of the political support in the frame of the EEG. Biomass, the substrate for biogas production, produced in the agricultural sector comprises crop and livestock based substrates. While livestock based substrates, like manure etc., are by-products of livestock production, the production of crop-based substrates raises a claim on the production factors and increase especially the competition for land that can also be used for crops processed in the food and feed industry. Furthermore, over the last years a competition between the final uses of agricultural commodities arose. Next to the traditional application of agricultural commodities to be the basis for feed and food production, technological progress and governmental support by the EEG extended this use spectrum by the electricity generation. Consequently, the competition for the use of biomass increased. The objective of this scenario is the analysis of the role of the agricultural sector in the framework of the *Energiewende*.

Scenario implementation into STAGE_D

Scenario 'Phase_out': Impact of the nuclear phase-out on the German economy

The nuclear phase-out, captured in scenario 'Phase_out', is implemented into the model by a reduction of capital demand $(FD_{fcap,aelnucl})$ for electricity generation based on nuclear power $(aelnucl)$ to zero. The factor supply (FS_f) for Germany remained fixed. The returns to capital for this activity are allowed to vary by relaxing the sectoral proportion for the capital price $(WFDIST_{fcap,aelnucl})$.

Additionally, the top level of the nested production function was changed from a CES into a Leontief form for nuclear electricity generation by adding the activity $aelnucl$ to the subset $aqxn$ to prevent a substitution between the intermediate inputs and value added-energy inputs. Due to the fact that capital demand of electricity generation based on nuclear power $(aelnucl)$ is reduced to zero and the Leontief assumption on the top level of the production structure, the nuclear phase-out is implemented into STAGE_D, with the consequence to stop the generation of nuclear based electricity.

The modification of the nested production structure, presented in section 5.2, as well as the development of the SAM on the basis of SUTs (see section 2.2.5) allows STAGE_D to differentiate between activities with different technologies and resulting different cost structures to produce the same good. For this simulation, electricity was declared as a homogeneous product by switching electricity $(cely)$ from the set $cxac$ that captures commodities that are differentiated by activity into the set $cxacn$, which does not differentiate between activities. This switch enables the model to capture the fact that electricity is produced by different types of power plants, e.g. coal, nuclear or wind power plants. In addition, it allows different treatment of electricity generating activities.

Scenario 'Complete': Increase of the importance of renewable energies in the electricity sector
For the implementation of scenario 'Complete' in the model, electricity was declared as a homogeneous product, by switching electricity $(cely)$ from the set $cxac$ into the set $cxacn$, like in scenario 'Phase_out'. This allows for the generation of electricity by different technologies.

Furthermore, for all electricity producing activities the Leontief production function on the top level of the production function was chosen. These activities comprise electricity generation based on nuclear power, brown coal, dark coal, gas, wind/solar and biomass $(aelnucl, aelbrown, aeldark, aelgas, aeloil, aelwindsol, aelbio)$ and for the extraction of dark coal $(adark)$. The Leontief assumption on the top level, with the underlying elasticity of substitution of zero, avoids a substitution between intermediate inputs and value added-energy inputs (see section 5.2).

To increase or decrease the production of the appropriate electricity generating activity, the implementation was done by changes of the factor demand for capital $(FD_{fcap,aelectricity})$[7]. The decision to make only the factor capital immobile and activity specific is a consequence of the characteristic of the electricity sector. Fossil and nuclear power plants require high investments over a long period, longer than the period of the politically decided phase-out or reduced use of power plants. To shut down the power plants, workers are still necessary.

Renewable power plants, like wind and solar plants, do not require substantial amount of labour input during their runtime. Also for biogas plants, it was assumed that these plants only require investments but no additional labour on the farms. Land was assumed as fix, due to the exclusive use of land by the agricultural and forestry sector.

To achieve the nuclear phase-out and the stop of the domestic extraction of dark coal, capital demand $(FD_{fcap,aelnucl}, FD_{fcap,adark})$ for these two activities was reduced down to zero.

Due to the technological advantages of gas power plants (see section 6.7) in order to adapt electricity generation to the required needs, electricity generation based on gas $(aelgas)$ is decided to rise up to the most important fossil energy source in this scenario. This is implemented by an increasing capital demand for this activity by factor eight.

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[7] The activity 'aelectricity' includes here all electricity generating activities.

Beyond, capital demand for the electricity producing activities wind and solar ($aelwindsol$) and biomass ($aelbio$) increases by the factors seven and five to achieve the objective of an electricity supply system based on renewable energy.

Capital demand for electricity generation based on brown coal ($aelbrown$), dark coal ($aeldark$) and oil ($aeloil$) is reduced by 30 %, 95 % and 25 % to provoke a reduction of the electricity supply of these fossil based activities.

Furthermore, it is assumed to achieve total electricity supply close to the base level in order to avoid a decline of economic growth as consequence of a lower electricity supply in this scenario.

Scenario 'Biomass': Analysing the role of the agricultural sector in the framework of the *Energiewende*

To analyse the impact of the use of biomass and the role of the agricultural sector as supplier and user of electricity, scenario 'Biomass' preserves all assumptions of scenario 'Complete' with exception of biomass. The amount of electricity generation based on biomass is generated endogenously by the model in this scenario. Scenario 'Complete' presents the reference scenario for the analysis of the results of scenario 'Biomass'. Therefore the implementation into STAGE_D is comparable with those in scenario 'Complete' with exception of the increase of capital demand for electricity generation based on biomass ($FD_{fcap,aelbio}$).

7.3 Model closures

To run a CGE model the number of equations has to be equal to the number of variables to close the model. The closure rules comprise the choice of variables that are fixed or unfixed to implement the experiment (see section 2.4.3). Model closures are an important component because these rules determine how the German economy operates from the modellers' perspective. For running the simulations the following closure rules are assumed:

Foreign exchange closure: The external trade balance is fixed. The exchange rate remains flexible in order to balance the account for the rest of the world.

Investment-savings closure:
The German economy is assumed to be investment driven. The value share of investment in total final domestic demand is fixed. The savings rate of households and enterprises is flexible to adjust to balance the capital accounts.

Government account closure:
Tax rates, government consumption expenditures and transfers are fixed. The government account is brought into equilibrium through flexible government savings.

Enterprise closure:
For enterprises, the volume as a share of final demand is fixed as well as the enterprise transfers to households. The value of commodity expenditures by enterprises is allowed to vary.

Numéraire: The consumer price index (CPI) is set as numéraire and therefore all prices are expressed relative to this fixed CPI.

Factor market closure:
Changes in the factor market closures are already described while presenting the implementation of the different scenarios into STAGE_D. Summarised, the factor market closures are implemented as follows: Labour is assumed to be fully employed and mobile. The basic factor market closure for land was not changed and is the same as in STAGE. Land is fully employed but due to the exclusive use by the agricultural and forestry sector *de facto* immobile.
Capital was made activity specific. Due to the long-term investments of fossil and nuclear power plants and the negligible demand for labour for conducting wind and solar plants, it was decided only to fix the factor capital by the relevant activities and let labour mobile. For the implementation in STAGE_D, capital demand for the relevant electricity generating activities and the activity mining of dark coal is fixed ($FD_{fcap,activ}$). Returns to capital are allowed to vary and unfixed ($WFDIST_{fcap,activ}$). The total factor supply (FS_f) remains fix.

7.4 Results

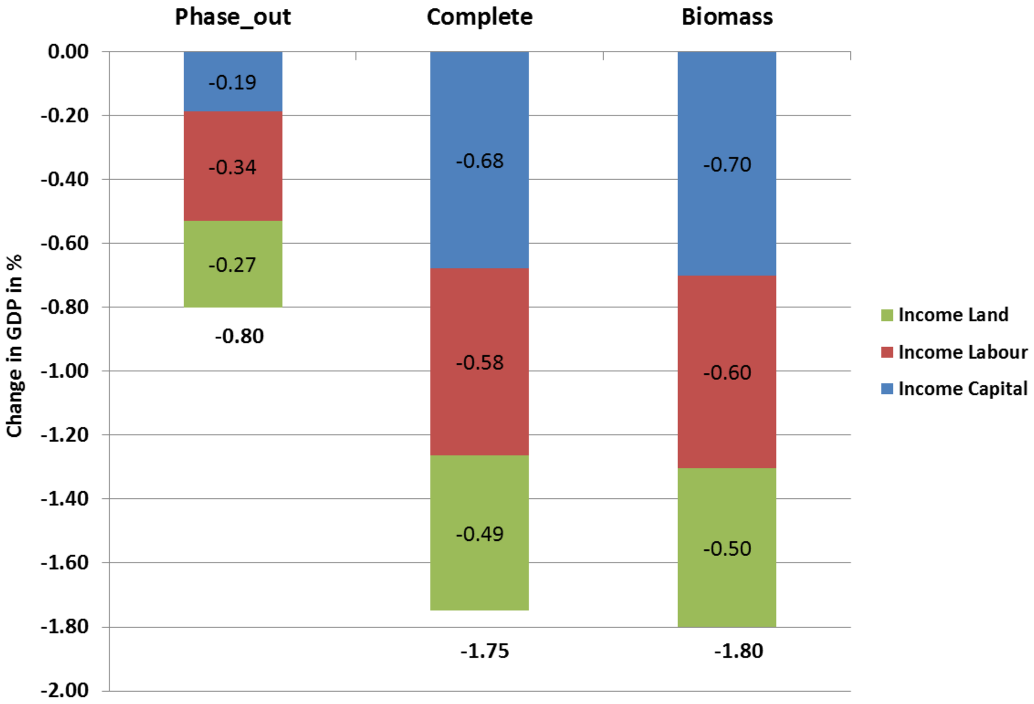
This section provides the presentation and analysis of the simulation results regarding the impact of the exit from nuclear and fossil-fuel energy in the electricity sector on the German economy with a special consideration of the agricultural sector.

7.4.1 Impact on Gross Domestic Product

GDP indicates the economic performance of an economy by measuring to the sum of the GVA of all resident institutional units involved in production processes (OECD 2002). Figure 20 depicts the macroeconomic effects of the conversion from fossil and nuclear to renewable electricity generation within the framework of the *Energiewende* by percentage changes in GDP for the considered scenarios.

GDP is going down in Germany in all three scenarios. The lowest reduction is caused by the nuclear phase-out ('Phase_out') with a decline of -0.80 %. The implementation of the objectives of the *Energiewende* in the electricity sector, shown in scenario 'Complete', results in a decline in GDP by -1.75 % but the most considerable economic effects become visible in scenario 'Biomass', with a decrease of GDP by -1.80 %.

Figure 20: Impacts on Gross Domestic Product (in percent)



Source: Own results

In addition to the total changes in GDP, Figure 20 presents a breakdown of GDP into the components of GVA - the income of labour, land and capital. While the income of labour and land is mostly reduced in scenario 'Phase_out' with declines of -0.34 % and -0.27 %, the income of capital is effected mostly in scenario 'Complete' and 'Biomass' with a reduction of -0.68 % and -0.70 %.

Overall, a decline in GDP is an indicator of a shrinking economic performance and shows that the implementation of the *Energiewende* in the electricity sector has negative economic impacts. This result contradicts the governmental objective of maintaining a high level of economic competitiveness and development. The influencing factors of these negative economic effects and the reasons for the differences between the scenarios are considered in the following sections, starting with the electricity sector.

7.4.2 Impact on the electricity sector

The nuclear phase-out, captured in scenario 'Phase_out', the replacement of fossil by renewable energy resources (scenario 'Complete') and especially the use of biomass for electricity generation in this replacement process (scenario 'Biomass') cause fundamental changes in the composition of resources used for electricity generation and in the total amount of electricity generation.

In addition, the application of new technologies and raw materials leads to changes in the cost structure of electricity generation that have an impact on electricity prices. This section focuses on these relationships, starting with the description of the changes in domestic electricity generation.

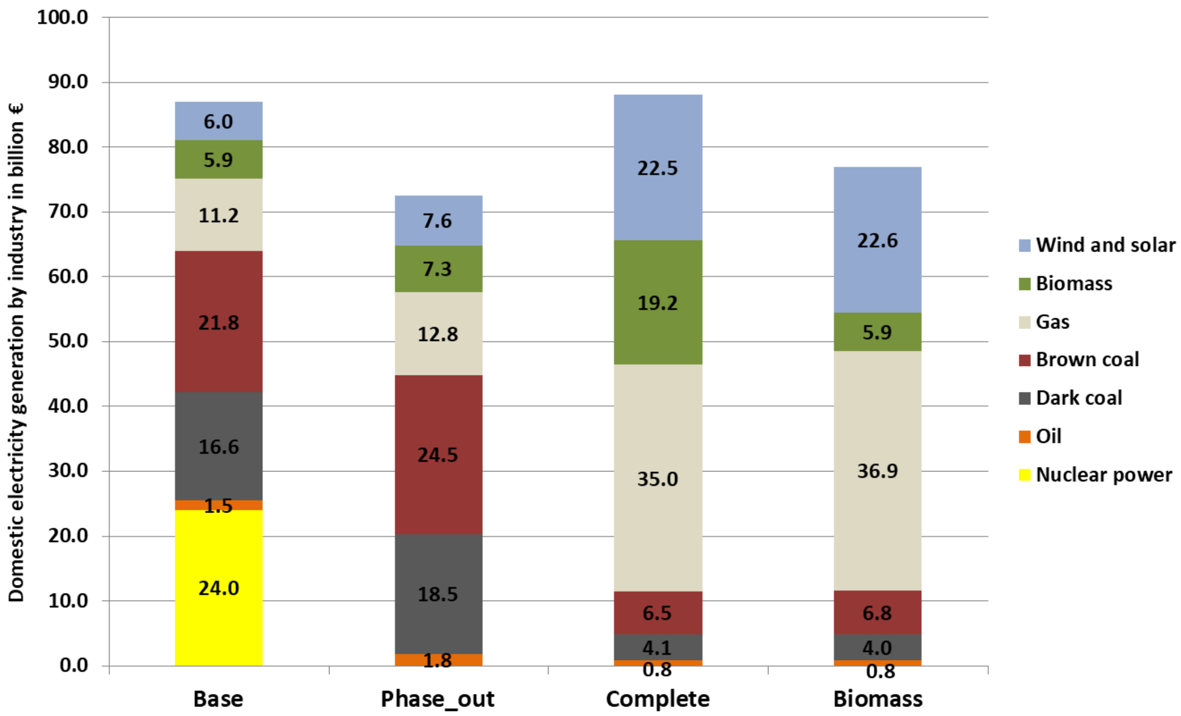
7.4.2.1 Domestic electricity generation

Figure 21 gives an overview of the domestic electricity generation by industries in the year 2007, the reference year, and the adjustments in the three scenarios expressed in monetary units. Referring to section 7.2, the changes in electricity generation presented here are also determined by the factor market closure rules implemented for the simulated model scenarios.

Altogether, two effects become apparent. The first effect is a change in the level of total of electricity generation; the second effect is a change in the composition of electricity supply by the generating industries. Both effects are now analysed in more detail.

In the base situation, the total value of generated electricity comprises 87.0 billion €. In scenario 'Phase_out', the nuclear phase-out has the effect of reducing total electricity generation to 72.5 billion €, which corresponds to a difference of -14.6 billion € compared to the initial situation. This value does not cover the whole value of nuclear power generation of 24.0 billion € as in the base. This means that the drop of nuclear power is partially compensated by other electricity generating industries. Brown coal compensates the highest part with an expansion of the production by 2.7 billion €, followed by dark coal with 1.8 billion €. Gas-based electricity generation expands by 1.6 billion €. But also renewable power plants increase their production by 1.6 billion € in the wind and solar industries and by 1.4 % in the generation of electricity based on biomass.

Figure 21: Domestic electricity generation by industries (in billion €)



Source: Own results

Electricity generation in scenario ‘Complete’ remains closely to the ‘base’ level with a value of 88.1 billion €. Due to technological advantages in terms of high flexibility to produce electricity in times of peak load (see section 6.7), the gas-based electricity generation is extended to the main pillar of fossil electricity generation with a value of 35.0 billion €. Wind and solar as well as biomass power plants increase electricity production by 22.5 billion € and 19.2 billion €, respectively.

Domestic production of brown coal-based electricity decreases in this scenario by -15.2 billion €. When implementing this scenario into the model, it was decided to reduce electricity generation based on brown coal and to increase gas-based electricity generation. This decision is contrary to the political objective of reducing the German import dependency on energy resource, as brown coal is a domestic resource and gas has to be imported (see section 6.6). Furthermore, gas power plants are characterised by high marginal costs (see section 6.7). Background, to decide for a decline of electricity generation based on brown coal, is the technological disadvantage of brown coal power plants in terms of their inflexibility to react to corresponding changes in electricity demand. Gas-fired power plants have the advantage of flexibility in this regard (see section 6.7). Furthermore, brown coal power plants are also large emitters of carbon dioxide. The operation of such power plants is therefore contrary to the political objective of reducing carbon emissions.

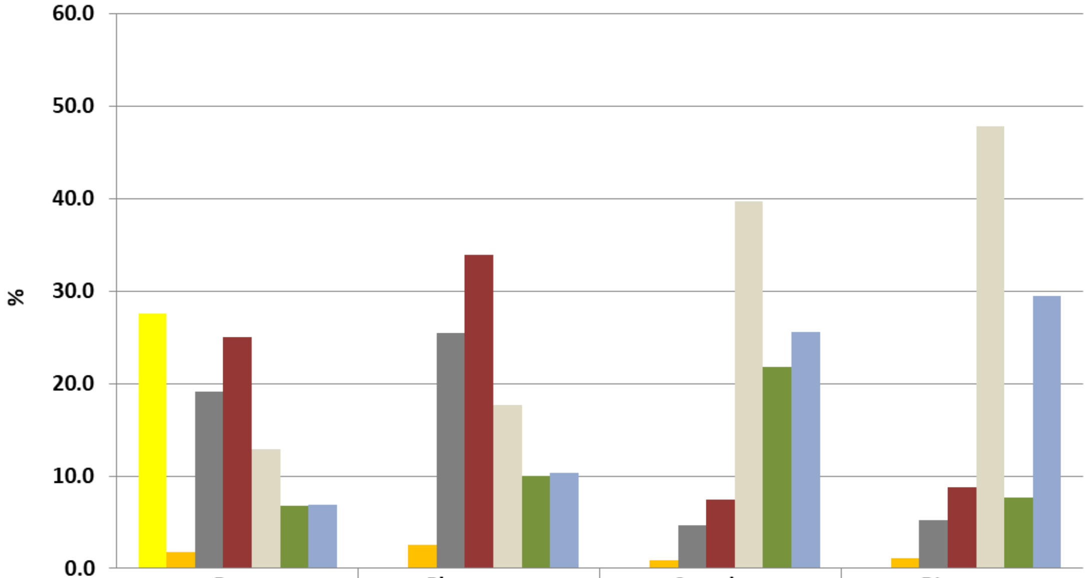
The same applies to electricity generation based on dark coal. In addition to ecological and technical disadvantages that correspond to those of brown coal, an important factor influencing the reduction of electricity generation based on dark coal is the abolition of dark coal subsidies for domestic extraction in 2018 (see section 6.2). The decline in dark coal subsidies will lead to a decline in the domestic competitiveness of this energy type compared to the domestic substitute brown coal and imported dark coal. Consequently, domestic dark coal extraction is expected to end in the year 2018 what may cause an increase of import demand for dark coal. For the simulation it is therefore decided to reduce the use of dark coal for electricity generation to 4.1 billion €.

Electricity generation based on oil remains at a low level and declines to an amount of 0.8 billion € to reduce the import dependence of fossil energy resources.

In scenario 'Biomass', total domestic electricity generation decreases to 77.0 billion €. In this scenario, all closure and simulation conditions are the same as in scenario 'Complete', with exception of electricity generation based on biomass. In order to assess the impact of biomass production for electricity generation in the agricultural sector, electricity generation based on biomass is here determined endogenously. As a result, electricity generation based on biomass declines and is generated by the same value as in the base situation of 5.9 billion €. Compared to scenario 'Complete', representing the reference scenario for scenario 'Biomass', the decline in electricity generation based on biomass is partly compensated by gas with an increase in production by 1.9 billion € and to a small extent by brown coal and renewable energies, wind and solar, with increases of 0.2 billion € and 0.1 billion €, respectively. Electricity generation based on dark coal declines by -0.1 billion €.

Changes in the composition of electricity generating industries determine the importance of the electricity produced by these industries. Figure 22 highlights these changes by recording the shares of electricity generation by industries in the base situation and the respective scenarios. The shares shown in the scenarios cannot be compared with the shares in the base situation, as the total supply of electricity changed in the scenarios like shown in Figure 21. But they are an indicator of the relevance of the various electricity providers in the particular situation that is captured in the scenarios.

Figure 22: Relative changes of electricity generation by industries (in percent)



	Base	Phase_out	Complete	Biomass
🟨 Nuclear power	27.6	0.0	0.0	0.0
🟧 Oil	1.8	2.5	0.9	1.1
⬛ Dark coal	19.1	25.5	4.6	5.2
🟥 Brown coal	25.0	33.9	7.4	8.8
⬜ Gas	12.9	17.7	39.7	47.8
🟩 Biomass	6.8	10.0	21.8	7.6
🟦 Wind and solar	6.9	10.4	25.6	29.4

Source: Own results

In 2007, the reference year, nuclear-based electricity generation is the most important source of electricity generation with a share of 27.6 % of total electricity generation. The conversion to electricity based on brown and dark coal comprises 25.0 % and 19.1 %, respectively. Together with gas and oil with a share of 12.9 % and 1.8 % respectively, the total nuclear- and fossil-based electricity generation covers 86.0 % of domestic electricity supply. Compared to today, electricity generation based on wind, solar and biomass was only slightly developed in 2007 (see section 6.4.1.1) and accounted for a total share of 13.7 %.

In scenario ‘Phase_out’, the nuclear phase-out causes the elimination of this energy source for electricity generation and thus, the loss of the most important pillar for electricity supply in Germany. Figure 22 shows that the nuclear phase-out causes an increasing importance of electricity generation based on coal. In the new situation, brown coal becomes the most important electricity supplier with a share of 33.9 %, followed by dark coal with a share of 25.5 %. Also, the role of gas and oil power plants increases, with shares of 17.7 % and 2.5 %, respectively. Nevertheless, in the complete picture the importance of fossil electricity on the total electricity supply decreases. Compared to the base situation, in which fossil and nuclear resources account for around 86.0 % of total electricity generation, the share of electricity based on fossil resources declines by around 6.0 % down to

80.0 %. Renewable energies are growing in importance, accounting for 20 % of the total electricity supply, while total electricity supply decreases.

In scenario 'Complete', the renewable energy sources wind, solar and biomass are the most important suppliers of electricity with a share of 47.4 %, followed by gas with 39.7 %. Overall, the German electricity supply system in this situation is based on renewables and gas, which together comprise 87.1 %. Brown and dark coals take together a share of 12.1 % and oil of 0.9 %.

The impact assessment of biomass-based electricity supply is the main concern of scenario 'Biomass'. The reduced importance of biomass in the electricity supply mix from 21.8 % in scenario 'Complete' down to 7.6 % in 'Biomass' causes an increasing importance of all other energy sources, but especially of gas. Gas-based electricity generation increases by 8.1 % up to a share of 47.8 %. The share of wind and solar energy increases by 3.8 % up to 29.4 %. Brown and dark coals account for 8.8 % and 5.2 %, respectively in this new equilibrium situation.

The impact of the changed input structure in the electricity sector on electricity prices and the domestic electricity demand are presented and analysed in the following section.

7.4.2.2 Impact on electricity prices and domestic electricity demand

Due to the drop of nuclear power and/ or the replacement of fossil by renewable energy sources, established and technically advanced technologies, such as nuclear power or coal power plants are replaced by new, less developed and thus more expensive technologies like electricity generation based on wind, solar or biomass but also gas. Furthermore, these new technologies require comprehensive investments, which additionally increase the cost of production and finally the price for electricity.

Moreover, established power plants such as nuclear and coal power plants are in most cases not completely depreciated because the 'normal' economic period for depreciation does not correspond to the politically decided shutdown (nuclear power plants) or capacity reduction (coal power plants) for these power plants. As a consequence, capital is fixed in these power plants and causes an increase in capital costs per unit of generated electricity.

The changing framework conditions in the electricity sector have impacts on the electricity price. Table 10 presents the relative changes in electricity prices and the impact on domestic electricity demand for the different scenarios. Overall, it becomes obvious that electricity prices in all scenarios increase and domestic electricity demand decreases.

In scenario 'Phase_out', the price for electricity rises by 18.5 % due to the reduction of electricity supply (see Figure 9) and the changed and more expensive resources used for the replacement of nuclear power (see Figure 22).

The highest increase in electricity prices can be observed under scenario 'Biomass' with a share of 24.2 %. The lowest increase of 10.6 % can be stated for scenario 'Complete', which is the reference scenario for 'Biomass'. Compared to scenario 'Complete', the lower use of biomass as input for electricity generation leads to an increase of the electricity price by 13.6 %. The reason for this price difference can be seen in the reduced total supply of electricity (see Figure 21) and the increasing production costs for electricity generation on the base of gas, which is characterised by high cost of production (see section 6.7) and the drop of electricity supply based on biomass.

Increasing prices for electricity influence the demand for this good, also presented in Table 13. The domestic electricity demand decreases in reverse order to the increase in electricity prices, i.e. the biggest decline of electricity demand by -24.4% can be observed for scenario 'Biomass' with the highest increase in electricity prices. In scenario 'Phase_out', the total domestic demand declines by -21.4 % and in scenario 'Complete' by -15.4 %.

Table 13: Relative change of electricity prices and domestic demand (in percent)

	Phase_out	Complete %	Biomass
Electricity price	18.5	10.6	24.2
Domestic electricity demand	-21.4	-15.4	-24.4

Source: Own results

A closer look at the various scenario results shows that there is no linear relationship between the increase in electricity prices and the decline in electricity demand. This means that it is not only electricity prices that determine the level of demand. Adjustments due to changing electricity prices are cross-sectoral and affect the entire economy with an impact on the electricity sector itself.
The impact of changing electricity prices on prices and production in other sectors as well as on prices and incomes of factors and the consumer behaviour of private households will be discussed in the next sections.

7.4.3 Cross-sectoral effects of the *Energiewende* in the economy

Electricity is used as an input for production processes in other sectors of the economy. Therefore, price changes for electricity lead to changes in the cost structure of the various sectoral production processes and ultimately to a change in overall electricity demand. In the scenarios, rising electricity prices lead to higher production costs in all sectors of the economy.

In addition to the use of electricity as a direct input, electricity is used for processing of intermediate goods, for example steel production, which is an input for the automotive industry. Along the entire value chain, the 'energy content' of intermediates increases the more the commodity is processed.

The longer the value chain of a product and the more processing steps were done, the more electricity is consumed. Therefore, the importance of higher electricity prices increases.

Activities are partly able to substitute electricity by capital or other energy inputs in the specific extent, which is limited by technical requirements. The possibility to substitute electricity and other energy inputs by capital is captured in STAGE_D by activity specific elasticities of substitution in the modified nested production function (see section 5.2 and 5.4).

In addition, the amount of electricity consumed directly in production processes influences the extent of the impact of increasing electricity prices in the different sectors. Energy-intensive activities, such as the agricultural sector or the heavy manufacturing, with a high share of electricity in their production processes, are more affected than less energy-intensive activities that are not as dependent on electricity for their production, i.e. the service sector.

Table 14 shows cross-sectoral production effects caused by the changes in the electricity sector on the production in the sectors: transport, construction, services, food industry, light and heavy manufacturing. A more detailed focus on the agricultural sector is given in section 7.4.8.

The results show that the increase in electricity prices in all scenarios leads to a decline in production in all sectors.

Table 14: Cross-sectoral production effects (in percent relative to the base)

	Phase_out	Complete	Biomass
		%	
Transport	-0.5	-1.3	-1.1
Construction	0.0	-0.9	-0.6
Services	-0.5	-1.4	-1.2
Food industry	-0.6	-1.5	-1.4
Heavy manufacturing	-1.4	-1.7	-2.1
Light manufacturing	-0.5	-1.1	-1.0

Source: Own results

The smallest percentage decline in production can be observed in scenario ‘Phase_out’, where production in the construction sector even remains unchanged. The largest decline in this scenario is recorded for the energy-intensive sector heavy manufacturing with a decline of -1.4%.

The decline in production is more significant in the scenarios ‘Complete’ and ‘Biomass’. Heavy manufacturing is also in these scenarios most affected. It is contained by a decline in production of -1.7 % and -2.1 %, followed by the food industry with a decline in production of -1.5 % in scenario ‘Complete’ and -1.4 % in scenario ‘Biomass’. The smallest effects can be observed in the construction sector, where production declines by -0.9 % and -0.6 % respectively.

Thus, the political objective of the *Energiewende* to secure the growth and competitiveness of German industry has not yet been achieved.

However, the increase in electricity prices is not the only influencing factor on cross-sectoral production decisions. Going back to Table 13, which shows the effects on electricity price, it becomes apparent that electricity prices increase by 18.5 % in scenario 'Phase_out', 10.6 % in scenario 'Complete' and by 24.2 % in scenario 'Biomass'. Normally, changes in domestic production would be expected to follow this order, but the cross-sectoral production effects in the scenario 'Complete' with the smallest increase in electricity prices are almost identical to the results of the scenario 'Biomass' with the highest increase. This means that the production decisions of the industries are influenced by further factors. A closer look at the changes in factor markets and household demand is necessary to explain the production decisions of the various sectors.

7.4.4 Effects on factor income and factor prices

In the previous analysis of developments in the electricity sector (see section 7.4.2) and the cross-sectoral adjustments (see section 7.4.3), it became obvious that the changes in the input structure for electricity generation resulted in increasing electricity prices. Higher prices for electricity cause higher cost production and result in a reduction of production level (see section 7.4.3). But it became also apparent that the reduced production not only depends on the increasing prices for electricity and intermediate inputs. The additional influencing factor can be found in the prices of production factors, the respective factor income and the behaviour of private households. A special focus on the drivers on the development of land, as a specific factor for agriculture, is given in section 7.4.8. Starting point here is the development of factor income.

Table 15: Relative change of factor income compared to the base situation (in percent)

	Phase_out	Complete	Biomass
		%	
Capital	-0.5	-2.0	-2.1
Labour	-0.9	-1.7	-1.8
Land	-0.7	-1.4	-1.5

Source: Own results

Table 15 presents the percentage changes in factor income for the considered three scenarios. Overall, the income declines for all factors in all scenarios. The lowest changes can be observed for scenario 'Phase_out' with a decline of capital income of -0.5 %, labour income of -0.9 % and income for land of -0.7 %. In the other two scenarios, the reduction effects on factor income are more significant, with a reduction of capital income by -2.0 % in scenario 'Complete' and -2.1 % in scenario 'Biomass'. Furthermore, in scenario 'Complete' the income for labour falls by -1.7 % and land income declines by -1.4 %. In scenario 'Biomass' labour income declines by -1.8 % and the income of land by -1.5 %. A classification of the impacts of the reduced factor income on households is given in section 7.4.5 in the context of the adaption reactions of households.

Before analysing the impact of the reduced factor incomes on private households, changes in factor prices are considered in more detail. Table 16 shows the percentage changes of factor prices. Overall, these changes correspond to the changes of factor incomes in the cases of labour and land, but capital represents an exception, which is discussed here in more detail.

In scenario 'Phase_out', the decline of factor prices by -0.5 % is equal to the reduction of the corresponding factor income as shown in Table 15. A different picture shows the factor income and price for scenario 'Complete' and 'Biomass'. In scenario 'Complete' factor income decreases by -2.0 % although the factor price increases by 0.7 %. Background to this contrary development is the high level of investments in renewable energies in the electricity sector to achieve the political objective to develop renewable energies as the main pillar for electricity generation but also the investments into the extension of gas power plants. These high investments increase capital demand and lead to higher capital prices. As a consequence, next to higher prices for the intermediate input electricity in scenario 'Complete' also the costs for the production factor capital increase.

This increase in capital cost also explains the non-linear modification of electricity demand on electricity prices shown in Table 13. Also, the high reduction of industrial production under scenario 'Complete' (see Table 14) is a consequence of the higher production costs due to higher electricity and capital prices. Furthermore, the reduced production in the various sectors is caused by a lower household demand as a consequence of a decreasing factor income.

Table 16: Relative change of factor prices compared to the base situation (in percent)

	Phase_out	**Complete** %	**Biomass**
Capital	-0.5	0.7	-0.2
Labour	-0.9	-1.7	-1.8
Land	-0.7	-1.4	-1.5

Source: Own results

In scenario 'Biomass', the price for capital declines by -0.2 % and capital income decreases by -2.1 %. Compared to scenario 'Complete', the lower level of biomass-based electricity generation causes a lower level of investments in this kind of electricity generation. Nevertheless, the composition of resources used for electricity generation in the electricity sector changed (see Figure 22) and causes higher electricity prices. Due to the higher production costs in the industries and the lower demand by private households, the prices for factors decline.

The impact of the reduced factor income on households is presented and analysed in more detail in the next section.

7.4.5 Impact on households

A decline in factor income has a direct impact on household income and their consumption behaviour. Table 17 shows the impact of the restructuring process in the electricity sector on income and consumption expenditure of private households.

The reduction in factor income, as shown in Table 15, leads to a decline of household income by -0.7 % in scenario 'Phase_out', which is the lowest reduction, by -1.6 % in scenario 'Complete' and -1.7 % in scenario 'Biomass'. As a consequence of the income reduction, households reduce their consumption expenditure. Here, the reduction of consumption expenditure correlates with the reduction of income. The higher the decline in income, the more extensive is the reduction of consumption expenditure. The lowest income reduction in scenario 'Phase_out' results in the lowest reduction of consumption expenditure by -0.8 %. The largest reduction of income causes the largest decline in consumption expenditure in scenario 'Biomass' by -1.8 %.

Table 17: Impact on private households' income and expenditure (in percent relative to the base)

	Phase_out	Complete %	Biomass
Household income	-0.7	-1.6	-1.7
Consumption expenditure	-0.8	-1.8	-1.8
Electricity consumption	-14.9	-10.3	-19.3

Source: Own results

At this point, the circular flow (see section 2.3.1) and the interrelation between the actors in the German economy become obvious and show the advantages of economic analysis using a CGE model. Going back to the cross-sectoral production effects as presented in Table 14 it becomes apparent that the increase of electricity prices causes an increase of production costs in other industries. Additionally, in scenario 'Complete', higher investment in the expansion of renewable energy sources for electricity generation increases the capital price (Table 16).

What is not shown in the results, because STAGE_D is a comparative-static model, but helps to understand the adjustment processes in an economy between the 'old' equilibrium and the situation in the 'new' equilibrium: Higher cost of production meanwhile cause higher prices for the produced goods and services by the industry. As a result, private household demand for the more expensive goods and services declines, reflected by the lower consumption expenditure of households, as shown in Table 17. This decline in consumption expenditure has a feedback effect on the industries that reduce their production due to the decline in private demand. This reduced private demand leads to a decline in prices for goods and services but furthermore a decline in the demand for production factors with the result that factor income also goes down (see Table 15). Consequently, lower factor income has a direct impact on the income of households that reduce their consumption. This decrease in demand has again negative consequences on the production of industries that reduce their production with the result of a slightly shrinking of the overall economic performance. The consequence of this adjustment process is a decline in economic growth as indicated in the reduction of GDP (see Figure 20).

But not only private households are affected by the restructuring process in the electricity sector due to their declining income. Households are also consumers of electricity and therefore directly affected by increasing electricity prices. In response to increasing electricity prices, the consumption level of this good decreases.

Table 17 presents the decline in electricity consumption by households. The biggest increase of electricity prices (see Table 13) in scenario 'Biomass' causes the highest decline in electricity consumption by -19.3 %. The lowest reduction in electricity use can be observed in scenario 'Complete' that is also characterised by the smallest increase of electricity prices.

Summarised, it can be stated that households are double burdened by the implementation of the *Energiewende*. They are directly concerned by paying higher prices for electricity and capital (scenario 'Complete') but furthermore, private households also receive a lower income. As presented in section 6.8, households have to pay higher prices for electricity than industry anyway due to higher taxes and levies. The German governments' objective of securing economic growth, strengthening the competiveness of the German economy and guaranteeing reasonable consumer prices for energy is therefore not achieved.

7.4.6 Trade effects

7.4.6.1 Imports and exports of electricity and energy resources

Germany, characterised as a country poor in resources, strongly depends on imports of energy commodities (see section 6.6). Changes in the domestic electricity generation and increasing prices for electricity, combined with changed composition of energy resources for electricity generation (see section 7.4.2), have significant impacts on international electricity trade as well as on trade with the relevant energy resources to produce electricity. In addition, the overall economic development is driving the demand for energy resources and hence, trade developments.

Table 18 shows the impact of the *Energiewende* on international electricity trading and trading with relevant energy resources for electricity generation in Germany. Due to the technological framework conditions of the European electricity market (see section 6.7), Germany receives and delivers electricity into this European grid in order to ensure a sufficient voltage in phases of volatile demand for electricity. Since 2007, Germany is an exporter of electricity (see section 6.9).

Table 18: Trade effects on energy commodities (in percent relative to the base)

	Phase_out	Complete	Biomass	Phase_out	Complete	Biomass
		Imports			Exports	
			%			
Electricity	-0.2	-2.4	2.7	-52.1	-37.0	-59.9
Dark coal	-10.3	-9.9	-15.8	-3.4	-4.3	-5.4
Crude oil	-4.5	0.0	-1.4	-0.7	-0.6	-0.7
Natural gas	-5.5	9.0	6.6	-0.9	-0.7	-0.8

Source: Own results

The scenario results for electricity trade show that this situation changes under the scenario 'Biomass'. The lower domestic electricity demand (see Table 13) and electricity generation (see Figure 21) cause a decline in electricity exports by -59.9 %. High domestic electricity prices (see Table 13) result in an increase in electricity imports by 2.7 % as a consequence of the relative lower electricity price abroad Germany.

Comparing the two scenarios 'Complete' and 'Biomass', imports and exports of electricity decline by -2.4 % and -37.0 %, respectively. Compared to scenario 'Biomass', the trade effects are less distinctive, due to the lower increase in electricity prices and the smaller decline in domestic demand (see Table 13). As a consequence, a reduced use of biomass for electricity generation, as shown in scenario 'Biomass', causes higher trade effects and shifts the German trade position from a net exporter to a net importer of electricity.

Due to the phase-out of nuclear power and the associated decline in electricity generation (see Figure 21), exports in scenario 'Phase_out' decline by -52.1 %. The lower demand for electricity driven by increasing electricity prices (see Table 13) and an overall shrinking economy lead to a decline in electricity imports of -0.2 %.

Changes in the composition of energy resources for electricity generation, as shown in Figure 22, and the resulting higher prices for electricity and capital in scenario 'Complete' have also an impact on trade with other energy commodities.

Therefore, Table 18 also presents the relative changes of imports and exports of dark coal, crude oil and natural gas. Due to high transport costs, there is hardly any significant international trade of brown coal (see Figure 15). The trade effects under scenario 'Phase_out' show that the decrease in total electricity generation and the lower demand for electricity lead to decline in imports of all energy commodities. The strongest decline can be observed for dark coal by -10.3 %. Exports are reduced on a low level with reductions of -3.4 % for dark coal and -0.9 % for natural gas.

Scenario ‘Complete’ shows an increase of natural gas imports by 9.0 %, as a consequence of the conversion of the electricity supply system with gas as the most important fossil cornerstone. The import of crude oil remains unchanged. Imports of dark coal decline as a result of the reduced use for electricity generation due to political efforts to reduce the import demand for energy resources. But also the technological disadvantages regarding the inflexibility of coal-fired power plants and the high carbon emissions of this resource cause a decline in domestic demand.

The effect of a lower use of biomass and the resulting decline in the total electricity supply due to higher electricity prices and lower total domestic demand cause a decline in imports in scenario ‘Biomass’. Imports of dark coal are reduced by -15.8 % and those of crude oil by -1.4 %. Natural gas imports are lower than in the reference scenario ‘Complete’ but still cover an increase by 6.6 % as a consequence that natural gas was assumed to become the most important fossil energy source for electricity generation.

7.4.6.2 Impact on trade in other sectors of the economy

Table 19 presents the trade effects on goods and services produced by other sectors of the economy due to the politically initiated restructuring process in the electricity sector. Higher production costs as a result of higher electricity prices (see Table 13) and prices for intermediate inputs but also the increase of capital prices (scenario ‘Complete’) cause higher prices for the domestically produced goods and services. Consequently, a higher import demand for foreign products and services would be expected, because of the relative lower prices for imports.

But the increase in prices for domestically produced goods and services causes a decline of the consumption of households and in consequence a drop in the domestic production of goods and services and a reduced economic growth (see Figure 20). These impacts cause a decline of imports and exports of domestically produced goods and services.

The extent of the different trade effects between the scenarios is a combination of the amount of the price increase for electricity and capital, the decline of domestic production of goods and services and the reduction of domestic demand as a consequence of the reduced consumption expenditure of households.

In scenario ‘Phase_out’, factor and household income show the lowest decline compared to the other two scenarios, with consequence that the consumption of households also shows the lowest decline. Therefore, the reduction of imports remains under 1 % for all goods and services. The decrease of exports is caused by the increasing costs of production of domestic industries because of higher electricity prices and the resulting decline of domestic demand. This becomes apparent by the consideration of commodities of the heavy manufacturing whose production is energy intensive. One exception are services that are exported by an increase of 0.2 %. The provision of services is characterised by a high share of the factor labour. Because of the decline in the labour price (see Table 15), the price for domestic services is lower than the price for foreign services and causes therefore increasing exports.

The restructuring process of the electricity sector by making renewable energies to the main energy source in the electricity sector, as captured in scenario ‘Complete’, causes the lowest increase of electricity prices (see Table 14). But high investments in upgrading renewable power plants (see Table 16) lead to an increase of capital prices and the cost of production of the domestic industries. The resulting reduction of factor and household income and the consequent drop of domestic demand cause a decline in domestic production (see Table 14) and imports. In this scenario, the reduction of imports is therefore primarily driven by the reduction of domestic demand, as a consequence of a higher price for capital than for electricity. The decline in import demands for all goods and services and comprises amounts between -1.4 % for construction and heavy manufacturing commodities with the lowest decline and -1.7 % for light manufacturing commodities with the highest decline. Exports are reduced as a consequence of the increase of the relative domestic prices caused by the price of capital and electricity in relation to foreign prices but also due to the decline of domestic production. The highest decline in exports can be observed for construction commodities with a decline by -1.8 % and the lowest decline in light manufacturing with a decline by -1.0 %.

Table 19: Trade effects on goods and services in other sectors of the economy (in percent relative to the base)

	Phase_out	Complete	Biomass	Phase_out	Complete	Biomass
		Imports			Exports	
			%			
Transport	-0.9	-1.6	-1.7	-0.5	-1.5	-1.2
Construction	-0.7	-1.4	-1.6	-0.6	-1.8	-1.4
Services	-0.8	-1.6	-1.6	0.2	-1.2	-0.3
Food industry	-0.6	-1.6	-1.5	-0.6	-1.4	-1.3
Heavy manufacturing	-0.7	-1.4	-1.3	-1.5	-1.7	-2.2
Light manufacturing	-0.8	-1.7	-1.6	-0.5	-1.0	-0.9

Source: Own results

Biomass-based electricity generation also has an impact on trade. The reduction of electricity generation based on biomass, in scenario ‘Biomass’, causes the highest increase of electricity prices (see Table 13) whose effects on trade become apparent by the comparison of the results of scenario ‘Complete’ and ‘Biomass’.

Due to a lower investment demand for biomass power plants in scenario ‘Biomass’, the price for capital decreases compared to scenario ‘Complete’ (see Table 16). The reduction of the domestic consumption expenditure of households is reduced by the same share of -1.8 % for both scenarios (see Table 17). Therefore the reduction of imports is caused by the reduction of domestic demand as a consequence of a reduced factor income and household demand. The decline in exports is primarily caused by an increase of electricity prices. It can be seen that especially products using a high share of electricity in their production process, e.g. heavy manufacturing with a decline of -2.2 %, are less exported. Therefore, the higher cost of production caused by higher electricity prices leads to a decline of exports because domestically produced goods and services become relatively more expensive. However, also the decline of domestic production causes the decline of exports in scenario 'Biomass'.

The results show that the transformation process in the electricity sector has negative impact on international trade. The higher costs of production due to increasing electricity prices (scenarios 'Phase_out' and 'Biomass') and/or of capital due to the high capital commitment for the development of renewable energy and gas power plants in the electricity sector (scenario 'Complete') increase the cost of production for domestically produced goods and services. As a consequence, domestically produced goods and services become more expensive and exports decline. Furthermore, higher prices for electricity cause a decline of household consumption expenditure, which meanwhile should increase imports, because foreign goods and services become relatively cheaper. But due to the lower demand for domestically produced goods and services, domestic production and household income decline. As a consequence of a shrinking economy, total import demand also declines. As a result, the decline in GDP as an indicator of economic growth and the decrease of imports and exports show that the German economy is losing its international competitiveness.

7.4.7 Impact of the *Energiewende* on carbon dioxide emissions

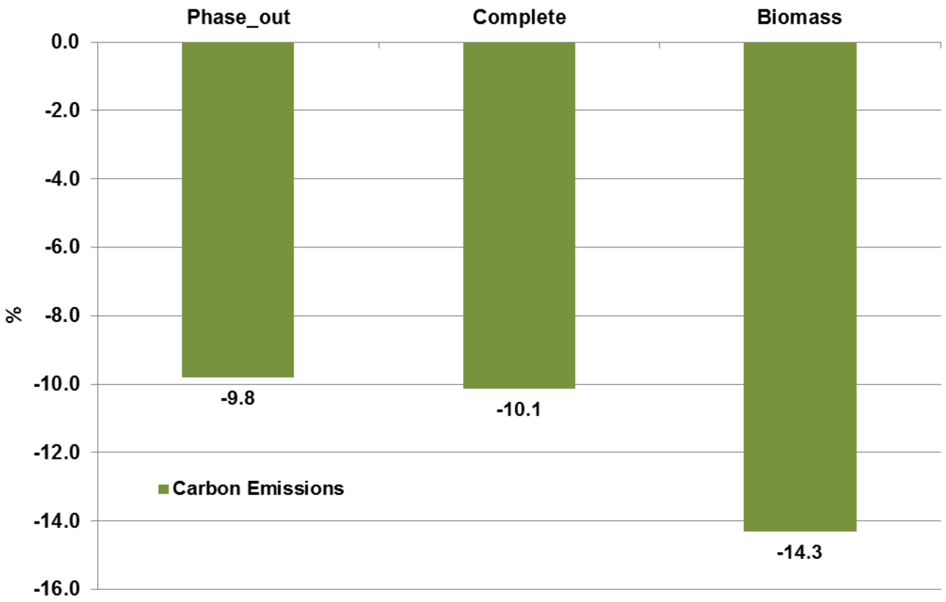
One objective of the *Energiewende* is the reduction of greenhouse gas emissions in Germany by -55 % in 2030. This section focusses on the changes in carbon emissions as a consequence of the nuclear phase-out, the implementation of the objectives of the *Energiewende* in the electricity sector and the role of biomass.

Figure 23 presents the percentage changes of carbon dioxide emission in the different scenarios. Generally, the objective of reducing carbon emissions has been achieved in all scenarios but on a different scale and under the acceptance of a reduced economic growth. The lowest reduction of carbon emissions is obtained by phasing out nuclear energy in scenario 'Phase_out' with a decline of -9.8 %. The complete implication of the *Energiewende* in scenario 'Complete' causes a decrease by -10.1 %. The highest share of reduction can be observed for scenario 'Biomass' with a decline by

-14.3 %. The influencing factors that cause these different reduction rates will be discussed in this section in more detail.

Nuclear power-based electricity generation is a low emitter of carbon dioxide. Therefore, the phase-out of nuclear power itself has no relevant impact on the amount of carbon emissions. The reduction of carbon emissions in scenario 'Phase_out' is a consequence of lower household consumption and the reduction of industrial production in Germany. The starting point for this development is the change in the cost structure in the electricity sector in order to replace nuclear power by other, predominantly fossil, energy sources (see Figure 21) that usually should increase carbon emissions. But, the increasing cost of production for electricity generation to replace nuclear power and the lower supply of electricity due to the phase-out cause higher electricity prices. These higher prices (see Table 13) cause higher costs for intermediate inputs and electricity in industrial production (see section 7.4.3), which were directly passed to final consumers, e.g. households. As a consequence of lower factor income, consumption expenditure of households decreases and causes lower demand for goods and services, what finally cause a decline of production in the industries and the negative development of GDP. Therefore, the reduction of carbon emissions in scenario 'Phase_out' is a consequence of a reduction of economic performance due to higher electricity prices.

Figure 23: Impact on the emissions of carbon dioxide (in percent)



Source: Own results

Interesting is the comparison of the development of carbon emissions between the scenarios 'Complete' and 'Biomass'. For scenario 'Biomass', it is expected that a lower use of biomass as renewable energy source would lead to a lower reduction of carbon emissions compared to scenario 'Complete', but the reduction is higher.

Looking at the development of the GDP, it becomes apparent that the reduction of GDP comprises almost the same amount for scenario 'Complete' with a decline by -1.75 % and -1.80 % for scenario 'Biomass'. This means that both scenarios are characterised by a shrinking economic performance and a lower domestic production. The differences between the two scenarios are related to the impact that causes the reduction in GDP and finally the different reduction of carbon emissions. Looking at the development of electricity prices, the main relevant difference between the two scenarios becomes obvious. While the electricity prices increase by 24.2 % in scenario 'Biomass', the growth of electricity prices in scenario 'Complete' is considerably lower with an increase by 10.6 % only. Here, the higher electricity prices in scenario 'Biomass' cause a lower domestic demand for electricity with a reduction of domestic demand by -24.4 % compared to -15.4 % in scenario 'Complete'. The higher reduction of electricity demand is a consequence of higher electricity prices, which is also a determining factor of the higher decline of carbon emissions, as projected in scenario 'Biomass'.

Another determining factor is the development of capital prices. In scenario 'Complete', the price for capital increases due to the capital commitment in the expansion of renewable energies. Therefore, the decline in GDP in scenario 'Complete' is more driven by higher capital costs than higher electricity prices. Finally, the lower reduction of electricity demand compared to scenario 'Biomass' explains the lower reduction of carbon emissions in scenario 'Complete'.

Summarised can be noted, that the objective of reducing carbon emissions was achieved in all scenarios but at the expense of the competitiveness of the German economy and higher electricity prices for consumers.

7.4.8 Impact on the agricultural sector

The agricultural sector plays a special role in the framework of the implementation of the *Energiewende*. Traditionally, agricultural commodities are used to produce food and feed. Due to technological developments and the governmental support to use agricultural crop and livestock commodities for energy generation under the framework of the EEG, this traditional use spectrum has been expanded by the generation of biogas for electricity generation (see section 6.4.1.1).

Forestry and agriculture are the only two sectors that require large areas of land as production factor, which is mainly sector specific. As a consequence of the enhanced demand for agricultural products for biogas production, competition for production factors and in particular for the factor land has intensified over the last years with increasing land prices (Federal Statistical Office 2015). Furthermore, competition between the various possibilities of use (feed, food, energy) of agricultural commodities increased.

Another characteristic of the agricultural sector is the high energy demand in crop and livestock production processes (see Figure 13). On the one hand, these production processes directly have a high demand for energy. On the other hand, agriculture uses intermediate inputs that are produced in energy intensive production processes such as the production of agricultural machinery, fertilisers or feed products.

Compared to wind and solar energy, which represent together with biomass the most important resources for electricity generation, the generation of biomass is confronted with an increasing competition for production factors and alternative final uses of the produced goods. As a consequence, the provision of biomass generates higher costs of production compared to wind and solar, which are - apart from initial investments - available as natural resources with very low marginal costs for provision. But while wind and solar energy depend on weather conditions, biomass has the advantage of a secured and continuous provision through the possibility of storing biomass and continuous production of biogas and electricity.

This section focusses on the impacts of the *Energiewende* on the agricultural sector, by analysing the effects on agricultural production and prices in section 7.4.8.1 and on international trade with agricultural commodities in section 7.4.8.2.

7.4.8.1 Impact of the *Energiewende* on agricultural production and prices

Table 20 presents production and price effects of the restructuring process of the electricity sector on the agricultural sector. It becomes apparent that the *Energiewende* causes a reduction of production and prices in all scenarios for almost all commodities.

The lowest decline in production can be observed in scenario 'Phase_out' with a decrease of agricultural commodity production between -0.3 % and -0.5 %. Prices for agricultural commodities decline between -0.1 % and -0.3 %. Higher impacts of production and prices changes can be observed in scenario 'Complete' with production changes between zero and -1.6 % and price changes between 2.1 % and -0.7 %. The lower use of biomass for electricity generation provokes a reduction of the production of agricultural commodities between -1.4 % and -0.9 % and price changes between zero and -0.7 % in scenario 'Biomass'.

Although being a supplier of electricity, the agricultural sector is negatively affected by the *Energiewende*, because prices and production of almost all agricultural commodities decrease in the scenarios. One exception is the scenario 'Complete'. Here, the price for 'other crops' increases by 2.1 % and the price for maize remains on the same level. The aggregate 'other crops' includes crops used for grass silage and whole plant silage, which represent two of the main plant substrates for biogas generation (see section 6.4.1.1). The prices of these agricultural products increase due to the higher input demand in biogas production.

Table 20: Production and price changes of agricultural commodities (in percent relative to the base)

	Phase_out	Complete	Biomass	Phase_out	Complete	Biomass
			%			
	Crop Production			Crop Prices		
Wheat	-0.4	-1.2	-1.1	-0.3	-0.4	-0.4
Barley	-0.4	-1.4	-1.2	-0.2	-0.3	-0.3
Rye	-0.4	-1.1	-1.0	-0.3	-0.5	-0.5
Maize	-0.5	-1.6	-1.4	-0.2	0.0	-0.1
Beet	-0.4	-1.4	-1.3	-0.2	-0.4	-0.3
Oilseeds	-0.3	-0.9	-0.9	-0.3	-0.7	-0.7
Vegetables and Fruit	-0.4	-1.3	-1.3	-0.2	-0.3	-0.2
other Crops	-0.3	0.0	-1.1	-0.1	2.1	0.0
other Grain	-0.4	-1.4	-1.2	-0.2	-0.3	-0.3
	Livestock Production			Livestock Prices		
Cattle	-0.5	-1.6	-1.4	-0.2	0.0	-0.1
Milk	-0.4	-1.4	-1.2	-0.2	-0.2	-0.3
Pig	-0.5	-1.6	-1.4	-0.2	0.0	-0.1
Poultry	-0.4	-1.4	-1.2	-0.2	-0.3	-0.3
other Animals	-0.4	-1.2	-1.2	-0.2	-0.4	-0.3

Source: Own results

The main crop used for biogas generation is maize. Next to the use of maize as substrate, maize is used as feed crop in cattle and dairy production. Because the production of cattle and milk decreases by -1.6 % and -1.4 %, the demand for maize as feedstuff declines but increases for the use as substrate in biogas generation. Both effects are balancing each other in this scenario and prices remain almost unchanged.

A similar effect becomes apparent in livestock production. Prices for cattle and pig production remain unchanged. Cattle and pig slurry used as substrate for biogas generation are by-products of beef and pig production. Often farms with livestock production are also running biogas plants. The higher electricity price therefore partly compensates the declining prices for cattle and pigs.

Nevertheless, a reduction of agricultural production and prices in all scenarios can be observed with a different extent. The fall in production and prices is generally caused by the same effects as in the other sectors in the economy (see Table 14) and can be traced back to higher prices for electricity, which directly increase production costs of agricultural commodities. Furthermore, higher electricity prices cause an increase of prices for intermediate inputs, like feed or fertilisers, whose production requires high energy input. In addition to the input side, the use of agricultural commodities decreases as consequence of a lower household demand (see Table 17). Background of this lower demand by households is the decline of factor income (see Table 15) due to lower production in the

whole economy (see Table 14). Of particular importance for the agricultural sector is the development in the food industry, which represents the most important purchaser of agricultural commodities as intermediate inputs for further processing into food and feed (see Table 14).
As private households receive a lower income as a consequence of a lower factor income, their consumption expenditure declines and this also comprises their consumption expenditure for food products.

Next to higher electricity prices and the lower domestic demand for food and feed, the increase of capital prices in scenario 'Complete' is an important driver for the decline of production and prices of agricultural commodities. Agricultural production is capital intensive. Crop production is characterised by high investments in machinery and storage facilities for crops. Livestock production requires investments in stables and silos. Additionally, the construction of biogas plants involves comprehensive investments. The increase of capital prices in scenario 'Complete' is driven by a high investment demand to expand capacities to produce renewable energies, e.g. biogas.

From the agricultural perspective, therefore, the implementation of the *Energiewende* and the expansion of investments in biogas plants are a boon and bane at the same time. Biogas production partly absorbs increasing electricity costs, but causes higher costs for capital due to higher investments. In consequence, only the production of some commodities is positively affected. The negative impact of higher capital and energy costs causes a decline in the production level and prices of almost all agricultural products.

The development of agricultural production with a decline in livestock and crop production as well as a drop in agricultural producer prices in all scenarios explains the reduction of land prices and land income, presented in section 7.4.4. Land prices and income decline by -0.7 % in scenario 'Phase_out', by -1.4 % in scenario 'Complete' and by -1.5 % in scenario 'Biomass'. Here, the lower demand of the food and feed industry for agricultural commodities as a result of the lower household income and consumption also contributes to the reduced prices and income for land. Even the higher demand for biomass for electricity generation could not fully compensate this decline in demand and the resulting negative impact on price and income for land.

Altogether, due to the only small contribution of the German agricultural sector to overall GDP of 0.7 % in total GDP in 2007 (Statista 2017), the expected increase of competition between production factors and/or the alternative use of agricultural commodities does not take place. The overall impact of the *Energiewende* indeed causes a higher demand for biogas for electricity generation but a reduced demand for agricultural commodities for feed and food production. The lower household demand predominates and causes a decline of agricultural production and prices for crop and livestock commodities.

Impact on regional level

The implementation of agricultural activities on the base of the federal states (*Bundesländer*) in STAGE_D (see section 4.4.2) allows an analysis of the impact of the *Energiewende* on the agricultural sector on a regional level, too. Table 21 presents the relative production changes per region in the particular scenarios. It becomes apparent that agricultural production is affected differently in the federal states.

In scenario 'Phase_out', the production in almost all regions decreases between -0.9 % or -0.1 % or remains on the same level due to the lower demand for agricultural crop or livestock commodities. In this scenario, the higher prices for electricity and the lower domestic demand of households for food products are responsible for this decline.

Interesting are the regional production effects in scenario 'Complete'. In this scenario, biomass-based electricity generation is extended to a share of 21.8 % on total electricity generation in Germany. Here, the adaption of agricultural production is different between the federal states. It becomes apparent that some regions extent their production, like Rhineland-Palatinate or Saxony by 2.8 % or 0.3 %, respectively, and production is reduced in other regions, like North Rhine-Westphalia or Bavaria by -2.1 % or -2.6 %.

Table 21: Relative production changes in the federal states of Germany (in percent)

	Phase_out	Complete	Biomass
		%	
Bavaria	-0.7	-2.6	-2.0
Brandenburg	0.0	0.0	-0.1
Baden-Württemberg	-0.4	-1.1	-1.3
Hesse	-0.6	-2.3	-1.7
Mecklenburg-Western Pomerania	-0.2	-0.5	-0.6
North Rhine-Westphalia	-0.6	-2.1	-1.7
Lower Saxony	-0.5	-1.7	-1.4
Rhineland-Palatinate	0.0	2.8	-0.7
Schleswig-Holstein	-0.4	-2.0	-1.4
Saarland	-0.9	-1.8	-1.2
Saxony	-0.1	0.3	0.0
Saxony-Anhalt	-0.2	-0.5	-0.4
Thuringia	0.0	0.3	0.2

Source: Own results

The differences in the change of production depend on the particular production structure of the region. Federal states characterised by a comprehensive livestock but also biogas production, i.e. Schleswig-Holstein, North Rhine-Westphalia, Lower-Saxony or Bavaria are more concerned than regions characterised by crop production, i.e. Brandenburg, Thuringia or Saxony.

The decline of production in regions with comprehensive livestock farming can be traced back on increasing cost for capital due to investments in the expansion of renewable resource based power plants including biogas power plants. Additionally, the decrease of household income causes a lower demand for food products and therefore a lower demand for agricultural products by the food industry. Together both effects cause this higher decline in agricultural production in these regions compared to regions with low livestock production.

Regions characterised by crop production even benefit from the increasing demand for crops used as substrates for biogas generation and increase their production. Because land is immobile and restricted, crop based substrates used for biogas generation cannot be produced in a necessary amount in regions where the biogas plant is running. Therefore crop based substrates are `traded' between the regions in this scenario. Furthermore the relative decline in livestock production due to the lower domestic demand reduces the availability of livestock based substrates and additionally increases crop production in other regions to replace these substrates.

In scenario 'Biomass', electricity generation based on biomass is lower compared to scenario 'Complete' and comprises a share of 7.6 % on total domestic electricity generation. In this scenario, the impact of a higher demand for crop based substrates is less important and a decline of production in these regions becomes obvious. Rather the higher price for electricity becomes relevant. Especially regions characterised by energy intensive livestock production are more concerned and reduce their production. Additionally, the decline of household demand for food products causes a decline of agricultural production in all federal states compared to scenario 'Complete'.

7.4.8.2 Impact on agricultural trade

Changes of the domestic production and prices for agricultural commodities have also an impact on international trade.

Table 22 presents the trade effects of the most important crop and livestock commodities. Overall, agricultural imports and exports decline in all scenarios, although the prices for domestically produced commodities decrease and these commodities should become relatively cheaper compared to foreign produced commodities. The influencing factors driving this development will be described and explained in this section.

Table 22: Change in trade of agricultural commodities (in percent relative to the base)

	Phase_out	Complete	Biomass	Phase_out	Complete	Biomass
	%					
	Import Crops			Export Crops		
Wheat	-0.6	-1.7	-1.5	-0.2	-0.8	-0.8
Barley	-0.6	-1.6	-1.4	-0.3	-1.2	-1.1
Rye	-0.6	-1.8	-1.5	-0.2	-0.7	-0.6
Oilseeds	-0.7	-1.9	-1.6	-0.1	-0.2	-0.3
Vegetables and fruit	-0.6	-1.6	-1.3	-0.4	-1.1	-1.4
	Import Livestock			Export Livestock		
Cattle	-0.5	-1.4	-1.3	-0.4	-1.8	-1.5
Pig	-0.5	-1.4	-1.3	-0.5	-1.8	-1.5
Poultry	-0.6	-1.6	-1.4	-0.3	-1.2	-1.1

Source: Own results

The lowest trade effects can be observed in scenario 'Phase_out' with a decline of imports of crop and livestock products between -0.5 % for cattle and pigs and -0.7 % for oilseeds. The reduction of exports is a range between -0.1 % for oilseeds and -0.5 % for pigs. Here, the impact of increased prices for electricity (see Table 13) becomes obvious. Higher electricity prices increase the cost of production for agricultural commodities. The prices for agricultural commodities decrease due to a lower demand of households for food products and a lower demand of the agricultural sector for feed products because livestock production also declines. As a consequence, the imports of agricultural commodities decrease due to a lower domestic demand of the food industry because of a lower household demand. Exports decrease due to higher costs of production for agricultural commodities but especially due to the decrease of domestic agricultural production and therefore at all (see Table 20).

The increase of renewable energies in the electricity sector captured in scenario 'Complete', causes higher impacts on trade with agricultural commodities compared to the nuclear 'Phase_out' scenario. Imports of crop and livestock commodities decrease between -1.4 % for cattle and pigs and -1.9 % for oilseeds. On the export side, especially the trade with animals is affected with reductions between of -1.8 % for cattle and pigs and -1.2 % for poultry.

Altogether, the analysed scenarios indicate a decrease of domestic production for all agricultural commodities, except those used for biogas generation (see Table 20). But, especially livestock production is affected, because of higher prices for electricity and capital. Livestock production in Germany is characterised as energy and capital intensive, due to high investments in equipment and stables but also due to investments in stock of animal. Therefore, the increase of prices for electricity and especially for capital causes the decline of domestic production and of exports of animals in scenario 'Complete'.

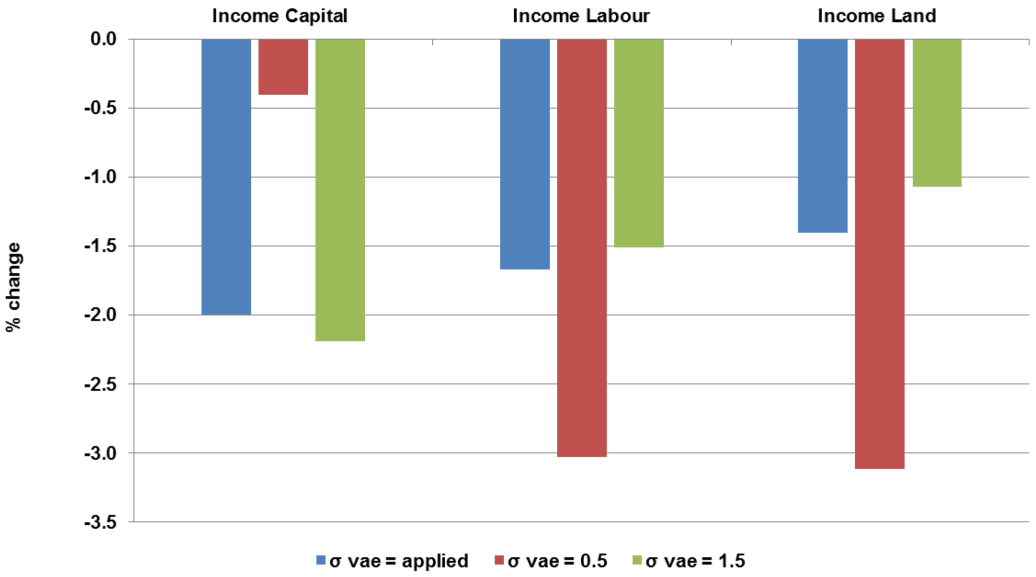
Compared to scenario 'Complete', the lower use of biomass, shown in scenario 'Biomass' causes lower reductions in trade with agricultural commodities compared to scenario 'Complete'. In this scenario, especially the increase of electricity prices causes higher cost of production for agricultural commodities and therefore a decline in the domestic agricultural production. Especially concerned are commodities, which require a high electricity use for their production like vegetables and fruits, cattle or pigs. Export of these commodities decline by -1.4 % and -1.5 %, respectively. Imports of agricultural commodities decline, like in the other scenarios, due to lower domestic demand because of lower consumption expenditures of households.

7.5 Sensitivity Analysis

As mentioned by Pyatt (1988), elasticities applied in a GCE model can be regarded as one of the weaknesses of CGE models, because they comprise information from outside the SAM framework. This section presents selected results of the sensitivity analysis done for the scenario 'Complete' to show the sensitivity of STAGE_D with regard to the applied elasticities. The sensitivity analysis was conducted by comparing the model results based on the applied elasticity with two additional elasticity values: one low value and one high value. The results of the sensitivity analysis presented in this section comprise the elasticity of substitution of the value added-energy aggregate (σ_{vae}), the energy aggregate (σ_{ve}) and the Armington import elasticity (σ).

Figure 24 presents the results of the sensitivity analysis applied for the elasticity of substitution of the value added energy-aggregate (σ_{vae}).

Figure 24: Sensitivity analysis: Impact of the elasticity of substitution of the value added-energy aggregate on factor income (in percent)



Source: Own results

Here, the percentage changes of factor income caused by the implementation of a high value for σ_{vae} (1.5) and a low value (0.5), as well as the applied value of σ_{vae} are shown. The results indicate that the model reacts sensitive to this elasticity. The income of capital decreases in a smaller share under low elasticity values than the income of labour and land. Because especially the factor income and the resulting household income have a strong impact on the adjustment reaction of the whole economy, the value of this elasticity influences the model results. The value chosen for this analysis implies relatively equal percentage adaptions of factor income for land, capital and labour.

The second sensitivity analysis considers the impacts of the value of the elasticity of substitution of the energy aggregate (σ_{ve}) on electricity prices. This elasticity determines the substitution of energy commodities used to produce the activity output. The results of the sensitivity analysis show that this elasticity has an impact on model results. The lower the elasticity of substitution, the less is the possibility of activities to substitute energy commodities by each other. As a consequence, a low value of elasticity of substitution of 0.2 causes a higher relative price change by 11.5 % than the high elasticity value (1.5) by 9.9. But furthermore, the possibility to substitute energy inputs by each other depends on the respective input structure of an activity that is determined in the SAM. The value of σ_{ve} applied in the case study is 0.5.

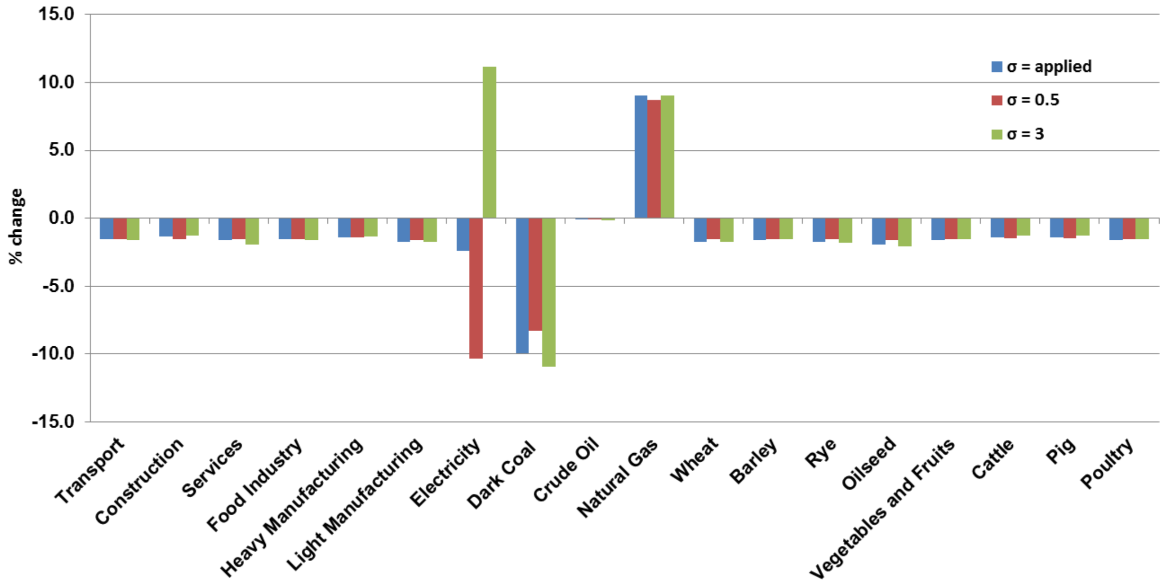
Table 23: Sensitivity analysis: Impact of the elasticity of substitution of the energy aggregate on electricity prices (in percent)

	σ_{ve} = applied	**σ_{ve} = 0.2**	**σ_{ve} = 1.5**
		%	
Electricity Price	10.6	11.5	9.9

Source: Own results

The model comprises two trade elasticities. The first is represented by the elasticity of substitution for the CES aggregation of imports and domestically produced products to combine these to a composite good (Armington import elasticity). The second trade elasticity is the elasticity of transformation of domestically produced output. This elasticity determines the relative share of exports and commodities produced for the domestic market. The sensitivity analysis was done for the Armington import elasticity (σ). Figure 25 shows that a small value for *sigma* causes a high decrease of electricity imports by -10.4 %. On the other hand, a small value for *sigma* implies a strong increase of electricity imports by 11.1 %. The commodity electricity is highly concerned by implementation of the scenario 'Complete', due to the changes in the supply structure. Nevertheless, the Armington elasticity is a sensitive parameter with regard to the model results. The high decrease of dark coal imports and the strong imports of natural gas are as well caused by the implementation of the scenario into the model. Domestic dark coal generation was phased-out and the domestic demand for natural gas increases due to the extension of electricity generation based on gas.

Figure 25: Sensitivity analysis: Impact of changes of the Armington elasticity on commodity imports (in percent)



Source: Own results

7.6 Summary and conclusions of the scenario results and recommendations

In this case study, the comparative-static model STAGE_D was applied to consider and analyse the impacts of the *Energiewende* on the German economy with a special emphasis on agriculture and the electricity sector in three scenarios. Scenario 'Phase_out' focusses on the impacts of an immediate nuclear phase-out. Scenario 'Complete' captures the complete implementation of the targets of the *Energiewende* in the electricity sector. Scenario 'Biomass' has a special focus on the role of biomass and the agricultural sector in the framework of a changed electricity supply system. This section provides a summary of the results, conclusions and recommendations for further analyses.

7.6.1 Summary of the scenario results

In the past, the German electricity supply system was mainly based on fossil and nuclear energy resources. One objective of the *Energiewende* is the phase-out of nuclear power and the development of renewable-based electricity generation to become the main pillar of electricity supply. In this transition process, the application of new technologies based on renewable resources causes changes in the cost structure of electricity generation. Old established coal-based power plants have to reduce their production or are completely phased-out (nuclear power plants). More expensive gas power plants expand electricity generation due to their technological advantage to provide electricity flexible in times when wind- and solar-based electricity is not available due to weather conditions.

The restructuring of the electricity supply system requires high investments to increase the capacity of renewable and gas power plants in order to replace old established power plants and to generate the necessary amount of electricity. As a consequence, the provision of electricity by more expensive production technologies leads to increasing electricity prices in all scenarios. Furthermore, in scenario 'Complete', capital prices increase due to high investments in the extension of renewable and gas-based power plants.

Increasing prices for electricity and capital cause cross sectoral effects. Industries use electricity either directly as input for production processes or indirectly via intermediate inputs. Along the entire value chain, the 'energy content' of intermediate goods increases the further these goods are processed. In the value added chain, the impact of higher electricity prices becomes increasingly relevant for the final user. Consequently, industries with a high direct use of electricity or those that depend on electricity intensive intermediate inputs are more concerned by higher electricity prices. The results in all scenarios show that high electricity prices cause a reduced production across all sectors. In scenario ‘Complete’, the higher capital price increases the production costs in addition to the electricity.

Private households have to carry a double burden due to the implementation of the *Energiewende*. On the one hand, they are directly concerned by paying higher prices for electricity and capital (scenario ‘Complete’). On the other hand, the decline in domestic production leads to lower factor prices and consequently to a decline in the disposable factor income of private households. Therefore, consumption expenditure of households decreases. This decrease of consumption expenditure can be regarded as the reason for the decline in domestic production of industries.

Changes in the domestic electricity supply system and increasing prices for electricity affect international trade of electricity and the relevant energy resources to produce electricity. Due to the technological framework conditions of the European electricity market, Germany receives and delivers electricity into this European grid in order to ensure a sufficient voltage in phases of volatile electricity demand. In 2007, Germany was an exporter of electricity. In all scenarios, electricity exports decrease as consequence of the domestic increase of electricity prices and a lower electricity generation in the scenarios ‘Phase_out’ and ‘Biomass’. With regard to imports, the reduced economic performance and the lower demand for electricity lead to a decline of imports in ‘Phase_out’ and ‘Complete’. The high domestic price for electricity in scenario ‘Biomass’, shifts Germany´s trading position from a net exporter to a net importer of electricity.

The increasing import dependency of energy resources for electricity generation shows that the nuclear phase-out (‘Phase_out’) implies a decrease of imports of the fossil resources dark coal, crude oil and natural gas. With exception of natural gas, imports of these energy resources decrease in the other scenarios, too. In the scenarios ‘Complete’ and ‘Biomass’, imports of natural gas increase as consequence of the enhanced domestic use for electricity generation.

The transformation process of the electricity sector has negative impacts on international competitiveness of domestic industries. The higher prices for electricity (scenarios ‘Phase_out’ and ‘Biomass’) and for capital (scenario ‘Complete’) increase the cost of production for domestically produced goods and services. As a consequence, domestically produced commodities become relatively more expensive and exports decline. Additionally, the reduction of factor and household income and the associated decline in domestic demand cause a decline in both: domestic production and imports.

One objective of the *Energiewende* is the reduction of greenhouse gas emissions. Generally, the analyses show that the objective to reduce carbon emissions is achieved in all scenarios. But the reduction of carbon emissions is predominantly a consequence of a reduction of economic performance initiated due to higher electricity prices (scenario ‘Phase_out’ and ‘Biomass’) and capital prices (scenario 'Complete'). The resulting declines in electricity demand by private households and industries, but also the overall reduction of domestic production by industries, have a stronger impact on the reduction of carbon emissions than the targeted increase in the efficiency of electricity use.

The phase-out of nuclear power and the increasing use of renewable energy resources ('Complete') reduce the application of fossil-based energy resources for electricity generation. As a net effect, however, German GDP declines in all three scenarios. A reduction in GDP is an indicator for a shrinking economic performance and shows that the implementation of the *Energiewende* in the electricity sector has negative impacts on the entire German economy.

This analysis of the consequences of the *Energiewende* on the German economy is done under particular consideration of the agricultural sector, because of the special role of agriculture in this framework. Traditionally, agricultural commodities are used for the production of food and feed. Due to technological developments and the governmental support in the frame of the EEG, this use spectrum is expanded by the generation of biogas for electricity production. The enhanced demand increases competition with regard to production factors, especially for the factor land, and the final use of agricultural commodities. Another characteristic of the agricultural sector is the high energy demand in crop and livestock production. On the one hand, energy resources are directly used in the agricultural production processes, i.e. electricity or diesel. On the other hand, the agricultural sector has a high and indirect energy demand caused by the use of intermediate inputs that are produced in energy intensive production processes, i.e. fertiliser or feed products. Next to this, the provision of biomass in the agricultural sector also generates higher costs of electricity production compared to wind and solar, which are available at very low marginal costs for provision.

In general, the *Energiewende* causes a decline of agricultural production and a price decrease for agricultural commodities in all scenarios, except of scenario 'Complete'. Here the prices for crops used for biogas generation increase or remain unchanged due to the higher input demand in biogas production.

The drop in agricultural production and prices can be traced-back on increased prices for electricity that directly increase the cost of production of agricultural commodities. Furthermore, higher electricity prices cause an increase of prices for intermediate inputs. Next to the input side, the use of agricultural commodities for feed and food decreases as a consequence of a lower household demand due to lower factor income. Important for the agricultural sector is the development in the food industry, which represents the most important purchaser of agricultural commodities as intermediate inputs for further processing into food and feed. As consequence of a lower factor income, the consumption expenditure of private households declines, which is also the case for the demand of food products. The reduced demand of the food and feed industry can be regarded as an important driver for the decline of production and prices of agricultural commodities.

Agricultural production is capital intensive; therefore, the increase of capital prices increases cost of production in crop and livestock production. The increase of capital prices in scenario 'Complete' is driven by high investment demand to expand capacities to produce renewable energies, e.g. biogas but also gas based electricity generation.

An increase in competition between production factors and/or the alternative use of agricultural commodities, due to the extension of the use spectrum by agricultural commodities, cannot be confirmed by the scenario results. Although the overall effects of the *Energiewende* cause a higher demand for biogas for electricity generation, the lower demand for agricultural commodities for feed and food as consequence of the lower household demand overweighs and implies a decline in agricultural production and prices for crop and livestock commodities.

Changes in domestic production and prices for agricultural commodities also have impact on international trade. Agricultural imports and exports decline in all scenarios due to the decrease of domestic production for all agricultural commodities, except for those used for biogas generation. Especially livestock production is affected by higher prices for electricity and capital. Livestock production in Germany is characterised as energy and capital intensive. Therefore, the increase of prices for electricity and especially for capital causes a decline of domestic production and exports. Imports of agricultural commodities decline due to lower domestic demand for food and feed.

From an agricultural perspective, the implementation of the *Energiewende* and the expansion of investments in biogas plants are a boon and bane at the same time. Higher biogas production compensates partly the increasing costs for electricity but also drives up costs for capital because of investments in the extension of biogas plants in scenario 'Complete'. In consequence only the production of some commodities is positively affected. Overall, the negative impact of higher capital and energy costs and the lower domestic demand for feed and food products cause a decline in the production level and prices of almost all agricultural commodities.

7.6.2 Conclusions

The German economy is currently in the transition phase of implementing the *Energiewende* with the objective of a fundamental long-term restructuring of the German energy supply system from a fossil and nuclear basis to a renewable basis. The intention is to improve environmental protection and reduce the current high dependence on energy imports. At the same time, affordable energy prices for consumers and a high level of economic competitiveness and development have to be maintained. The establishment of a sustainable energy supply, initiated by the German government, therefore includes environmental, economic and social objectives, which must be taken into account at the same time.

The objective of this case study is to analyse the implementation of the *Energiewende* in Germany with a particular focus on achieving these various objectives. The focus here is on the electricity and the agricultural sectors. For this analysis, the CGE model STAGE_D is used, which was developed within the scope of this research. This analysis tool is intended to provide a better understanding of the complex interrelationships between the economic, ecological and social impacts of the *Energiewende* on all economic actors.

The application of STAGE_D in the three scenarios ‘Phase_out’, ‘Complete’ and ‘Biomass’ shows that the political objectives are not realised yet. Moreover, the restructuring of the electricity supply is having a negative impact on Germany’s economic development, indicated by a relative decline in GDP.

This decline in GDP is caused by a reduced income for the production factors capital, labour and land as consequence of a reduced production of domestic industries. While the nuclear phase-out and the complete restructuring of the electricity supply system, German industries are confronted with increasing prices for electricity due to the implementation of more costly technologies to supply electricity. Furthermore, the expansion of electricity production based on renewables and gas requires high investments, which additionally increase the capital price. The political objective to offer electricity at competitive prices was therefore not achieved. Moreover, due to the resulting decline of domestic production because of the higher input prices and the lower domestic demand, German industries sustain a loss in international competitiveness, visible in a decline of imports and exports of goods and services.

Private households carry the main burden in the implementation of the *Energiewende*. On the one hand, households are confronted with rising electricity prices and on the other hand with income losses due to the declining economic development. The political objective to supply electricity at affordable prices for consumers is therefore not achieved.

From the environmental perspective, the political objective of reducing carbon emissions is primarily achieved by a decline in economic performance and the overall reduced use of energy resources.

7.6.3 Recommendations

With regard to the future energy policy of the government, it is recommended to adjust the promotion of renewable energies against the background of the still existing old structures of power plants in the electricity sector. As nuclear power already is decided to be phased-out in 2022, an adjustment of electricity generation based on coal and gas needs to be considered. Electricity generation based on inflexible coal-fired power plants should be reduced, while gas-fired power generation should be expanded.

The support of renewable energies under the EEG should be adapted. Electricity generation on the basis of renewable energies became increasingly established in recent years. The guaranteed purchase and the support of renewable electricity in the frame of the EEG increase electricity prices. This has negative impacts on the German economy. In the national context, this is due to higher production costs and lower household consumption expenditure. On the international markets, the German economy is losing competitiveness, due to the more expensive production. In order to strengthen industries and households, a reduction of the EEG-levy and a reduced support of renewables in the frame of the EEG should be considered.

It is also recommended to promote technological progress in electricity generation in order to reduce electricity prices in the long term. The efficiency of electricity use should also be promoted in order to achieve the desired reduction in electricity use and so positive environmental effects.

With the agricultural sector in view, it is advisable to maintain biogas production for electricity generation in the medium term. This is against the background that this renewable energy source is continuously available. Nevertheless, with regard to increasing demand for the use of agricultural products for food and other purposes, a further expansion of biogas production is not recommended. The expansion of renewable energies for power generation in future should concentrate on wind and solar energy.

With regard to the application of the single-country CGE model STAGE_D it can be stated that the model demonstrated its ability to measure the complex intra- and inter-sectoral impacts of the German energy policy. Nevertheless, the model version applied in this study indicates starting points for further research.

Recommendations for further research to develop STAGE_D and the SAM:

- The Social Accounting Matrix can be updated to reflect the current state of the implementation of the *Energiewende* and the economic situation.
- The structure of the nested production function can be extended to allow the model a substitution between capital and electricity, dark and brown coal, petrol and bioethanol, diesel and biodiesel.
- In this research, the agricultural sector is recorded as a multiple output 'industry'. The underlying assumption that the composition of output remains the same, regardless of relative prices of the produced commodities can be improved by a flexible output composition.
- Technological progress can be considered by making the shift parameter adx_a a variable for relevant activities that supply and use energy.
- Electricity and energy taxes as well as subsidies can be disaggregated in the SAM and implemented into STAGE_D for a better consideration of political measures.
- The presentation of households can be improved by a disaggregation of households on the base of their income in the SAM and adjustments of the Stone-Geary utility function in STAGE_D.
- A division of capital into immobile long-term capital and mobile short-term capital could address the issue of long-term investments of power plants in the energy sector.
- The connection to global trade models can improve the trade relationships between Germany and the rest of the world.
- Econometric estimates of elasticities would improve elasticity values.
- A dynamic version of STAGE_D can improve the visibility of adaption processes in the economy on changed political or economic framework conditions.

Application examples of the model and further research topics:

- With this model, the monitoring process of the energy transition for measuring and analysing economic, social and ecological impacts can be supported.
- Analyses focusing on the impact on a reduced EEG-levy and generally on the impact of lower prices of electricity can be done.
- The recommendation of all objectives of the *Energiewende*, including biofuels and heat generation, can improve the results and give a complete picture of the *Energiewende*.
- Electric mobility will become an important topic in the future. Analyses of changing national and international markets for electricity and fuels outline an interesting topic for global and single country CGE models.

8 Summary of the study

The German energy sector is currently characterised by a transformation process from a nuclear- and fossil-oriented to a renewable-oriented input base. Initial point of this process was the decision of the *Energy Concept* by the German government in 2010. The implementation of the so-called *Energiewende* (Energy Shift) is planned with a transitional period until 2050 and requires a fundamental long-term restructuring of Germany's energy supply system.

In the electricity sector, this restructuring process should primarily take part by using nuclear power as a 'bridge technology' until renewable-based electricity generation has been expanded to a sufficient amount. However, as a consequence of the Fukushima Daiichi (Japan) nuclear accident in March 2011, the government reconsidered the long-term role of nuclear power with the result to phase-out the use of nuclear power until the year 2022. In order to phase-out nuclear power more quickly, the process of reorganising Germany's energy supply on the base of renewable energy sources needed to be substantially accelerated. This process was implemented by the government in the framework of the *Energy Package* in June and July 2011.

The most important renewable energy sources in Germany are biomass, wind and solar energy. Electricity generation based on these resources experienced a considerable extension over the last years as a consequence of the implementation of the *Energiewende* and the governmental support in the framework of the Renewable Energy Act (EEG). While the supply of wind- and solar-based electricity generation causes marginal costs, which tend to be zero, the costs of biomass-based electricity are significantly higher. Traditionally, agricultural products are used for food and feed production. Due to technological development and the governmental support to use agricultural commodities for energy production, this traditional use spectrum was expanded by the generation of biogas for electricity generation. As a consequence of this additional use of agricultural products, competition for production factors and in particular for land has intensified over the last decade. In addition, competition between the various possibilities to use agricultural commodities (feed, food, energy) has emerged. Next to its new role as electricity provider, the agricultural sector is characterised by a high energy demand for the production processes of crop and livestock production and therefore directly affected by price changes of energy commodities.

The politically initiated adjustment process of the electricity sector is accompanied by the objectives of a long term securing of the domestic energy supply on the base of renewable energies, the improvement of environmental protection and the reduction of the currently strong dependence on imported energy resources. At the same time affordable energy prices for consumers and a high level of economic competitiveness and development shall be also maintained. Thus, the establishment of a sustainable energy supply system involves environmental, economic and social objectives, which have to be considered simultaneously.

In order to determine the consequences of the comprehensive restructuring process of the electricity sector on the German economy and on the agricultural sector in particular, this research focusses on the achievement of two objectives.

The first objective is the provision of an analytical instrument able to capture the economic, environmental and social impacts of the energy policy on all agents of the German economy. This instrument should be able to monitor the process of the *Energiewende* and allow for recommendations for the government. Therefore, the **St**atic **A**pplied **G**eneral **E**quilibrium Model for Germany (STAGE_D) was developed on the basis of the STAGE standard model. STAGE_D is a comparative-static single-country CGE model and provides the methodological basis for the necessary intra- and inter-sectoral, social and environmental analysis.

The second objective is the application of the model STAGE_D in order to analyse the impact of the exit from nuclear- and fossil-based energy on the German economy and, particularly, on the electricity and the agricultural sector in the frame of a case study.

The analyses based on STAGE_D required the development of an adequate database for Germany, including disaggregated data for the electricity and agricultural sector as well as a satellite account that records data on carbon emissions associated with different production systems. The database for STAGE_D is presented as a SAM and follows the principles and accounting rules of the SNA. A SAM can be regarded as a comprehensive and flexible accounting framework, in which the accounts of all agents of an economy are represented in the format of a square matrix. This matrix captures the interconnections between the agents and their interactions via factor and product markets within the economy and the rest of the world.

The development of STAGE_D follows the SAM approach to modelling and uses the SAM as database and analytical framework to calibrate the model. Therefore, STAGE_D can be explained within the submatrices of the German SAM. Also the prices for industries and products, applied in the model, derive from the developed German SAM.

For the construction of the German SAM different data sources have been combined to capture the structural characteristic of the German economy. SUTs of the year 2007, provided by the German Federal Statistical Office, represent the underlying main source data.

The distinctive features of the model derive from the focus of the analysis on the impact of energy policy on all sectors of the economy in Germany and on the electricity and agricultural sector in particular. Therefore, these two sectors are captured and modelled on a more detailed level than in the standard national accounts database. Additional disaggregation of inputs - intermediate use and final demand, outputs – joint- and by-production within the electricity and agricultural sectors and its use for further processing has been done in the framework of the setup of the German SAM.

The model STAGE_D itself includes a detailed specification of the supply, production and demand for energy and agricultural products in Germany. The modified model allows multiple production technologies for electricity that encompass existing and new technologies for electricity generation with different cost structures. This formulation of electricity production addresses the problem presented by a homogenous product – electricity – being produced by different technologies with different cost structures.

The agricultural sector is captured in STAGE_D as a multi-product sector. Agricultural activities are distinguished at the regional level by federal states (*Bundesländer*). That means that one state represents all farms of that region and that this agricultural activity is able to produce multiple output, i.e. crops, livestock as well as biomass for biogas generation. This consideration enables the user of the model to capture regional differences in the production structure.

Furthermore, STAGE_D is able to record carbon emissions caused by the use of energy commodities by industries and households. For this purpose, an external database in form of an external satellite account was developed in addition to the SAM.

In this study, STAGE_D is applied to capture and analyse the impacts of the *Energiewende* on the German economy with a special consideration of agriculture and the electricity sector in three scenarios. Scenario ‘Phase_out’ focusses on the impacts of an immediate nuclear phase-out, scenario ‘Complete’ captures the complete implementation of the targets of the *Energiewende* in the electricity sector and scenario ‘Biomass’ has a special focus on the role of biomass in the framework of a changed electricity supply system.

The results show that the political objectives have not yet been achieved and that the restructuring of the electricity supply system has negative impacts on the economic growth in Germany, indicated by a reduction in GDP compared to the reference year 2007.

This decline in GDP is caused by a reduced income for the production factors capital, labour and land as a consequence of a lower production of domestic industries. While the nuclear phase-out and the complete restructuring of the electricity supply system, German industries are confronted with increasing prices for electricity due to the implementation of more costly technologies to supply electricity. Furthermore, the expansion of electricity production based on renewables requires high investments, which additionally increase the price for capital. The political objective to offer electricity at prices to preserve the competitiveness of German industries therefore has not been achieved. Moreover, due to the resulting decline of domestic production as a consequence of higher input prices and a reduced domestic demand, German industries suffer a loss in international competitiveness visible by the decline of imports and exports of goods and services.

Private households carry the main burden while the implementation of the *Energiewende*. On the one hand, households are confronted with increasing electricity prices and on the other hand with a reduced income due to the decline of economic performance. The political objective to supply electricity to affordable prices for consumers is therefore not achieved.

From the environmental perspective, the political objective to reduce carbon emissions is achieved in the first consideration but this reduction is mainly reached by the reduction of economic performance and the overall reduced use of energy resources.

From an agricultural point of view, the implementation of the *Energiewende* and the expansion of investments in biogas plants are a boon and bane at the same time. Higher biogas production compensates partly the increasing costs for electricity, but also drives up costs for capital because of investments in the extension of biogas plants. In consequence only the production of some crops used for biogas generation is positively affected. Altogether, higher capital and energy costs and the lower domestic demand for feed and food products cause a decline in agricultural production and lower prices for almost all agricultural commodities. The consideration of the impact of the *Energiewende* on the regional level shows that federal states, characterised by energy and capital intensive livestock production, are more concerned than federal states with dominant crop production.

For the future energy policy of the government, it is recommended to modify the support for renewable energies with regard to the existing power plant structures in the electricity sector. Adjustments of electricity generation based on coal and gas should be considered. Electricity generation by inflexible coal-fired power plants should be reduced and electricity generation by gas plants expanded.

The promotion of renewable energies under the EEG should also be reconsidered. Electricity generation based on renewable energies has become increasingly established in recent years. The guaranteed purchase and support for electricity generation based renewables increase electricity prices. A reduction of the support in the frame of the EEG and also a reduced EEG-levy would cause lower prices for consumers. This could strengthen the national and international competitiveness of the German industry and relieve households.

Additionally, it is recommended to support technological progress for processes for electricity generation in order to reduce production cost and to reduce the electricity price in the long term. Furthermore, support measures to increase the efficiency of electricity use should be fostered.

With regard to agriculture, it is advisable to maintain biogas production for electricity generation in the medium term, as this renewable energy source is constantly available. But with a view to the rising demand for the use of agricultural commodities for food and other purposes, a further expansion of biogas production is not recommended. In the future, the expansion of renewable energies for electricity generation should concentrate on wind and solar energy. This is also due to the fact that electricity generation on this basis is more cost-effective and environmentally friendly.

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10 Addendum

10.1 Variables, parameters and sets

The description of the variables, parameters and sets follows McDonald (2007) and has been adjusted appropriate to the model adaptions made in this study.

Parameters, variables and sets are listed in alphabetic order.

10.1.1 Model Variables

A Table 1: Model Variables

Variable name	Variable description
$ADVAE_a$	Shift parameter for CES production functions for QVAE
ADVAEADJ	Scaling factor for Shift parameter on CES functions for QVAE
$ADVE_a$	Shift parameter for CES production functions for QVE
ADVEADJ	Scaling factor for Shift parameter on CES functions for QVE
$ADVKE_a$	Shift parameter for CES production functions for QVKE
ADVKEADJ	Scaling factor for Shift parameter on CES functions for QVKE
$ADVLL_a$	Shift parameter for CES production functions for QVLL
ADVLLADJ	Scaling factor for Shift parameter on CES functions for QVLL
CAPGOV	Government savings
CAPWOR	Current account balance
CPI	Consumer price index
DADVAE	Partial scaling factor for Shift parameter on CES functions for QVAE
DADVE	Partial scaling factor for Shift parameter on CES functions for QVE
DADVKE	Partial scaling factor for Shift parameter on CES functions for QVKE
DADVLL	Partial scaling factor for Shift parameter on CES functions for QVLL
DS	Partial household and enterprise savings rate scaling factor
DTAX	Direct income tax revenue
DTE	Partial export tax rate scaling factor
DTEX	Partial excise tax rate scaling factor
DTF	Partial fuel tax rate scaling factor
DTM	Partial tariff rate scaling factor
DTS	Partial sales tax rate scaling factor
DTX	Partial indirect tax rate scaling factor
DTYE	Partial direct tax on enterprise rate scaling factor
DTYF	Partial direct tax on factor rate scaling factor
DTYH	Partial direct tax on household rate scaling factor
EG	Expenditure by government
EGADJ	Transfers to corporations by government scaling factor
ER	Exchange rate (domestic per world unit)

ETAX	Export tax revenue
EXTAX	Excise tax revenue
$FD_{f,a}$	Demand for factor f by industry a
FS_{f}	Supply of factor f
FTAX	Fuel tax revenue
FYTAX	Factor income tax revenue
$GOVENT_{e}$	Government income from enterprise e
$HEXP_{h}$	Household consumption expenditure
HGADJ	Scaling factor for government transfers to households
$HOENT_{h,e}$	Household Income from enterprise e
$HOHO_{h,hp}$	Inter household transfer
IADJ	Investment scaling factor
INVEST	Total investment expenditure
INVESTSH	Value share of investment in total final domestic demand
$IOQXACQXV_{a,c}$	Share of product c in output by industry a
ITAX	Indirect tax revenue
MTAX	Tariff revenue
PD_{c}	Consumer price for domestic supply of product c
PEc	Domestic price of exports by industry a
PINTa	Price of aggregate intermediate input
PM_{c}	Domestic price of competitive imports of product c
PPI	Producer (domestic) price index
PQD_{c}	Purchaser price of composite product c
$PQDDIST_{c,a}$	Sectoral proportion for energy commodity prices
PQSc	Supply price of composite product c
PVAa	Value added price for industry a
$PVAE_{a}$	Value added- energy price for activity a
PVE_{a}	Price for aggregate energy used by activity a
$PVKE_{a}$	Price for aggregate capital energy used by activity a
$PVLL_{a}$	Price for aggregate quantity of labour and land used by activity a
PWE_{c}	World price of exports in Dollar
PWM_{c}	World price of imports in Dollar
PX_{a}	Composite price of output by industry a
$PXAC_{a,c}$	Industry product prices
PXC_{c}	Producer price of composite domestic output
$QCD_{c,h}$	Household consumption by product c
QD_{c}	Domestic demand for product c
QE_{c}	Domestic output exported by product c
QEDADJ	Enterprise demand volume scaling factor
$QED_{c,e}$	Enterprise consumption by product c
QGDADJ	Government consumption demand scaling factor
QGD_{c}	Government consumption demand by product c

$QINT_a$	Aggregate quantity of intermediates used by industry a
$QINTD_{c,a}$	Demand of activities for intermediate inputs by commodity
$QINTD_c$	Demand for intermediate inputs by product c
$QINVD_c$	Investment demand by product c
QM_c	Imports of product c
QQ_c	Supply of composite product c
QVA_a	Quantity of aggregate value added for level 1 production
$QVAE_a$	Quantity of aggregate value added-energy
QVE_a	Quantity of aggregate energy
$QVKE_a$	Quantity of aggregate capital energy
$QVLL_a$	Quantity of aggregate labour land
QX_a	Domestic production by industry a
$QXAC_{a,c}$	Domestic product output by each industry
QXC_c	Domestic production by product c
SADJ	Savings rate scaling factor for BOTH households and corporations
SEADJ	Savings rate scaling factor for corporations
SEN_e	Corporation savings rates
SHADJ	Savings rate scaling factor for households
SHH_h	Household savings rates
STAX	Sales tax revenue
TEADJ	Export subsidy scaling factor
TE_c	Export taxes on exported product c
TEXADJ	Excise tax rate scaling factor
TEX_c	Excise tax rate
TFADJ	Tax rate on factor use scaling factor
TF_c	Tax rate on factor use
TMADJ	Tariff rate scaling factor
TM_c	Tariff rates on imported product c
TOTSAV	Total savings
TSADJ	Sales tax rate scaling factor
TS_c	Sales tax rate
TX_a	Indirect tax rate
TXADJ	Indirect tax scaling factor
TYEADJ	Enterprise income tax scaling factor
TYE_e	Direct tax rate on corporations
TYFADJ	Factor tax scaling factor
TYF_f	Direct tax rate on factor income
TYHADJ	Household income tax scaling factor
TYH_h	Direct tax rate on households
VED_e	Value of enterprise e consumption expenditure
$VEDSH_e$	Value share of enterprise consumption in total final domestic demand
VFDOMD	Value of final domestic demand

VGD	Value of government consumption expenditure
VGDSH	Value share of govt consumption in total final domestic demand
WALRAS	Slack variable for Walras's Law
$WFDIST_{f,a}$	Sectoral proportion for factor prices
WF_f	Price of factor f
YE_e	Enterprise incomes
$YFDISP_f$	Factor income for distribution after depreciation
YF_f	Income to factor f
$YFWOR_f$	Foreign factor income
YG	Government income
YH_h	Income to household h

10.1.2 Model parameters

The following parameters are used in the behavioural specifications/equations of the model. In addition to these parameters, there is an additional set of parameters. This set of parameters is used for model calibration and for deriving results; there exists one parameter for each variable and they are identified by appending a zero to the respective variable name.

A Table 2: Model Parameters

Parameter name	**Parameter description**
ac_c	Shift parameter for Armington CES function
$adva_a$	Shift parameter for CES production functions for QVA (base model)
$advaeb_a$	Shift parameter for CES production functions for QVAE
$adveb_a$	Shift parameter for CES production functions for QVE
$advkeb_a$	Shift parameter for CES production functions for QKE
$advllb_a$	Shift parameter for CES production functions for QVLL
adx_a	Shift parameter for CES production functions for QX
$adxc_c$	Shift parameter for product output CES aggregation
$alphah_{c,h}$	Expenditure share by product c for household h
at_c	Shift parameter for export CET function
$betac_{,h}$	Marginal budget shares
$caphosh_h$	Shares of household income saved (after taxes)
$comactactco_{c,a}$	Intermediate input output coefficients
$comactco_{c,a}$	Use matrix coefficients
$comgovconst_c$	Government demand volume
$comhoav_{c,h}$	Household consumption shares
$comtotsh_c$	Share of product c in total product demand
$dabadvae_a$	Change in base shift parameter on functions for QVAE
$dabadve_a$	Change in base shift parameter on functions for QVE
$dabadvke_a$	Change in base shift parameter on functions for QVKE

$dabadvll_a$	Change in base shift parameter on functions for QVLL
$dabsen_e$	Change in base enterprise saving rates
$dabshh_h$	Change in base household saving rates
$dabte_c$	Change in base export taxes on product c imported from region w
$dabtex_c$	Change in base excise tax rate
$dabtm_c$	Change in base tariff rates on product c imported from region w
$dabts_c$	Change in base sales tax rate
$dabtx_a$	Change in base indirect tax rate
$dabtye_e$	Change in base direct tax rate on corporations
$dabtyf_f$	Change in base direct tax rate on factors
$dabtyh_h$	Change in base direct tax rate on households
$delta_c$	Share parameter for Armington CES function
$deltavae_a$	Share parameters for CES production functions for QVAE
$deltave_{cel,a}$	Share parameters for CES production functions for QVE
$deltavke_a$	Share parameters for CES production functions for QVKE
$deltavll_a$	Share parameters for CES production functions for QVLL
$deltax_a$	Share parameter for CES production functions for QX
$deltaxc_{a,c}$	Share parameters for product output CES aggregation
$deprec_f$	Depreciation rate by factor f
$dstocconst_c$	Stock change demand volume
$econ_c$	Constant for export demand equations
$entgovconst_e$	Government transfers to enterprise e
$entvash_{e,f}$	Share of income from factor f to enterprise e
$entwor_e$	Transfers to enterprise e from world (constant in foreign currency)
eta_c	Export demand elasticity
$factwor_f$	Factor payments from RoW (constant in foreign currency)
$frisch_h$	Elasticity of the marginal utility of income
$gamma_c$	Share parameter for export CET function
$gammai_c$	Share parameter for output CET function
$goventsh_e$	Share of enterprise income after tax, savings and consumption to govt
$govvash_f$	Share of income from factor f to government
govwor	Transfers to government from world (constant in foreign currency)
hexpsh	Subsistence consumption expenditure
hoentconsth,e	Transfers to household h from enterprise e (nominal)
hoentshh,e	Share of enterprise income after tax, savings and consumption to household h
$hogovconst_h$	Transfers to household h from government (nominal but scalable)
$hohoconsth_{,hp}$	Interhousehold transfers
$hohosh_{h,hp}$	Share of household h after tax and saving income transferred to hp
$hovash_{h,f}$	Share of income from factor f to household h
$howor_h$	Transfers to household from world (constant in foreign currency)
$invconst_c$	Investment demand volume

$ioqintqx_a$	Agg intermediate quantity per unit QX for Level 1 Leontief agg
$ioqtdqd_{c,a}$	Intermediate input output coefficients
$ioqvaqx_a$	Agg value added quant per unit QX for Level 1 Leontief agg
$ioqxacqx_{a,c}$	Share of product c in output by industry a
$kapentsh_e$	Average savings rate for enterprise e out of after tax income
$predeltax_a$	Dummy used to estimated deltax
$pwse_c$	World price of export substitutes
$qcdconst_{c,h}$	Volume of subsistence consumption
$qedconst_{c,e}$	Enterprise demand volume
$rhoc_c$	Elasticity parameter for Armington CES function
$rhocva_a$	Elasticity parameter for CES production function for QVA (base model)
rhocxa	Elasticity parameter for CES production function for QX
$rhocxc_c$	Elasticity parameter for product output CES aggregation
$rhot_c$	Elasticity parameter for export CET function
$rhoti_a$	Elasticity parameter for output CET function
$rhovae_a$	Elasticity parameter for CES production function for QVAE
$rhove_a$	Elasticity parameter for CES production function for QVE
$rhovke_a$	Elasticity parameter for CES production function for QVKE
$rhovll_a$	Elasticity parameter for CES production function for QVLL
$sumelast_h$	Weighted sum of income elasticities
$te01_c$	0-1 par for potential flexing of export taxes on products
$tex01_c$	0-1 par for potential flexing of excise tax rates
$tfue01_c$	0-1 par for potential flexing of fuel tax rates
$tm01_c$	0-1 par for potential flexing of tariff rates on products
$ts01_c$	0-1 par for potential flexing of sales tax rates
$tx01_a$	0-1 par for potential flexing of indirect tax rates
$tye01_e$	0-1 par for potential flexing of direct tax rates on corporations
$tyf01_f$	0-1 par for potential flexing of direct tax rates on factors
$tyh01_h$	0-1 par for potential flexing of direct tax rates on households
$use_{c,a}$	Use matrix transactions
$vddtotsh_c$	Share of value of domestic output for the domestic market
$worvash_f$	Share of income from factor f to rest of world
$yhelast_{c,h}$	(Normalised) household income elasticities

10.1.3 Model set description

A Table 3: Model Sets

cel_c	Energy commodities
$celn_c$	Non energy commodities
a_h_{sac}	Activity and commodity accounts - Carbon emissions
a_{a_h}	Activity accounts - Carbon emissions
h_{a_h}	Household accounts - Carbon emissions
ce_c	Export commodities
cen_c	Non-export commodities
ced_c	Export commodities with export demand functions
$cedn_c$	Export commodities without export demand functions
cm_c	Imported commodities
cmn_c	Non-imported commodities
cx_c	Commodities produced domestically
cxn_c	Commodities NOT produced domestically AND imported
$cxac_c$	Commodities that are differentiated by activity
$cxacn_c$	Commodities that are NOT differentiated by activity
cd_c	Commodities produced and demanded domestically
cdn_c	Commodities NOT produced and demanded domestically
aqx_a	Activities with CES aggregation function at Level 1 of nest
$aqxn_a$	Activities with Leontief aggregation function at Level 1 of nest
sac	SAM Accounts
c	Products, Commodities
a	Industries, Activities
f	Factors
h	Households
g	Government
e	Enterprises
i	Investment
w	Rest of World

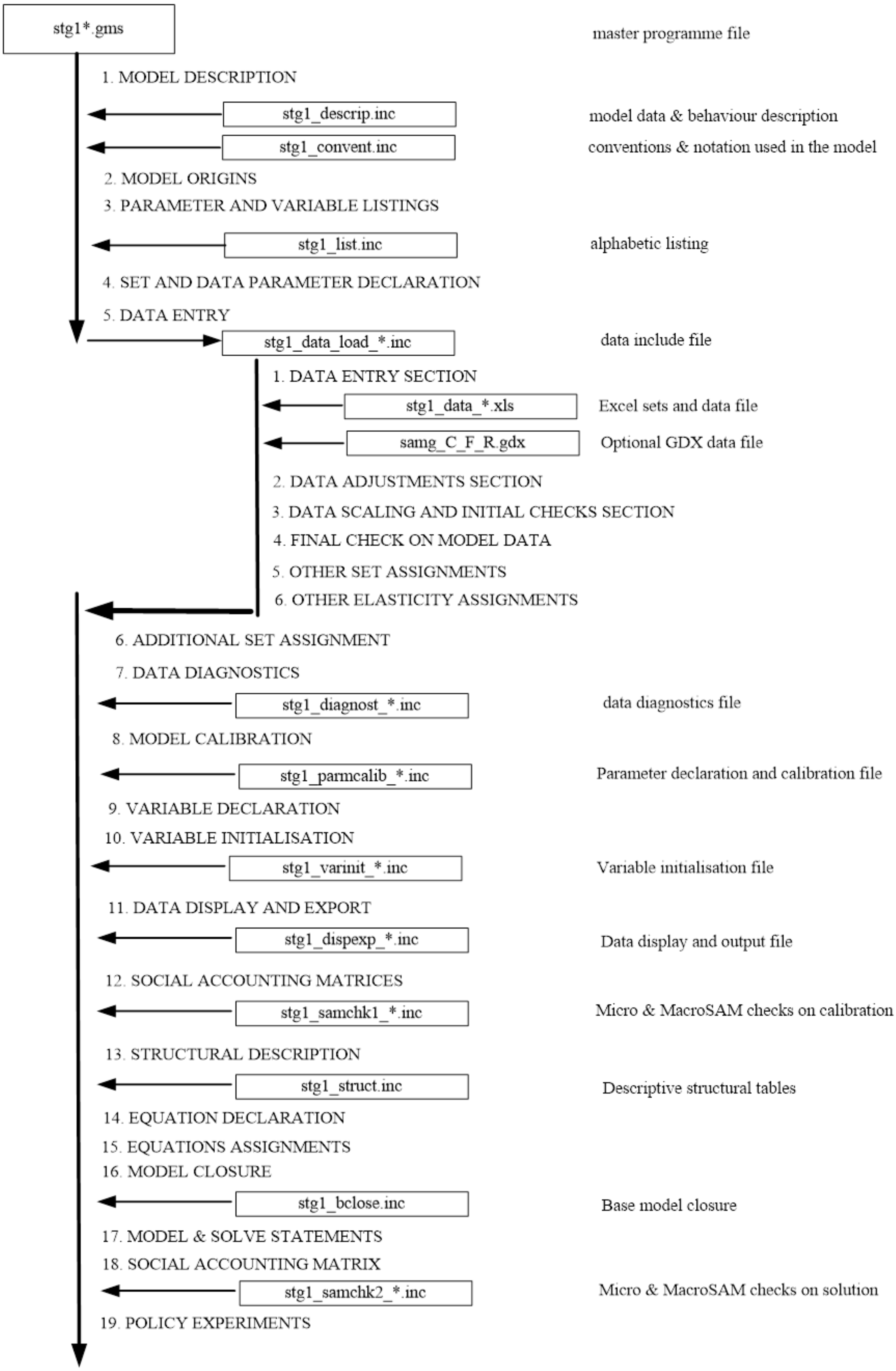
A Table 4: Commodities included in the 2007 German Supply and Use Tables

Number	Commodity
1	Products of agriculture, hunting and related services
2	Products of forestry, logging and related services
3	Fish and other fishing products; services incidental of fishing
4	Coal and lignite; peat
5	Crude petroleum and natural gas; services incidental to oil and gas extraction
6	Uranium and thorium ores
7	Metal ores
8	Other mining and quarrying products
9	Food and feed products
10	Beverages
11	Tobacco products
12	Textiles
13	Wearing apparel; furs
14	Leather and leather products
15	Wood and products of wood and cork
16	Pulp, paper
17	Paper products
18	Publishing commodities
19	Printed matter and recorded media
20	Coke, refined petroleum products and nuclear fuels
21	Pharmazeutics
22	Chemicals, chemical products and man-made fibres
23	Rubber products
24	Plastic products
25	Glass
26	Ceramic, stone and abrasive products
27	Basic metals
28	Other non-metallic mineral products
29	Foundry
30	Fabricated metal products, except machinery and equipment
31	Machinery and equipment n.e.c.
32	Office machinery and computers
33	Electrical machinery and apparatus n.e.c.
34	Radio, television and communication equipment and apparatus
35	Medical, precision and optical instruments, watches and clocks
36	Motor vehicles, trailers and semi-trailers
37	Other transport equipment
38	Furniture; other manufactured goods n.e.c.
39	Secondary raw materials
40	Electricity, district heat, Services
41	Gas, Services of gas supply
42	Water, services of water supply
43	general construction and civil engineering.
44	Construction work
45	Trade, maintenance and repair services of motor vehicles and motorcycles
46	Wholesale trade and commission trade services
47	Retail trade services, repair services of personal and household goods
48	Hotel and restaurant services
49	Rail transport services
50	Land transport; transport via pipeline services
51	Water transport services
52	Air transport services
53	Supporting and auxiliary transport services; travel agency services
54	Post and telecommunication services
55	Financial intermediation services
56	Insurance and pension funding services
57	Services auxiliary to financial services and insurance services
58	Real estate services
59	Renting services of machinery and equipment
60	Computer and related services
61	Research and development services
62	Other business services
63	Public administration and defence services
64	Compulsory social security services
65	Education services
66	Health and social work services
67	Sewage and refuse disposal services, sanitation and similar services
68	Membership organisation services n.e.c.
69	Recreational, cultural and sporting services
70	Other services
71	Private households with employed persons

A Table 5: Activities included in the 2007 German Supply and Use Tables

Number	Activity	Number	Activity
1	Agriculture, hunting and related service activities	31	Recycling
2	Forestry, logging and related service activities	32	Electricity, gas, steam and hot water supply
3	Fishing, operating of fish hatcheries and fish farms	33	Collection, purification and distribution of water
4	Mining of coal and lignite; extraction of peat	34	Construction
5	Extraction of crude petroleum and natural gas	35	Sale, maintenance and repair of motor vehicles and motorcycles
6	Mining of uranium and thorium ores	36	Wholesale trade and commission trade
7	Mining of metal ores	37	Retail trade, except of motor vehicles and motorcycles
8	Other mining and quarrying	38	Hotels and restaurants
9	Manufacture of food products and beverages	39	Land transport; transport via pipelines
10	Manufacture of tobacco products	40	Water transport
11	Manufacture of textiles	41	Air transport
12	Manufacture of wearing apparel; dressing and dyeing of fur	42	Supporting and auxiliary transport activities; activities of travel agencies
13	Tanning and dressing of leather	43	Post and telecommunications
14	Manufacture of wood and of products of wood and cork	44	Financial intermediation, except insurance and pension funding
15	Manufacture of pulp, paper and paper products	45	Insurance and pension funding, except compulsory social security
16	Publishing, printing and reproduction of recorded media	46	Activities auxiliary to financial intermediat.
17	Manufacture of coke, refined petroleum products and nuclear fuels	47	Real estate activities
18	Manufacture of chemicals and chemical products	48	Renting of machinery and equipment
19	Manufacture of rubber and plastic products	49	Computer and related activities
20	Manufacture of other non-metallic mineral products	50	Research and development
21	Manufacture of basic metals	51	Other business activities
22	Manufacture of fabricated metal products	52	Public administration and defence; compulsory social security
23	Manufacture of machinery and equipment n.e.c.	53	Education
24	Manufacture of office machinery and computers	54	Health and social work
25	Manufacture of electrical machinery and apparatus n.e.c.	55	Sewage and refuse disposal, sanitation and similar activities
26	Manufacture of radio, television and communication equipment and apparatus	56	Activities of membership organisation n.e.c.
27	Manufacture of medical, precision and optical instruments, watches and clocks	57	Recreational, cultural and sporting activities
28	Manufacture of motor vehicles, trailers and semi-trailers	58	Other service activities
29	Manufacture of other transport equipment	59	Private households with employed persons
30	Manufacture of furniture; manufacturing n.e.c.		

A Figure 1: File structure of the STAGE model



Source: McDonald (2013)

10.2 Model equations of the STAGE base model

The model equations listed in this section are taken from the technical documentation of the STAGE base model of McDonald (2007).

A Table 6: STAGE model equations

Name	**Equation and set control**	**Number of Equations**	**Variable**	**Number of Variables**
	EXPORTS BLOCK			
PEDEF$_c$	$PE_c = PWE_c * ER * \left(1 - TE_c\right) \qquad \forall ce$	*ce*	PE_c	*ce*
CET$_c$	$QXC_c = at_c * \left(\gamma_c * QE_c^{rhot_c} + \left(1-\gamma_c\right) * QD_c^{rhot_c}\right)^{\frac{1}{rhot_c}} \qquad \forall ce \textbf{ AND } cd$	*c*	QDD_c	*c*
ESUPPLY$_a$	$\frac{QE_c}{QD_c} = \left[\frac{PE_c}{PD_c} * \frac{\left(1-\gamma_c\right)}{\gamma_c}\right]^{\frac{1}{\left(rhot_c - 1\right)}} \qquad \forall ce \textbf{ AND } cd$	*c*	QE_c	*c*
EDEMAND$_c$	$QE_c = econ_c * \left(\frac{PWE_c}{pwse_c}\right)^{-eta_c} \qquad \forall ced$			
CETALT$_c$	$QXC_c = QD_c + QE_c \qquad \forall \left(cen \textbf{ AND } cd\right) \textbf{ OR } \left(ce \textbf{ AND } cdn\right)$			

Name	Equation	Number of Equations	Variable	Number of Variables
	IMPORTS BLOCK			
PMDEF$_c$	$PM_c = PWM_c * ER * (1 + TM_c) \qquad \forall cm$	cm	PM$_c$	cm
ARMINGTON$_c$	$QQ_c = ac_c \left(\delta_c QM_c^{-rhoc_c} + (1 - \delta_c) QD_c^{-rhoc_c} \right)^{-\frac{1}{rhoc_c}} \qquad \forall cm \textbf{ AND } cx$	c	QQ$_c$	c
COSTMIN$_c$	$\frac{QM_c}{QD_c} = \left[\frac{PD_c}{PM_c} * \frac{\delta_c}{(1 - \delta_c)} \right]^{\frac{1}{(1+rhoc_c)}} \qquad \forall cm \textbf{ AND } cx$	c	QM$_c$	c
ARMALT$_c$	$QQ_c = QD_c + QM_c \qquad \forall (cmn \textbf{ AND } cx) \textbf{ OR } (cm \textbf{ AND } cxn)$			
	COMMODITY PRICE BLOCK			
PQDDEF$_c$	$PQD_c = PQS_c * (1 + TS_c + TEX_c)$	c	PQD$_c$	c
PQSDEF$_c$	$PQS_c = \frac{PD_c * QD_c + PM_c * QM_c}{QQ_c} \qquad \forall cd \textbf{ OR } cm$	c	PQS_c	c
PXCDEF$_c$	$PXC_c = \frac{PD_c * QD_c + (PE_c * QE_c)\$ce_c}{QXC_c} \qquad \forall cx$	cx	PXC_c	cx
	NUMÉRAIRE BLOCK			
CPIDEF	$CPI = \sum_c comtotsh_c * PQD_c$	1	CPI	1
PPIDEF	$PPI = \sum_c vddtotsh_c * PD_c$	1	PPI	1

Name	Equation	Number of Equations	Variable	Number of Variables
	PRODUCTION BLOCK			
PXDEF$_a$	$PX_a = \sum_c ioqxacqx_{a,c} * PXC_c$	a	PX_a	a
PVADEF$_a$	$PX_a * (1 - TX_a) * QX_a = (PVA_a * QVA_a) + (PINT_a * QINT_a)$	a	PV_a	a
PINTDEF$_a$	$PINT_a = \sum_c (ioqtdqd_{c,a} * PQD)_c$	a	PINT$_a$	a
ADXEQ$_a$	$ADX_a = \left[(adxb_a + dabadx_a) * ADXADJ\right] + (DADX * adx01_a)$	a	ADX$_a$	a
QXPRODFN$_a$	$QX_a = AD_a^x \left(\delta_a^x QVA_a^{-rhoc_a^x} + (1 - \delta_a^x) QINT_a^{-rhoc_a^x}\right)^{-\frac{1}{rhoc_a^x}}$ $\forall aqx_a$	a	QX_a	a
QXFOC$_a$	$\frac{QVA_a}{QINT_a} = \left[\frac{PINT_a}{PVA_a} * \frac{\delta_a^x}{(1 - \delta_a^x)}\right]^{\frac{1}{(1 + rhoc_a^x)}} \qquad \forall aqx_a$	a	$QINT_a$	a
	$QINT_a = ioqintqx_a * QX_a \qquad \forall aqx_a$			
QVADEF	$QVA_a = ioqvaqx_a * QX_a \qquad \forall aqxn_a$			
QINTDEF	$QINT_a = ioqintqx_a * QX_a \qquad \forall aqx_a$			

Name	**Equation**	**Number of Equations**	**Variable**	**Number of Variables**
QVAPRODFN$_a$	$QVA_a = AD_a^{va} * \left[\sum_{f\$\delta_{f,a}^{va}} \delta_{f,a}^{va} * ADFD_{f,a} * FD_{f,a}^{-\rho_a^{va}} \right]^{-1/\rho_a^{va}}$	a	QVA_a	a
QVAFOC$_{f,a}$	$WF_f * WFDIST_{f,a} * \left(1 + TF_{f,a}\right)$ $= PVA_a * QVA_a * AD_a^{va} * \left[\sum_{f\$\delta_{f,a}^{va}} \delta_{f,a}^{va} * ADFD_{f,a} * FD_{f,a}^{-\rho_a^{va}} \right]^{-1}$ $* \delta_{f,a}^{va} * ADFD_{f,a}^{-\rho_a^{va}} * \delta_{f,a}^{va} * FD_{f,a}^{\left(-\rho_a^{va} - 1\right)}$	(f*a)	$FD_{f,a}$	(f*a)
QINTDEQ$_c$	$QINTD_c = \sum_a ioqtdqd_{c,a} * QINT_a$	c	QINTD$_c$	c
COMOUT$_c$	$QXC_c = adxc_c * \left[\sum_{a\$\delta_{a,c}^{xc}} \delta_{a,c}^{xc} * QXAC_{a,c}^{-\rho_c^{xc}} \right]^{-1/\rho_c^{xc}} \quad \forall cx_c \text{ and } cxac_c$ $QXC_c = \sum_a QXAC_{a,c} \quad \forall cx_c \text{ and } cxacn_c$	c	QXC$_c$	c
COMOUTFOC$_{a,c}$	$PXAC_{a,c} = PXC_c * QXC_c * \left[\sum_{a\$\delta_{a,c}^{xc}} \delta_{a,c}^{xc} * QXAC_{a,c}^{-\rho_c^{xc}} \right]^{-\left(\frac{1+\rho_c^{xc}}{\rho_c^{xc}}\right)}$ $* \delta_{a,c}^{xc} * QXAC_{a,c}^{\left(-\rho_c^{xc} - 1\right)} \quad \forall cxac_c$ $PXAC_{a,c} = PXC \quad \forall cxacn_c$	(a*c)	PXAC$_{a,c}$	(a*c)
ACTIVOUT$_{a,c}$	$QXAC_{a,c} = ioqxacqx_{a,c} * QX_a$	(a*c)	QXAC$_{a,c}$	(a*c)

Name	Equation	Number of Equations	Variable	Number of Variables
	FACTOR BLOCK			
$YFEQ_f$	$YF_f = \left(\sum_a WF_f * WFDIST_{f,a} * FD_{f,a} \right) + \left(factwor_f * ER \right)$	f	YF_f	f
$YFDISPEQ_f$	$YFDISP_f = \left(YF_f * \left(1 - deprec_f\right)\right) * \left(1 - TYF_f\right)$	f	$YFDIST_f$	f
	HOUSEHOLD BLOCK			
$YHEQ_h$	$YH_h = \left(\sum_f hovash_{h,f} * YFDISP_f \right) + \left(\sum_{hp} HOHO_{h,hp} \right)$ $+ HOENT_h + \left(hogovconst_h * HGADJ * CPI \right)$ $+ \left(howor_h * ER \right)$	h	YH_h	h
$HOHOEQ_{h,hp}$	$HOHO_{h,hp} = hohosh_{h,hp} * \left(YH_h * \left(1 - TYH_h\right)\right) * \left(1 - SHH_h\right)$	h*hp	$HOHO_{h,hp}$	h*hp
$HEXPEQ_h$	$HEXP_h = \left(\left(YH_h * \left(1 - TYH_h\right)\right) * \left(1 - SHH_h\right)\right) - \left(\sum_{hp} HOHO_{hp,h} \right)$	h	$HEXP_h$	h
$QCDEQ_c$	$QCD_c = \dfrac{\left(\sum_h \left(PQD_c * qcdconst_{c,h} + \sum_h beta_{c,h} * \left(HEXP_h - \sum_c \left(PQD_c * qcdconst_{c,h} \right)\right)\right)\right)}{PQD_c}$	c	QCD_c	c

Name	Equation	Number of Equations	Variable	Number of Variables
	ENTERPRISE BLOCK			
YEEQ$_e$	$YE_e = \left(\sum_f entvash_{e,f} * YFDISP_f \right) + \left(entgovconst_e * EGADJ * CPI \right) + \left(entwor_e * ER \right)$	1	YE	1
QENTDEQ$_{c,e}$	$QED_{c,e} = qedconst_{c,e} * QEDADJ$	c	QENTD$_c$	c
VENTDEQ$_e$	$VED_e = \left(\sum_c QED_{c,e} * PQD_c \right)$	1	VENTD	1
HOENTEQ$_{h,e}$	$HOENT_{h,e} = hoentsh_{h,e} * \begin{pmatrix} \left(YE_e * \left(1 - TYE_e \right) \right) * \left(1 - SEN_e \right) \\ - \sum_c \left(QED_{c,e} * PQD_c \right) \end{pmatrix}$	h	HOENT$_h$	h
GOVENTEQ$_e$	$GOVENT_e = goventsh_e * \begin{pmatrix} \left(YE_e * \left(1 - TYE_e \right) \right) * \left(1 - SEN_e \right) \\ - \sum_c \left(QED_c * PQD_c \right) \end{pmatrix}$	1	GOVENT	1

Name	Equation	Number of Equations	Variable	Number of Variables
	TAX RATE BLOCK			
TMDEF$_c$	$TM_c = ((tmb_c + dabtm_c) * TMADJ) + (DTM * tm01_c)$	cm	TM	cm
TEDEF$_c$	$TE_c = ((teb_c + dabte_c) * TEADJ) + (DTE * te01_c)$	ce	TE	ce
TSDEF$_c$	$TS_c = ((tsb_c + dabts_c) * TSADJ) + (DTS * ts01_c)$	c	TS	c
TEXDEF$_c$	$TEX_c = ((texb_c + dabtex_c) * TEXADJ) + (DTEX * tex01_c)$	c	TEX	c
TXDEF$_a$	$TX_a = ((txb_a + dabtx_a) * TXADJ) + (DTX * tx01_a)$	a	TX	a
TFDEF$_{f,a}$	$TF_{f,a} = ((tfb_{f,a} + dabtf_{f,a}) * TFADJ) + (DTF * tf01_{f,a})$	f*a	TF	f*a
TYFDEF$_f$	$TYF_f = ((tyfb_f + dabtyf_f) * TYFADJ) + (DTYF * tyf01_f)$	f	TYF	f
THYDEF$_h$	$TYH_h = ((tyhb_h + dabtyh_h) * TYHADJ) + (DTYH * tyh01_h)$	h	TYH	h
TYEDEF$_e$	$TYE_e = ((tyeb_e + dabtye_e) * TYEADJ) + (DTYE * tye01_e)$	e	TYE	e

Name	Equation	Number of Equations	Variable	Number of Variables
	TAX REVENUE BLOCK			
MTAXEQ	$MTAX = \sum_{c} \left(TM_c * PWM_c * ER * QM_c \right)$	1	MTAX	1
ETAXEQ	$ETAX = \sum_{c} \left(TE_c * PWE_c * ER * QE_c \right)$	1	ETAX	1
STAXEQ	$STAX = \sum_{c} \begin{pmatrix} TS_c * PQS_c * \\ \left(QINTD_c + QCD_c + QED_c + QGD_c + QINVD_c + dstocconst_c \right) \end{pmatrix}$ $= \sum_{c} \left(TS_c * PQS_c * QQ_c \right)$	1	STAX	1
EXTAXEQ	$EXTAX = \sum_{c} \left(TEX_c * PQS_c * QQ_c \right)$	1	EXTAX	1
ITAXEQ	$ITAX = \sum_{a} \left(TX_a * PX_a * QX_a \right)$	1	*ITAX*	1
FTAXEQ	$FTAX = \sum_{f,a} \left(TF_{f,a} * WF_f * WFDIST_{f,a} * FD_{f,a} \right)$	1	*FTAX*	1
FYTAXEQ	$FYTAX = \sum_{f} \left(TYF_f * \left(YF_f * \left(1 - deprec_f \right) \right) \right)$	1	FTAX	1
DTAXEQ	$DTAX = \sum_{h} \left(TYH_h * YH_h \right) + \sum_{e} \left(TYE_e * YE \right)$	1	*DTAX*	1

Name	Equation	Number of Equations	Variable	Number of Variables
	GOVERNMENT BLOCK			
YGEQ	$YG = MTAX + ETAX + STAX + EXTAX + FTAX + ITAX + FYTAX + DTAX$ $+\left(\sum_{f} govvash_f * YFDISP_f\right) + GOVENT + \left(govwor * ER\right)$	1	YG	1
$QGDEQ_c$	$QGD_c = qgdconst_c * QGDADJ$	c	QGD_c	c
VGDEQ	$VGD = \left(\sum_{c} QGD_c * PQD_c\right)$	1	VQGD	1
EGEQ	$EG = \left(\sum_{c} QGD_c * PQD_c\right) + \left(\sum_{h} hogovconst_h * HGADJ * CPI\right)$ $+\left(\sum_{e} entgovconst_e * EGADJ * CPI\right)$	1	EG	1

Name	Equation	Number of Equations	Variable	Number of Variables
	INVESTMENT BLOCK			
SHHDEF$_h$	$SHH_h = \left(\left(shhb_h + dabshh_h\right) * SHADJ * SADJ\right) + \left(DSHH * DS * shh01_h\right)$	h	SHH	H
SENDEF$_e$	$SEN_e = \left(\left(sen_e + dabsen_e\right) * SEADJ * SADJ\right) + \left(DSEN * DS * sen01_e\right)$	e	SEN	e
TOTSAVEQ	$TOTSAV = \sum_h \left(\left(YH_h * (1 - TYH_h)\right) * SHH_h\right)$ $+ \sum_e \left(\left(YE * (1 - TYE_e)\right) * SEN_e\right)$ $+ \sum_f \left(YF_f * deprec_f\right) + KAPGOV + \left(CAPWOR * ER\right)$	1	$TOTSAV$	1
QINVDEQ$_c$	$QINVD_c = \left(IADJ * qinvdconst_c\right)$	c	$QINVD_c$	c
INVEST	$INVEST = \sum_c \left(PQD_c * \left(QINVD_c + dstocconst_c\right)\right)$	1	$INVEST$	1
	FOREIGN INSTITUTIONS BLOCK			
YFWOREQ$_f$	$YFWOR_f = worvash_f * YFDISP_f$	f	$YFWOR_f$	f

Name	Equation	Number of Equations	Variable	Number of Variables
	MARKET CLEARING BLOCK			
FMEQUIL$_f$	$FS_f = \sum_a FD_{f,a}$	*f*	FS_f	*f*
QEQUIL$_c$	$QQ_c = QINTD_c + \sum_h QCD_{c,h} + \sum_e QED_{c,e} + QGD_c + QINVD_c + dstocconst_c$	*c*		
CAPGOVEQ	$KAPGOV = YG - EG$	1	*CAPGOV*	1
CAEQUIL	$CAPWOR = \left(\sum_c pwm_c * QM_c\right) + \left(\sum_f \frac{YFWOR_f}{ER}\right) - \left(\sum_c pwe_c * QE_c\right) - \left(\sum_f factwor_f\right) - \left(\sum_h howor_h\right) - entwor - govwor$	1	*CAPWOR*	1
VFDOMDEQ	$VFDOMD = \sum_c PQD_c * \left(\sum_h QCD_{c,h} + \sum_e QED_{c,e} + QGD_c + QINVD_c + dstocconst_c\right)$	1	*VFDOMD*	1
VENTDSHEQ	$VENTDSH_e = {VENTD_e}/{VFDOMD}$	1	*VENTDSH*	1
VGDSHEQ	$VGDSH = {VGD}/{VFDOMD}$	1	*VGDSH*	1
INVESTSHEQ	$INVESTSH = {INVEST}/{VFDOMD}$	1	*INVESTSH*	1
WALRASEQ	$TOTSAV = INVEST + WALRAS$	1	*WALRAS*	1

Name	Equation	Number of Equations	Variable	Number of Variables
	MODEL CLOSURE			
			$\overline{ER}$ or $\overline{CAPWOR}$	1
			$\overline{PWM_c}$ and $\overline{PWE_c}$ or $\overline{PWE_{cedn}}$	2c
			$\overline{SADJ}, \overline{SHADJ}, \overline{SEADJ}$ or $\overline{IADJ}$ or $\overline{INVEST}$ or $\overline{INVESTSH}$	1
			$\overline{QEDADJ}$ or $\overline{VED}$ or $\overline{VEDSH}$	1
			At least **one** of $\overline{TMADJ}$, $\overline{TEADJ}$, $\overline{TSADJ}$, $\overline{TEXADJ}$, $\overline{TFADJ}$, $\overline{TXADJ}$, $\overline{TFADJ}$, $\overline{TYHADJ}$, $\overline{TYEADJ}$	7
			$\overline{DTM}, \overline{DTE}, \overline{DTS}, \overline{DTEX}, \overline{DTF}, \overline{DTX}, \overline{DTYF}, \overline{DTYH}, \overline{DTYE}$, and $\overline{CAPGOV}$	
			at least **two** of $\overline{QGDADJ}$, $\overline{HGADJ}$, $\overline{EGADJ}$, $\overline{VGD}$ and $\overline{VGDSH}$	3
			$\overline{FS_f}$ and $\overline{WFDIST_{f,a}}$	(f*(a+1))
			$\overline{CPI}$ or $\overline{PPI}$	1

Eidesstattliche Erklärung

1. Hiermit erkläre ich, dass diese Arbeit weder in gleicher noch in ähnlicher Form bereits anderen Prüfungsbehörden vorgelegen hat.

Weiter erkläre ich, dass ich mich an keiner anderen Hochschule um einen Doktorgrad beworben habe.

Göttingen, den 03.04.2017

Andrea Polese

(Unterschrift)

2. Hiermit erkläre ich eidesstattlich, dass diese Dissertation selbständig und ohne unerlaubte Hilfe angefertigt wurde.

Göttingen, den 03.04.2017

Andrea Polese

(Unterschrift)