Zentrum für Entwicklungsforschung

Trees, crops, and rural livelihoods: Afforestation of marginal croplands in Uzbekistan

Inaugural – Dissertation

zur

Erlangung des Grades
Doktor der Agrarwissenschaften
(Dr.agr.)

der
Landwirtschaftlichen Fakultät

der
Rheinischen Friedrich-Wilhelms-Universität Bonn

vorgelegt am 29.10.2013

von

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Tag der mündlichen Prüfung:	26.03.2014
Erscheinungsjahr:	2014

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Abstract

The livelihoods of rural population in Uzbekistan, Central Asia, highly depend on irrigated agriculture. However, agricultural production is threatened by the impacts of land degradation, irrigation water scarcity and climate change. The conversion of marginal croplands to tree plantations could represent an option to tackle such problems, while also improving population welfare. Yet, this land use is currently not practiced, owing to lack of farmers' knowledge on revenues and impacts on livelihoods. In addition, state policies prohibit the conversion of croplands into tree plantations. Therefore, the main objective of this study is to investigate economically viable options of afforestation of degraded irrigated croplands using an example of the Khorezm region and three southern districts of the Autonomous Republic of Karakalpakstan, Uzbekistan. This includes analyzing the impacts on the rural livelihoods by Clean Development Mechanism (CDM) afforestation with its carbon sequestration reward of temporary Certified Emission Reduction (tCER). Using an example of irrigated areas in Uzbekistan, this study contributes to the general knowledge of sustainable rural development via converting marginal lands from crop cultivation to tree plantations.

This research employed various methodologies at different scales to evaluate the economic conditions of introducing short-rotation tree plantations along with the CDM requirements. At the field level analysis (1 ha), the net present value and stochastic dominance analyses were employed to investigate the financial attractiveness of afforestation on marginal croplands and to derive tCER payments that would initiate CDM afforestation. At the farm level, the expected utility method was employed to determine the tCER price that would facilitate CDM afforestation on marginal croplands, and to analyze respective effects on land use and farm incomes. At the system level, that comprises commercial farms and rural households, the farm-household stochastic dynamic nonlinear programming model was developed to analyze the effects on rural livelihoods from converting marginal farmlands to tree plantations.

The results of the study indicate that due to benefits from non-timber products the short-term afforestation can be a more viable land use option on marginal croplands than the cultivation of major crops. At the same time, using the field level analysis while considering variabilites in land use revenues would necessitate an extreme increase in tCER prices, from the current tCER price of 4.76 USD (as of 2009). In contrast, when considering uncertainties in land use returns at the whole farm level, the current tCER price would be sufficient to initiate CDM afforestation. This is because tree plantations would economically improve a commercial farmer's cropping pattern, while mitigating the impacts of revenue risks via a land use diversification option. Afforestation of marginal croplands at a commercial farm would affect the structure of employment and agricultural contracts between commercial farm and rural households, and thus have positive spillover effects on the rural population and increase of rural households' income by 27,400 USD in comparison to crop cultivation on marginal lands. The spillover effects would come from the reduced labor demand at commercial farm between the periods of tree plantation establishment and harvest, while the subsequent increase in farm employment would occur during the establishment and harvest of trees. The inclusion of fuelwood and tree foliage into the payment schemes would replace fossil fuels and fodder products and reduce rural households' expenditure for domestic energy (36%) and fodder products (15%).

Bäume, Getreide und ländlichen Existenzgrundlage: Aufforstung auf unproduktiven landwirtschaftlichen Flächen in Usbekistan

Zusammenfassung

Bewässerungslandwirtschaft stellt die Existenzgrundlage der ländlichen Bevölkerung in Usbekistan (Zentralasien) dar. Die landwirtschaftliche Produktion wird jedoch durch Bodendegradation, Wasserknappheit und die Folgen des Klimawandels bedroht. Die Umnutzung nicht produktiver Landwirtschaftsflächen zu Baumplantagen stellt eine Möglichkeit dar solchen Problemen zu begegnen und gleichzeitig die Gesamtwohlfahrt zu steigern. Da Erträge und Rückkopplungen dieser alternativen Nutzungsstrategien noch unklar sind, wird diese Landnutzung jedoch noch nicht praktiziert. Politische Richtlinien verbieten die Umnutzung von landwirtschaftlicher Produktionsfläche zu Baumplantagen ohnehin. Entsprechend sind die Ziele der vorliegenden Arbeit ökonomisch durchführbare Aufforstungsvarianten an Beispielen in der Region Khorezm sowie den drei südlichen Distrikten der autonomen Republik Karakalpakstan zu untersuchen. Dies beinhaltet die Analyse der Auswirkungen des Mechanismus für umweltverträgliche Entwicklung (Clean Development Mechanism–CDM) samt der temporären Emissionsreduktionseinheiten (temporary Certified Emission Reduction–tCER) auf die Existenzgrundlage der ländlichen Bevölkerung. Anhand des Beispiels der Bewässerungslandwirtschaft in Usbekistan trägt diese Studie zum generellen Verständnis nachhaltiger ländlicher Entwicklung durch Umnutzung nicht produktiver landwirtschaftlicher Flächen zu Baumplantagen bei.

Auf verschiedenen Skalen wurden verschiedene Methoden angewandt um die ökonomischen Rahmenbedingungen der Einführung von Kurzumtriebsplantagen unter Berücksichtigung der CDM Anforderungen zu analysieren. Auf Feldskala wurden die Kapitalwertmethode sowie die stochastische Dominanzanalyse angewandt um zu bestimmen, wie attraktiv besagte Aufforstungensstrategien aus finanzieller Sicht sind und um tCER Zahlungen abzuleiten, die Aufforstungen unter CDM anstoßen könnten. Auf Betriebsebene wurde die Erwartungsnutzen Methode andewandt um die tCER Preise zu bestimmen, die CDM Aufforstung ermöglichen würden sowie um die entsprechenden Effekte auf Landnutzung und Einkommen der Landwirte und Haushalte zu analysieren. Auf Systemebene, die landwirtschaftliche Großbetriebe sowie ländliche Haushalte beinhaltet, wurde das Stochastische Dynamische Betriebs-Haushalts Programmierungsmodell entwickelt um die Effekte der Aufforstung auf die ländlichen Existenzgrundlage zu analysieren.Die Ergebnisse der vorliegenden Studie lassen darauf schließen, dass kurzfristige Aufforstungsmaßnahmen durch Gewinne aus Nichtholzprodukten für den Landwirt mehr Einkommen generieren als der Anbau der gängigen Feldfrüchte. Gleichzeitig zeigt die Analyse auf Feldskala unter Berücksichtigung von Ertragsvariabilitäten, dass eine Erhöhung der tCER Preise vom momentanen Stand (4.76 USD im Jahr 2009) nötig wäre. Gegenläufig verhalten sich die Ergebnisse auf Betriebsebene; hier wären die angenommenen tCER Preise ausreichend um CDM Aufforstung zu initialisieren. Grund hierfür ist die Tatsache, dass Baumpflanzungen die Fruchtfolge von Großbetrieben ökonomisch verbessern würden und gleichzeitig das Umsatzrisiko durch die Möglichkeit zur Diversifikation herabsetzen. Aufforstung von unproduktiven Landwrtschaftsflächen auf Ebene der Großbetriebe hätte Auswirkungen auf die Beschäftigungsstrukturen und die Vertragsverhältnisse zwischen Großbetrieben und der ländlichen Bevölkerung. Externe Effekte würden hier das Einkommen der ländlichen Haushalte im Vergleich zum Anbau klassischer Feldfrüchte um 27,400 USD erhöhen. Diese externen Effekte beruhen auf dem niedrigeren Bedarf an Arbeitskräften in Großbetrieben zwischen Pflanzung der Bäume und Rodung. Die Einführung von Brennholz und Blattwerk in die Vergütungsstruktur würde fossile Brennstoffe und Futterkäufe ersetzen und dadurch die Ausgaben der Haushalte für Energie (36%) und Futterzukäufe (15%) verringern.

Table of contents

List of Acronyms and Abbreviations

BAU	Business-as-usual
Bonitet	Soil fertility indicator
C	Carbon
CO_2	Carbon dioxide
CAC	Central Asian Countries
CE	Certainty Equivalent
CER	Certified Emission Reduction
CDM A/R	Clean Development Mechanism Afforestation and Reforestation projects
CA	Cluster Analysis
Dekhqans	Smallholders in Uzbekistan
EU	Expected utility
GHG	Greenhouse gases
GDP	Gross Domestic Product
GM	Gross Margins
IRR	Internal Rate of Return
lCER	Long-term Certified Emission Reduction
tCER	Temporary Certified Emission Reduction
MAWR	Ministry of Agriculture and Water Resources of Uzbekistan
NPV	Net Present Value
NQ–QES	Normalized Quadratic–Quadratic Expenditure System
PCA	Principal Component Analysis
SD	Stochastic Dominance
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

Units

USD	United States Dollar
ha	hectare
kg	kilogram
t	tone

Exchange rate

1 USD = 2,200 Uzbekistan soum

Acknowledgments

I would like to express my deep gratitude to all who have contributed to this research.

I gratefully acknowledge the support of the Robert Bosch Foundation for the implementation of this study within the framework of the German-Uzbek Agroforestry project, the International Postgraduate Studies in Water Technologies program of BMBF for funding my doctoral research and the Dr. Herman Eiselen Doctoral program of the Foundation fiat panis for the financial support to participate in conferences. The supports of the ZEF/UNESCO program in the Khorezm region as well as South Karakalpakstan Water Resources Management Improvement Project are also highly appreciated.

The thesis would have been a lot more difficult without the support and encouragement of many people. I am thankful to Prof. Dr. Joachim von Braun for his motivating academic guidance and advice, and challenging me with constructive comments to improve my dissertation. Prof. Dr. Ernst Berg inspired and provided useful guidance during my research especially with regard to the implementation of risk and uncertainty in the model. I am grateful to Dr. Anik Bhaduri for his helpful tutoring and thorough reviews of my thesis throughout the PhD period. I am also thankful to Prof. Dr. Asia Khamzina for the opportunity to be involved in the German-Uzbek Agroforestry project, and her research advices particularly in incorporating of agroforestry aspect into my study. Special thanks to Dr. John P.A. Lamers, who gave valuable ideas and continued encouragement before and during PhD.

I would like to thank my colleagues from the project, especially Holm Voigt for his help in translating into German the abstract of my thesis and Julia Tüshaus in preparing for me the map of the study area. My sincere thanks go to Prof. Dr. Kristof van Assche, Dr. Günther Manske, Mrs. Zabel, Mrs. Maike Retat-Amin, Dr. Kirsten Kienzler, Dr. Ihtiyor Bobojonov and Dr. Marc Müller, senior and junior researchers and administration in ZEF, and ZEF/UNESCO project team. I also would like to thank my research assistants, as well as farmers, rural households and other respondents, who were willing to be interviewed during my surveys. I want to express my cordial thanks to Dr. Grace B. Villamor and Dr. Nodir Djanibekov for their inspiring guidance, valuable advices, constant encouragement, support and friendship, which contributed to an enjoyable time during my PhD, both academically and personally.

I dedicate this accomplishment to my parents.

1. Introduction

1.1 Role of afforestation on marginal irrigated croplands

Unsustainable land use practices are one of the major causes of global environmental change (Turner et al., 2007), such as illustrated in 50% decline of the land productivity (Bai et al., 2008). Cropland degradation reduces agricultural production and on a global scale annually costs about 400 billion USD, thus affecting 1.5 billion people (Lal, 1998; Bai et al., 2008). Irrigated agricultural systems experience cropland degradation on 20% of the area, with 2,500-5,000 km^2 lost due to excessive salt and waterlogging every year (Bai et al., 2008; UNEP, 2009). In Central Asian countries (CAC), where the economy is relying on irrigated agriculture, approximately 30% of irrigated croplands are considered marginal (El Beltagy, 2002), which could further be exacerbated through temperature increases of 1-2°C (Lioubimtseva et al., 2005) and reduction in irrigation water resources (Perelet, 2007), resulting in economic losses to agricultural producers. Uzbekistan is one of the CAC where the rural welfare heavily depends on irrigated agriculture, and at the same time faces acute problems of irrigated areas. At present, around half of its arable lands are affected by different levels of salinity, and 25% of croplands are considered as having marginal productivity, mainly belonging to commercial farms and leading to economic losses in the region (MAWR, 2010). Moreover, to date, the downstream areas of CAC, such as Uzbekistan, have increased agricultural water demand due to deteriorating irrigation and drainage systems, and at the same time the frequency of droughts have also increased in these regions (Bucknall et al., 2003). Consequently, these problems lead to risks for agricultural production and have repercussions on the livelihoods of rural population in the country (Bobojonov, 2008).

Despite several options proven to be suitable for land improvement while contributing to climate change mitigation, sustainable irrigation water use and improvement of rural welfare, there are few incentives for investing in such activities (Reij and Waters-Bayer, 2001; Bobojonov, 2008). This is because such activities and technologies require high costs of waiting, and absence of secure tenure rights, a relative abundance of arable land and its low market value further prevents investments (Scherr, 2000; Reij and Waters-Bayer, 2001). Therefore, appropriate land use practices and policies are required to prevent and cope with these problems while improving rural welfare. Several studies showed that marginal croplands failing to generate economic returns from crop production can be converted into tree plantations and provide various products (Van Kooten, 2000; Lamers et al., 2006; Niu and Duiker, 2006; Croitoru, 2007; ICRAF, 2007; Khamzina et al., 2012). The introduction of forestry practices on commercial farms' marginal lands is one such effective land use practices that could make more food available, reduce poverty and improve the environment (ICRAF, 2007; UNEP, 2011). Moreover, afforestation[1] could diversify farmland use, buffer against agricultural market (e.g., price volatility) and production (e.g., reduced crop yields) risks (Baumgärtner and Quaas, 2010). Diversifying farming activities through afforestation could reduce the impacts of agricultural risks by providing various products to land users (Knoke et al., 2008). According to Babu and Rajasekaran (1991), the introduction of tree plantations in irrigated agricultural systems would increase incomes and thus reduce the negative impacts of revenue risks of crops. Furthermore, afforestation of marginal croplands can combat land degradation via replenishing nutrient stocks for lowering soil salinity (Khamzina et al., 2008, 2009a, 2012). Given that trees can rely on elevated groundwater and require less irrigation water than crops, the water not used for marginal lands could be applied on fertile lands, thus expanding the impact of tree planting beyond the afforested area (Wallace, 2000; Khamzina et al., 2012).

In addition, in the recent decades the issue of global warming has become a major environmental concern; with the reduction of greenhouse gases (GHG) in the atmosphere via terrestrial ecosystems have attracted the wide attention of policy makers. Indeed, afforestation of degraded croplands in drylands may represent a suitable land use that sequesters carbon (C) (Nosetto et al., 2006; Khamzina et al., 2012). Storing C via such land uses is considered as a cheaper solution to decrease emissions, as opposed to other offset schemes (Boyd et al., 2007). Sequestering C in wood could generate additional benefits for farmers in the form of Certified Emission Reduction (CER) obtained through participation in the Clean Development Mechanism Afforestation and Reforestation (CDM A/R) projects of the Kyoto Protocol. This type of projects are the most common source of forest C credits, accounting for half of the forest C market value (52.2 million USD), i.e., CDM, Reducing Emissions from Deforestation and Forest Degradation and other activities implemented to enhance C stocks (Hamilton et al., 2010). The CDM A/R projects have dual aims, namely addressing climate change mitigation and sustainable development, thus contributing to the environment and livelihoods of rural communities (Palm et al., 2009). To address the non-permanence issue of C sequestration, i.e., emission reductions in forestry projects are reversible, the CDM has defined temporary and long-term Certified Emission Reductions (tCERs and lCERs) (Neeff and Henders, 2007). Short-term credits (tCERs) are valid for a commitment period of five years and credits for C stocks are re-issued following each verification event (Neeff and Henders, 2007).

[1] In this study, the terms “afforestation”, “tree plantations” and “farm forestry” are used interchangeably.

Despite the environmental and economic attractiveness of tree planting on marginal croplands, such land use is not currently practiced in Uzbekistan. The main reason is that current legislation in Uzbekistan does not permit the conversion of croplands into tree plantations (Kan et al., 2008; Djanibekov et al., 2012b). Long-term land use investments such as tree plantations are also constrained by transition policies such as the state cotton procurement, the continuous and nonlinear manner of commercial farm restructuring process and land tenure insecurity (Kan et al., 2008; Djanibekov et al., 2010a). Hence, flexibility in land use policies may increase attractiveness of afforestation, and short-term afforestation could be considered a preferable practice for farmers (Djanibekov et al., 2012c; Djanibekov et al., 2013b). Furthermore, given that Uzbekistan is a member of the international agreement in the Kyoto Protocol, afforestation in the framework of the CDM with temporary CER (tCER) could provide security for commercial farmers for investing into tree plantations, and define property rights of their land through participation in the CDM. However, the economic impacts of C forestry on marginal croplands have contrasting results according to existing literature. Xu et al. (2007) concluded that C sequestration tree projects can be regarded as a poverty alleviation measure in the underdeveloped areas. In contrast, a study estimating the economy-wide impact of CDM forestry by Glomsrød et al. (2011) found that such projects reveal weakness in reducing poverty. High initial investments and low CER revenues reduce the economic attractiveness of CDM afforestation[2] on marginal croplands, while the CER payments may be insufficient to initiate such land use (Tal and Gordon, 2010; Thomas et al., 2010). Moreover, even though it is important to identify price of supplied environmental services, e.g., CER, to incentivize afforestation on marginal croplands (Costanza et al., 1997; Engel et al., 2008), the main problem for farmers could relate to uncertainty over its returns (Schatzki, 2003). The environmental payments and overall profits of afforestation depend on different revenue uncertainties, e.g., yield and price, and their variability may result in negative and positive outcomes. Consequently, uncertainties in returns of afforestation may reduce commercial farmers' interest in such land use (Castro et al., 2013).

Furthermore, in Uzbekistan, afforestation of marginal croplands is considered a new land use practice, with farmers lacking knowledge of its possible benefits and costs, as well as management practices and general impact on their wellbeing (Kan et al., 2008). The shift of agricultural land to tree plantation may have wider effects beyond the borders of an implementing commercial farm. In many post-socialist countries, farm reforms have resulted in a bimodal

[2] In this study, the terms "CDM afforestation", "CDM forestry", and "C forestry" are used interchangeably.

farming system comprising large-scale commercial farms and rural households (Kostov and Lingard, 2002; Lerman et al., 2004). These two agricultural actors are interdependent through agricultural contract relationships, whereby commercial farms hire rural households to accomplish their farming activities. Such changes in commercial farm employment are vital in environmental projects, especially for non-participating rural population that may have limited means to earn income yet depend on activities at commercial farm (Pagiola et al., 2005). Accordingly, in countries such as Uzbekistan, where commercial farms represent one of the main sources of rural employment, the implementation of afforestation projects will have spillover effects on rural households, which impact is currently unknown.

1.2 Motivation of the study

Previous research that focused on the introduction of new land use options and their impact on rural livelihoods and ecology have emphasized issues of sustainable development in irrigated regions (MEA, 2005; Stringer et al., 2012; Stringer and Dougill, 2012). Some of these researchers focused on crop and agricultural diversification (e.g., Pingali and Rosegrant, 1995; Bobojonov et al., 2012), the introduction of alternative irrigation and soil conservation practices (Dixon et al., 1989; Reij and Waters-Bayer, 2001). However, such practices may not be always efficient to implement on marginal croplands and in transitional country settings (Djanibekov et al., 2012b). Other studies focused on introducing afforestation on marginal croplands, considering aspects of farm diversification, new land use practices and the necessity of delivering knowledge on such innovative land use to population (Niu and Duiker, 2006; Kan et al., 2008; Lamers et al., 2008; Hegde and Bull, 2011). Afforestation of marginal croplands is influenced by agricultural characteristics, and vice versa, and hence, in agricultural settings, both afforestation and crop cultivation need to be considered simultaneously. At the same time, the multiple benefits of trees, e.g., fruits for consumption, fuelwood for cooking and heating, leaves for livestock fodder, and ecosystem services such as C sequestration and land rehabilitation (Khamzina et al., 2012), would further necessitate considering various socio-economic and environmental aspects. In bimodal farming systems such as in Uzbekistan, afforestation of marginal croplands will have both direct and indirect effects on rural livelihoods through agricultural contract relationship (Djanibekov et al., 2013b). Agricultural contracts between commercial farms and rural households could provide useful information to examine the changes in rural economy. However, previous studies on afforestation of marginal croplands and CDM forestry did not simultaneously consider its multiple products (e.g., tCER payments, fuelwood, leaves as fodder, fruits), uncertainties in revenues (e.g., variability in yields, prices and irrigation water availability), coping with income risks (e.g., land use diversification), and the direct and indirect effects on rural incomes in irrigated agricultural settings (Van Kooten, 2000; Niu and Duiker, 2006; Xu et al., 2007; Shuifa et al., 2010; Glomsrød et al., 2011; Knoke et al., 2011). Accordingly, before providing recommendations on implementing afforestation on marginal croplands in irrigated areas to both decision and policy makers, it is necessary to analyze the multidimensional effects of such land uses on rural livelihoods. This research attempts to provide scientific guidance with respect to the possible changes in rural livelihoods from introducing afforestation on degraded croplands under the CDM framework in irrigated drylands of Uzbekistan.

1.3 Objectives, research questions and hypothesis

1.3.1 Objectives of the study

Taking the aforementioned research challenges into account, the overall goal of this study is to analyze the diversity of effects from afforestation on degraded irrigated croplands of commercial farms in Uzbekistan, exemplified by the Khorezm region and three southern districts of the Autonomous Republic of Karakalpakstan. The specific objectives of this study are as follows:

- To evaluate the financial attractiveness of afforestation on marginal croplands, and its tCER price;
- To investigate the impact of afforestation on marginal croplands on farm income and determine tCER price of such land uses under uncertainty;
- To investigate direct and indirect impacts on rural livelihoods from shifting crop cultivation on marginal lands to tree plantations; and
- To identify rural development policies that may be efficient for land use change, including shifting crop cultivation on marginal lands to tree plantations.

1.3.2 Research questions

Based on the above objectives, the research questions for this study are as follows:

- What tCER price level would make CDM afforestation attractive for commercial farmers in the study area?

- What are the options of afforestation of marginal croplands to cope with land use revenue risks?

- What are the impacts of afforestation of marginal croplands on rural livelihoods?

- What policies are needed to facilitate the adoption of more sustainable land use on marginal lands – afforestation?

1.3.3 Hypothesis

Establishing CDM afforestation on commercial farms' degraded croplands in Uzbekistan would bring benefits not only for ecological improvement, but also in diversifying land use and increasing the risk coping abilities of agricultural producers and consequently their incomes. Accordingly, the overall hypotheses of this study are summarized as following:

- Afforestation of degraded croplands is presently more profitable than the current cropping systems on such lands;

- Diversifying farming activities by including tree plantations on marginal croplands will reduce the effects of agricultural revenue risks; and

- Planting trees on marginal croplands will increase rural livelihoods.

1.4 Conceptual framework

This research addresses issues of the efficient use of degraded croplands, while increasing rural incomes and coping with land use revenue risks with regard to land use change through afforestation of marginal croplands. This study aims to provide options for action to decision and policy makers by assessing the possible impacts of introducing afforestation on marginal croplands in irrigated drylands, where the tree planting is currently not practiced.

The conceptual framework of this study relates the interaction of both crop cultivation and afforestation of marginal lands on commercial farm, considering the spillover effects on rural household (Figure 1.1) under modifications of agricultural policy and under different risks affecting land use revenues. The introduction of tree plantations on marginal croplands at commercial farm depends on the crops cultivated on both marginal and productive lands, policy settings (i.e., state cotton procurement policy) as well as market and production conditions (i.e., uncertainties in prices, yields and irrigation water availability). At the same time, to allow for tree planting on marginal croplands, the state policy settings should permit more flexible decision making. Given that afforestation is a new land use practice, introducing it may lead to changes in crop production, and the diversification of commercial farmland and hence risk managing options of agricultural production. As the farms and rural households are closely interrelated through agricultural contracts in land and labor use and commodity exchange, the changes in the usage of commercial farmland will consequently affect rural households employed at these farms through changes in farm activities. Consequently, the change in livelihoods conditions of these rural households may occur as a response to the altered farm employment. Besides, change in the payment structure affects the activities module of farm and rural households. For instance, the inclusion of tree products such as leaves as fodder and fuelwood into the agricultural contracts will have an effect on rural household expenditures on purchasing expensive fodder and energy products. Payment structure also have a feedback effect on land use decisions (e.g., via land transfers from farm to rural households). The land use decisions of rural household are also affected by the market and production conditions (i.e., uncertainties in prices, yields and irrigation water availability).

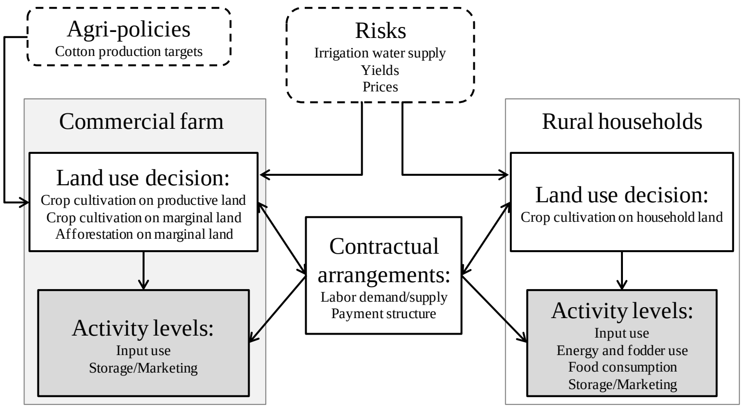

Figure 1.1: Conceptual framework of the study.

The following four analytical modules are employed to operationalize the conceptual framework of this study: (1) field level analysis of net present value (NPV) of tree plantations and their opportunity cost on marginal lands, i.e., crops, and the required tCER price level to initialize afforestation within the CDM framework. This approach calculates and compares NPV of CDM afforestation on marginal lands with other crops on a hectare level; (2) commercial farm level analysis of land use diversification options of afforestation and the determination of tCER value under uncertainty by using two approaches – stochastic dominance and expected utility. In this module, uncertain profits of afforestation on marginal lands are compared with crops, and analyzed the changes in land use pattern and the income of whole farm under market and production uncertainties; (3) principal component and cluster analyses to classify and determine rural households that depend on commercial farm employment; and (4) the application of analysis at levels of the revealed farm-household interdependencies of the impact of afforestation on rural livelihoods in the bimodal agricultural system, using a stochastic dynamic nonlinear programming model. The model simultaneously considers the direct impacts of afforestation on commercial farm incomes and spillover effects on rural households' livelihoods.

1.5 Structure of the thesis

Following this introduction chapter, Chapter 2 provides a description of the socio-economic and agro-ecological situation in the study area, and the role and possibility of planting trees on its marginal croplands. This information serves to provide a background of the study area, which will be used to construct and develop analytical models. Chapter 3 addresses the first research objective and analyzes costs and benefits of afforestation on marginal croplands and its tCER price. In Chapter 4 the second research objective is tackled, and the impact of afforestation of marginal croplands on farm income and tCER price under uncertainty is analyzed. For this, a one hectare level and whole-farm level analysis was performed and compared. Following that chapter, Chapter 5 tackles the third and fourth research objectives, and analyzed the direct and indirect impacts on rural livelihoods from shifting crop cultivation on marginal farmlands to tree plantations. In that chapter, rural households are first classified and further the impacts on rural livelihoods from afforestation on marginal croplands are presented. Chapter 6 summarizes the main findings of the study and provides policy recommendations on the impact and adoption of afforestation on marginal croplands.

2. Background of the study area

This chapter provides an overview of the socio-economic, agro-ecological and institutional characteristics of the study area. The description is subdivided according to the geographical characteristics of the study area, agricultural production, bimodal agricultural system, agricultural policies, afforestation of marginal croplands in Uzbekistan, and CDM afforestation.

2.1 Geographical characteristics of the study area

The study area of this research covers the Khorezm region and three southern districts of the Autonomous Republic of Karakalpakstan, namely Beruniy, Ellikkala and Turtkul, located at the lowlands of the Amu Darya River in the northwestern part of Uzbekistan at 40.62 and 42.71 N latitude and 60.02 and 62.44 E longitude (Figure 2.1). The study area borders Karakum and Kizilkum deserts to the south and east, Turkmenistan to the southwest, and other districts of the Autonomous Republic of Karakalpakstan to the north. Around 270,000 ha in the Khorezm region is arable, while 140,000 ha in the southern districts of Karakalpakstan, and depend entirely on irrigation water diverted from the Amu Darya River.

The mean annual temperature has been 13°C over the past two decades, while with a minimum temperature of -30°C and the maximum of +50°C. The climate is arid with an annual precipitation of around 100 mm and evapotranspiration of 1,400-1,600 mm[3]. Given its downstream location on the Amu Darya River, the study area is one of final receivers of water for agricultural production. Nearly 2 million people reside in the study area with about 70% being rural. The economic, health and ecological conditions of the population is affected by the geographic proximity to the degrading Aral Sea area (Arzikulov et al., 2012; Niyazov et al., 2012). In this research, the Khorezm region and southern districts of the Autonomous Republic of Karakalpakstan are considered as one homogeneous study area with similar climate, soil properties, water use, crop growth, agricultural markets, policies and institutions.

[3]http://snobear.colorado.edu/Markw/Geodata/geodata.html

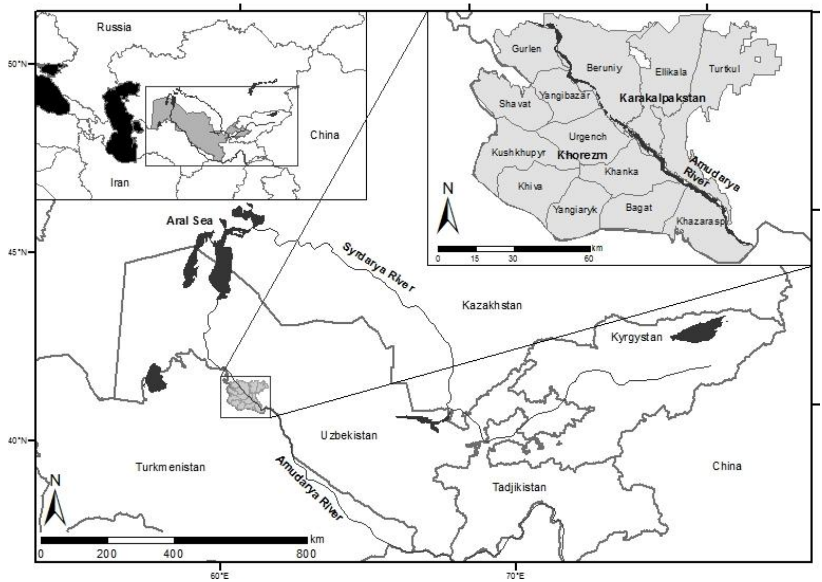

Figure 2.1: Map of the study area.

2.2 Agricultural production

Agriculture accounts for approximately 65% of the gross regional production, providing around 60% of employment in the study area (as of 2009) (State Statistical Committee of Uzbekistan, 2010). Cotton is the main crop contributing to agricultural export revenues, while winter wheat (hereafter referred to as wheat) is the main crop for food self-sufficiency. Wheat is mainly used as a double cropping system, grown as a first crop and followed by rice or maize in the summer season. Over recent years, the share of cultivated area of wheat has increased (Figure 2.2). An increase of the wheat area (by almost 23% of total sown area) was observed following the establishment of a policy of grain independence in 1992 (Djanibekov, 2008). In 2009, in response to the rising wheat prices in Uzbekistan due to the global food crisis and drought in the country, the government decreased the area under cotton cultivation in favor of wheat (MAWR, 2010). With regards to the livestock, the sector produces about 50% of the agricultural total output (State Statistical Committee of Uzbekistan, 2010). The main feed components for livestock include wheat and rice straw, maize and alfalfa.

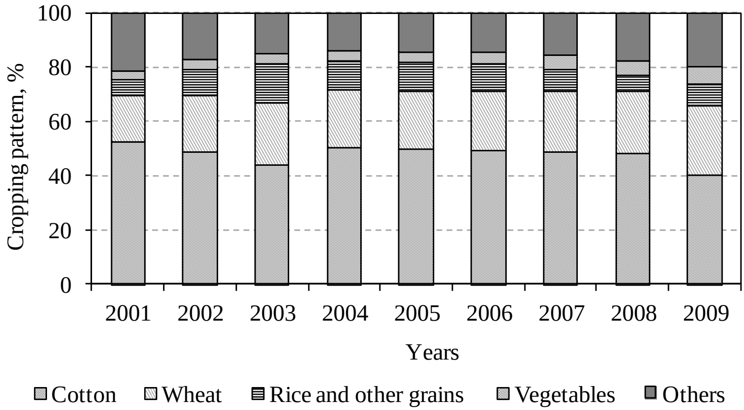

Figure 2.2: Cropping pattern in the study area.
Source: MAWR (2010).

2.2.1 Marginal croplands

Over the last decades, improper crop rotation, the low efficiency of drainage systems, and wind erosion have reduced the productivity of croplands (CACILM, 2006). Soil salinization is one of the main factors reducing land fertility in Uzbekistan, where between 1990 and 2001, the area of saline lands increased by 33%, resulting in more than 50% of the croplands being saline (Khusamov et al., 2009). Around 25% (880,000 ha) of croplands in Uzbekistan are considered marginal (MAWR, 2010), resulting in annual loss of 80 t ha^{-1} of fertile soil (CACILM, 2006). In the study area, the share of marginal lands is around 20-30% of total arable lands (MAWR, 2010). Crop cultivation on these marginal lands results in economic losses for farmers (Djanibekov et al., 2012b). Annually, Uzbekistan loses around 31 million USD due to salinization, and about 12 million USD is used to withdraw highly saline lands from agricultural production (World Bank, 2002). Besides, due to improper tillage practices cultivation of major crops, i.e., cotton and wheat, leads to the soil erosion (Nkonya et al., 2011). Economic losses from salinity for cotton and wheat is 13.3 million USD (Nkonya et al., 2011).

The productivity of croplands in Uzbekistan are classified by the *bonitet* level, a quantitative soil fertility indicator used to assess the land suitability for crop cultivation (Land Resources, 2002). It includes characteristics on soil texture, organic matter, salinity, and groundwater level

(Ramazanov and Yusupbekov, 2003). The climatic variables on temperature and humidity are considered homogeneous in a province level according to the *bonitet* level estimation (Land Resources, 2002). *Bonitet* estimation of arable lands is done with respect to the yield of the main crop – cotton. Rated on a 100 scale, lower than 41 *bonitet* level is considered marginal (Land Resources, 2002). In contrast, lands with 100 *bonitet* level are considered the most productive. Throughout the empirical analysis of this study, the marginal croplands are defined as those with a *bonitet* level lower than 41. In Table 2.1 is provided information concerning the main crops grown by productivity level in the Khorezm region, highlighting the main crops cultivated on marginal lands as cotton, wheat, maize and other fodder. As of 2005 around 23% of commercial farms' lands (for the description on commercial farms see Section 2.3.1) in the Khorezm region are considered below *bonitet* 41, 56% are between *bonitet* 41 and 60, 20% are between *bonitet* 61 and 80, and about 1% are highly productive soils with a *bonitet* level between 81 and 100 (Khorezm Region Land Cadastre, 2006).

Table 2.1: The area of the major crops by *bonitet* level in the Khorezm region (as of 2005).

Bonitet level	Soil fertility class	Crop area, ha			
		Cotton	Wheat	Maize and other fodder	Vegetables
0-10	Unsuitable for crops	0	0	0	0
11-20	Very low	0	0	10	0
21-30	Low	652	178	2,018	43
31-40	Poor	4,500	919	8,783	2,077
41-50	Lower than average	20,601	4,276	8,422	1,050
51-60	Average	49,754	14,728	7,334	1,723
61-70	Higher than average	22,312	8,969	3,028	681
71-80	Good	2,848	2,208	20	522
81-90	Very good	3	38	0	10
91-100	Highest	0	0	0	0

Source: Land Cadastre of Khorezm (2006).

2.2.2 Irrigation water and crop yield response

The annual evaporation substantially exceeds precipitation occurring during the autumn and winter seasons, thus making crop cultivation only feasible through irrigation. The main source for irrigating crop fields is the Amu Darya River (Martius et al., 2009). The croplands located further away from the river have low probability of receiving required amounts of water for crops (Tischbein et al., 2012). Consequently, the increase of water demand in the upstream countries could negatively affect irrigated agricultural production in downstream Uzbekistan, and particularly in the lower reaches of the Amu Darya River (Martius et al., 2009; Dukhovny and Ziganshina, 2011). Over recent years, the annual and seasonal fluctuations in water supply have increased, confirmed by observed drought in 2001 and 2008 (Müller, 2006; MAWR, 2010) (Figure 2.3). Between the period 2001 and 2009, the lowest irrigation water use level was 5,800 m^3 ha^{-1}, the highest was 14,900 m^3 ha^{-1}, and a standard deviation was 3,300 m^3 ha^{-1}. It is projected that the uncertainty of irrigation water availability will increase in the region (Glantz, 1999).

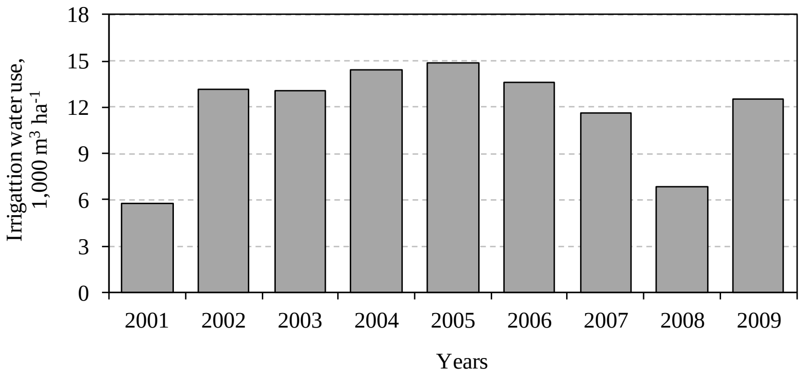

Figure 2.3: Irrigation water use in the Khorezm region in 2001-2009.
Source: MAWR (2010).

The irrigation water supply is designed according to the crop allocation areas and recommended values for the water-demand of different crops, with the water use recommendations employed by the water management organizations to plan water delivery to the users. Ministry of Agriculture and Water Resources of Uzbekistan (MAWR, 2001) developed recommendations for farmers to obtain certain crop yields depending on land productivity, i.e., *bonitet* level and irrigation rate. Figure 2.4 shows the water-yield response functions of the main crops in the study area on marginal, average, good, and highly productive lands, derived based upon recommendations provided by MAWR (2001) for farmers to achieve crop yields at certain *bonitet* level with applied irrigation rate. From this figure, rice is the most water-demanding crop, and has the same yield response irrespective of the soil productivity. In contrast, maize is the least water-demanding crop to achieve optimal yield. Due to the use of flood and furrow irrigation technique, there is a high water use per hectare. The water is not priced volumetrically, and the water users only pay fixed monthly fees.

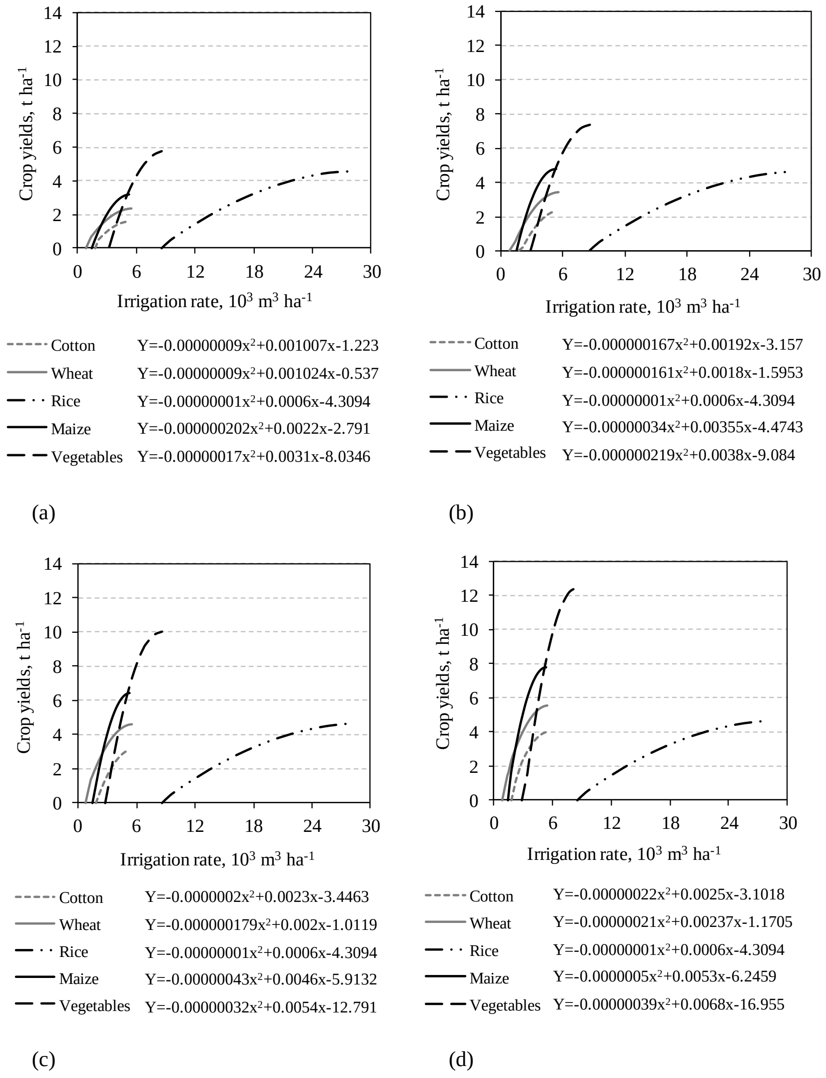

Figure 2.4: Crop water-yield response on marginal (a), average (b), good (c) and highly (d) productive lands.
Data source: MAWR (2001); Land Resources (2002).
Note: Y is the crop yield; X is the irrigation rate; X is larger than 0.

2.2.3 Variability in crop yields and prices

The fluctuations in irrigation water availability affect the soil properties and crop yields (Dubovyk et al., 2013). Accordingly, the crop yields vary in the study area (Figure 2.5). For instance, the average cotton yield was 2.4 t ha^{-1} between 2001 and 2009, while the lowest one was 1.7 t ha^{-1} observed in 2001, with the highest 2.7 t ha^{-1} observed in 2009. Rice was the most affected crop during the irrigation water scarce years. For example, the yield of rice was 1.9 t ha^{-1} in 2001, when the irrigation water availability was low (see Figure 2.3), and the average yield of this crop over 2001 and 2009 was 3.6 t ha^{-1}. As rural population largely depends on agricultural output, the risks of low crop yields may reduce the rural welfare. In overall, between years 2001 and 2009 yield of crops did not show the decreasing trend. Due to the underdeveloped infrastructure (e.g., storage, processing), fluctuation of irrigation water availability, as well as a lack of insurance options and risk coping mechanisms the variability of crop prices is also high (Bobojonov, 2008) (Figure 2.6). In particular, the hike in prices in 2008 may be explained by that year's drought, which reduced crop yields (Djanibekov et al., 2012a). High variability in prices was observed for wheat and rice with their prices almost increasing threefold in 2008 in comparison to the previous year. An increase in food price variability may have negative effects on rural population, and especially on those who rely on off-farm employment (von Braun and Tadesse, 2012). At the same time, there is no negative trend in crop prices.

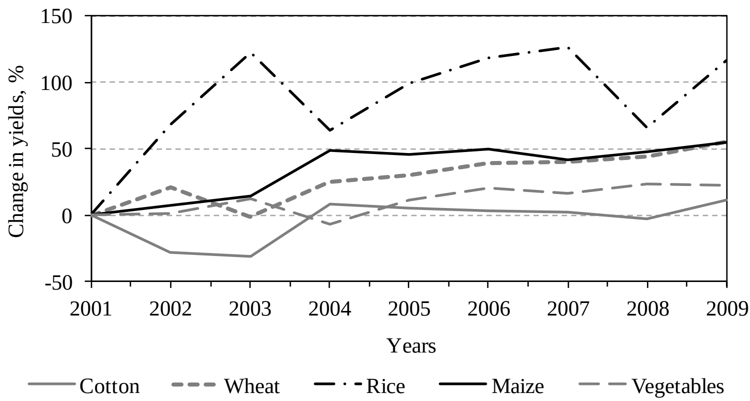

Figure 2.5: Change in crop yields in the study area in 2001-2009.
Source: MAWR (2010).
Note: 0% is initial yield level, i.e., observed in 2001.

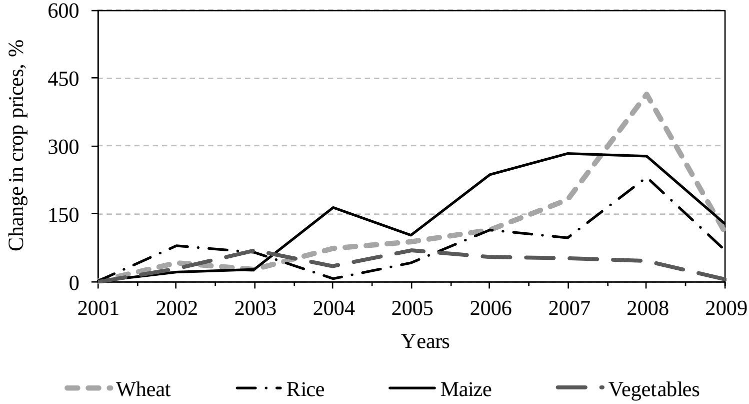

Figure 2.6: Change in crop prices in the study area in 2001-2009.
Source: MAWR (2010).
Note: 0% is initial price level, i.e., observed in 2001.

2.3 Bimodal agricultural system

In post-Soviet economies such as Central and Eastern Europe and Central Asia, agricultural production is organized in a bimodal agricultural system (Kostov and Lingard, 2002; Lerman et al., 2004). Bimodal agricultural system is comprised of large-scale commercial farms and rural households, which were formed as a result of economic reforms since independence in 1991. These two agricultural producers are distinguished according to their specialization, size, employment and other factors (Table 2.2). Commercial farms are defined as private agricultural enterprises managed under the long-term lease contract with the state (from 30 to 50 years), trading agricultural products and employing labor based on contract agreement. According to the state classification, the commercial farms are mainly divided into four typologies: (1) cotton-grain; (2) livestock; (3) horticulture; and (4) others. Rural households/smallholders (*dekhqans* in Uzbek) are the smallest agricultural producers in Uzbekistan, that produce for their own consumption, and whose incomes are limited to sales of their surplus crops and employment at commercial farms (Djanibekov, 2008).

Table 2.2: Characteristics of commercial farms and rural households in the study area.

	Characteristics of producers	
	Commercial farms	Rural households
Production specialization	Cotton-grain, livestock rearing, horticulture, and others	Vegetables, fruits, wheat, livestock products (consume largest share of own products)
State policies	Cotton and winter wheat procurement	No state procurement
Form of land tenure	Long-term lease contract (30-50 years)	Lifetime inheritable possession
Form of labor	Family workers and hired labor	Family workers
Employment	At own farm	At commercial farm and non-agricultural activities

Source: Djanibekov (2008), Veldwisch and Bock (2011), Own observation (2011).

2.3.1 Commercial farms

There are about 7,200 registered commercial farms (hereafter referred to as farms) in the study area, with a total arable land of about 350,000 ha (as of 2009) (State Statistical Committee of Uzbekistan, 2010). The dominant farm type is the cotton-grain and its average size is 100 ha (MAWR, 2010). The cotton-grain farm type has to fulfill the state procurement policies for cotton and wheat (for a description of the state procurement policy see Section 2.4.1). The second largest farm type is the livestock rearing, followed by the horticultural farm producers, and other farm typologies, which are small in size and few in number – vegetables and melons, sericulture, poultry, fishery, apiculture, and pig stock rearing (MAWR, 2010). The main crops cultivated at farms are cotton, followed by wheat, rice and other crops (Figure 2.7). Owing to a lack of capital and knowledge, farmers are unable to operate the whole farmland, and thus rely on the labor of nearby residing rural households (Veldwisch and Bock, 2011; Djanibekov et al., 2013c).

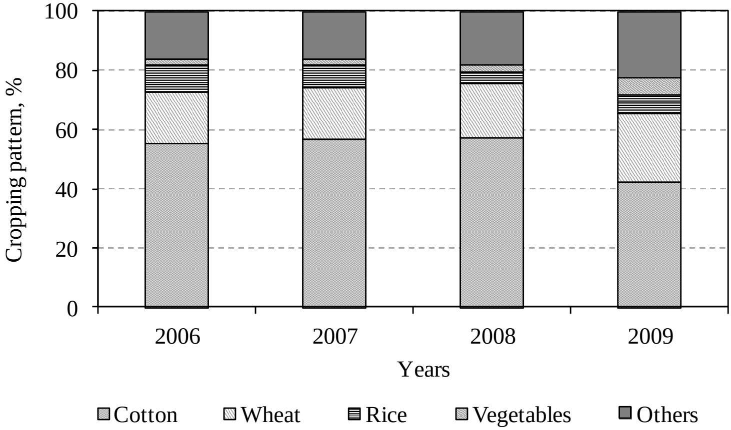

Figure 2.7: Cropping pattern of commercial farms in the study area.
Source: State Statistical Committee (2010).

2.3.2 Rural households

The total arable land area in the possession of rural households is around 60,000 ha (State Statistical Committee of Uzbekistan, 2010). They have an attached plot of 0.08 ha and a distant additional plot of 0.12 ha. These plots serve to complement income and food security and beyond the state procurement policy (Spoor, 2004). Smallholders mainly specialize in growing vegetables, wheat, rice and other crops (Figure 2.8), while a double cropping calendar is used in the attached and distanced plots (Veldwisch and Bock, 2011). Owing to the location and size, the distant plots dominate in the use of production activities and mainly cultivated with rice, wheat and maize (Veldwisch and Bock, 2011). Smallholders are the main type of rural population involved in livestock rearing, and it represents an important asset for their income and food security (Veldwisch and Bock, 2011).

Rural households are abundant in labor, yet scarce in land, lack storage and transportation facilities, as well as lack sufficient buffer wealth to sell the output short after the harvest (Veldwisch and Bock, 2011). Most of the rural households produce insufficient amount of wheat to cover their annual consumption demand, despite wheat being the second major crop in the study area (Table 2.3). Hence, the demand for this crop and other products that are insufficiently produced in households is satisfied from other sources, i.e., from farmer and market. At the same time, smallholders that can satisfy own consumption demand through production on own plots, e.g., meat and vegetables, still obtain agricultural products from other sources, and the surplus of these commodities is usually marketed. Besides, due to frequent interruption or no access to the central supply of gas the rural households rely on cotton stem, which they purchase from the market or receive from farmer as payment, as a source of energy for cooking and heating.

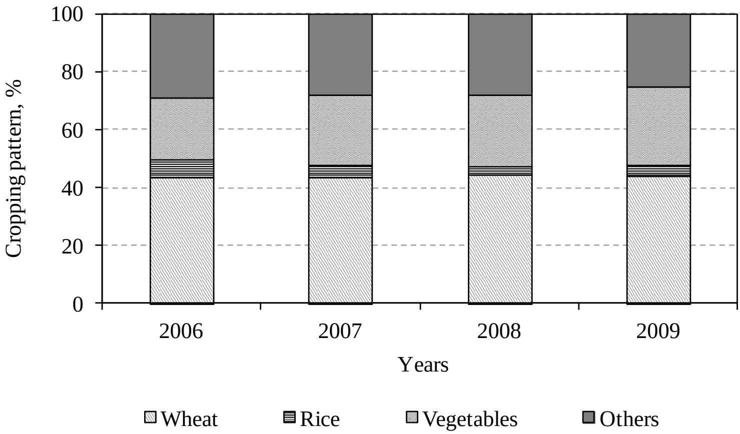

Figure 2.8: Cropping pattern of rural households in the study area.
Source: State Statistical Committee (2010).

Table 2.3: Rural household use of the main agricultural products by destination, in average values.

Products	Market price	Total consumption	Household plot production	Products obtained from other sources
	USD t^{-1}	kg $person^{-1}$ $year^{-1}$		
Wheat	227	164	80	90
Rice	682	33	25	82
Meat	3,500	30	32	2
Milk products	247	153	160	3
Eggs	103	84	80	4
Vegetables	260	206	220	28
Cotton stem	36	110	n.a.	110

Source: Own observation (2011).
Note: n.a. is not applicable to produce cotton at rural household plots; Other sources from where rural households obtain products include farm and market.

2.4 Agricultural policies in Uzbekistan

2.4.1 Procurement policy

Since independence in 1991, the market reforms in Uzbekistan have been aimed at liberalizing agricultural commodity markets. However, the main agricultural policies continued to be set by the state, for example cotton procurement policy, which is export-oriented (Djanibekov et al., 2013a). The state determines a set of cotton policies related to the area, location and output of cotton cultivation. In the area-based target of cotton policy, all cotton-grain farms are mandated to cultivate cotton, usually accounting for around 50% of their total arable area. According to the location-based target, the cotton-grain farms have to cultivate cotton on the fields that are the most suitable for this crop, delivering the output target depending on the *bonitet* level. Furthermore, farmers can only sell cotton to the existing state-run ginneries; the raw cotton procurement price is fixed and is lower than world prices (Djanibekov et al., 2012c; MacDonald, 2012). The determinants of the state procurement price for cotton are unclear. Rudenko et al. (2009) described that a price for cotton is derived based upon a process whereby the state joint stock ginning companies in Uzbekistan negotiate a price with the Uzbek foreign trade companies. This state procurement price system has reduced the volatility of cotton prices by acting as a smoothing mechanism (MacDonald, 2012) (Figure 2.9). Moreover, cotton-grain farmers who cultivate wheat are requested to sell half of the entire wheat output to the state at a fixed price of 0.11 USD kg^{-1}, which is lower than its local market price (as of 2009) (Djanibekov et al., 2012c). Of the remaining 50% harvest of wheat, the farmer can freely trade within the domestic market. The production of cotton and wheat involve indirect subsidies from the state, including priority in the provision of irrigation water and reduced prices for fertilizers and machinery leasing, which are mainly allocated to the entire agricultural sector rather than to individual farmers (Djanibekov et al., 2010b).

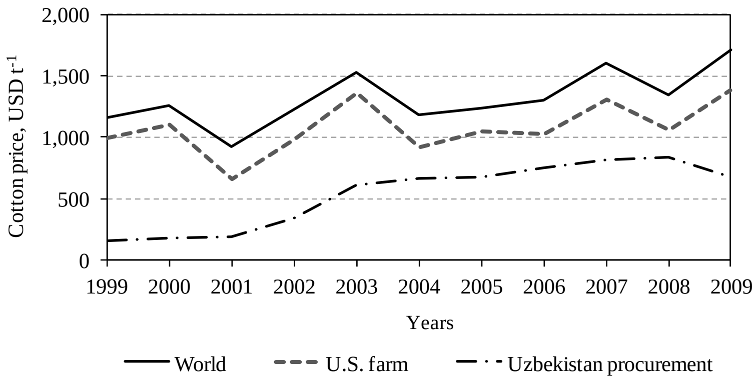

Figure 2.9: Comparison between Uzbekistan state procurement, U.S. farm and average world cotton prices.
Source: MacDonald (2012), Cotlook ltd (2011), International Cotton Advisory Committee (2011), U.S. Department of Agriculture (2011).

2.4.2 Land tenure

In the recent land reconsolidation reform that started in 2008, farm sizes were re-adjusted by merging smaller farms into larger ones to suit the existent infrastructure design (Djanibekov et al., 2010a). While secure tenure rights are important for farmers to make long-term investments (Djanibekov et al., 2012b), the recent land consolidation reform prompted the risk of farmers losing their land, consequently restraining their interest in investing in long-term activities (Kan et al., 2008; Djanibekov et al., 2010a). The instability and uncertainty in tenure arrangements has discouraged farmers from making investments in land uses for increasing the productive capacity of agriculture and incomes in the long run (Trevisani, 2009). The state regulation on land uses further increases the reluctance of farmers to invest in long-term activities. According to the state legislation, farmers are prohibited from converting lands used for cotton and grain into other uses (Kan et al., 2008).

2.5 Afforestation of marginal croplands

2.5.1 Establishing tree plantations on marginal croplands

The issue of combating desertification and land degradation is of high priority in Uzbekistan. Since 1999, in accordance with Uzbekistan's national Action Program to Combat Desertification, the re-integration of trees in the agricultural landscape has been advised to rehabilitate degraded lands (UNEP and GLAVGIDROMET, 1999). In 2006, the Department of Forestry of MAWR developed afforestation and reforestation programs to prevent salt and dust erosion from the soil surface at the dried bottom of Aral Sea, as well as the conservation of riparian forests (Botman, 2009). Planting indigenous and exotic tree and shrub species can represent an alternative option for degraded croplands (Fimkin, 1983; Toderich et al., 2001; Lamers et al., 2006). A study by Khamzina et al. (2006) showed that tree species such as *Elaeagnus angustifolia* L., *Populus euphratica* Oliv., and *Ulmus pumila* L. have high potential to grow on marginal irrigated croplands. These tree species are native for the study areas and differed in tolerance to drought and salinity, and grow mainly in the remnants of the riparian forests and as shelterbelts of croplands (Lamers et al., 2006). Khamzina et al. (2008) showed that these tree species would require an irrigation amount of 800-1,600 m^3 ha^{-1} during the first two years and could thereafter rely on shallow groundwater table. Hence, the irrigation water not used by tree plantations on marginal lands could be used for more fertile lands (Khamzina et al., 2012). Besides, introduction of tree plantations on marginal croplands would lead to land use diversification option, where strategies combining several land uses with independent revenue fluctuations may become an effective buffer against land use revenue risks (Knoke et al., 2011), such as variability of irrigation water, crop yields and prices.

In the study area, some of the cotton-grain farm types have small tree plots of 0.5-1 ha, established between 1994 and 1998 to meet the demand for timber. However, farm forestry is currently not practiced. Despite the various evident benefits of afforestation of marginal croplands in Uzbekistan (Djanibekov et al., 2012c; Khamzina et al., 2012), the state regulation on cropland remains among the most important factors affecting the introduction of such land uses (Djanibekov et al., 2012b). Besides, ongoing farmland consolidation restrains farmers from making long-term investments in forestry (Djanibekov et al., 2012b), and the short-term afforestation of marginal croplands could represent a suitable land use in the study area (Djanibekov et al., 2012c). Furthermore, currently farmers lack knowledge of possible benefits (e.g., C revenues), management practices (e.g., trimming, harvest), and general impact on their wellbeing from planting trees on marginal croplands (Kan et al., 2008).

2.5.2 Tree products

The demand of population for tree products predominantly satisfied through purchasing from markets. Markets for tree products are mainly divided into food products (fruits), timber and fuelwood markets. Of the tree species that could grow on marginal lands, only *E. angusitfolia* produces fruit, which is available in local food market. The timber market largely consists of hardwood and softwood, as well as board imported from Russia and Kazakhstan (Vildanova, 2006). Given that the rural population experiences a frequent interruption of central-grid gas supply for domestic uses (Vildanova, 2006), fuelwood, cotton stem and coal are of high interest as alternative means to central gas (Table 2.4). Fuelwood is harvested from the state reserves and field boundaries for the domestic needs (Vildanova, 2006). The tree foliage provides protein-rich feed, and its inclusion into the ration of dairy cows offers the potential to both increase the nutritional value of the milk produced and reduce the feed costs (Djumaeva et al., 2009; Lamers and Khamzina, 2010). Foliage could be a substitute for fodder products in the study area that are mainly crop by-products such as wheat and rice straw, maize grain and stem, which are of low nutrient content (Table 2.5) (Djanibekov, 2008). The existing demand on tree products and bimodal agricultural system may imply that afforestation on marginal farmlands would also impact the rural households employed at such farms.

Table 2.4: Characteristics of energy products used in rural areas.

Energy products	Number of households (out of 400 interviewed respondents) using this energy product	Price USD t^{-1}	Energy content MJ t^{-1}
Coal	60	45	21,000
LPG	48	682	46,000
Cotton stem	354	36	17,007
Fuelwood of *E. angustifolia**	130	41	19,000
Fuelwood of *P. euphratica**		39	18,800
Fuelwood of *U. pumila**		45	18,600

Source: Cao et al. (2008), Lamers and Khamzina (2008), Carbon Trust (2011), Own observation (2011).
Note: LPG is the liquefied petroleum gas; MJ is the megajoules; *as the households could not distinguish consumed fuelwood by tree species, the values are aggregated for the fuelwood consumption.

Table 2.5: Characteristics of fodder products.

Fodder products	Price	Nutrient content	
	USD t^{-1}	ME, MJ kg^{-1}	CP, g kg^{-1}
Wheat and rice straw	33	6	74
Maize grain	227	14	217
Maize stem	30	7	95
Leaves of *E. angustifolia*	53	9	206
Leaves of *P. euphratica*	33	8	132
Leaves of *U. pumila*	39	9	149

Source: Djumaeva et al. (2009), Lamers and Khamzina (2010), Own observation (2011).
Note: Prices of leaves were derived based upon the crude protein content of dry alfalfa and subsequently this fodder product market price was assigned (for detailed description of leaves valuation see Lamers et al. (2008)); Prices of other fodder products are from the weekly fodder market survey conducted between June 2010 and March 2011; ME is the metabolizable energy; CP is the crude protein content.

2.5.3 Clean Development Mechanism Afforestation and Reforestation

The possibility of generating revenues through environmental payments such as for sequestered C in trees would be an additional incentive to initiate forestry on marginal farmlands. Since Uzbekistan ratified the Kyoto Protocol on October 12, 1999, it is eligible to sell C sequestered in tree plantations, and Clean Development Mechanism Afforestation and Reforestation (CDM A/R) on degraded croplands could represent a land use option that is aimed to contribute to mitigation of climate change while leading to sustainable development. Considering the land tenure insecurity in the study area, according to article 2 of the law of Uzbekistan on forest, if an international agreement establishes rules different from those contained in the forest legislation of Uzbekistan (e.g., CDM rules), the regulations of the international agreement will be applied. Hence, in the study area, the short-rotation CDM afforestation could be a land use option to generate C revenues as well as other non-timber products, and address issues of high waiting costs due to land tenure.

3. Costs and benefits of afforestation on marginal croplands[4]

This chapter addresses the first specific objective of the study: to evaluate the financial attractiveness of afforestation on marginal croplands. The cost-benefit analysis is applied for financial evaluation of establishing multiple product tree plantations on marginal croplands at a field level (1 ha). Section 3.1 provides a review of studies on cost-benefit analyses for financial evaluation of pure forestry and providing various environmental services of forestry on marginal lands. Based on the presented examples, Section 3.2 presents a description of the database and methods applied in this study to analyze the financial attractiveness of tree plantations. More specifically, that section describes an approach used to derive the price of temporary Certified Emission Reductions (tCER) taking into account the irrigation water availability levels for crop production. Afterwards, Section 3.3 provides results regarding the financial attractiveness of establishing tree plantations, their opportunity costs, influenced by irrigation water availability, and the respective tCER prices to outweigh these opportunity costs.

3.1 Literature review

Afforestation of marginal croplands represents a long-term land use investment, and the cost-benefit analysis allows comparing the gains and losses of undertaking such activities over time. The studies of long-term costs and benefits of land uses for providing policies related to forestry applied the method of the net present value (NPV), or the internal rate of return (IRR) and benefit-cost ratio (BCR). The cost-benefit analysis has the following main disadvantages related to its normative and theoretical foundations: (1) it is an inadequate indicator of human well-being and social welfare as it is focused on subjective utility rather than actual functioning, and hence fails to acknowledge the multiple dimensions of populations livelihoods (Sen, 1985); (2) provides usually aggregated results that does not capture different effects on markets and on various groups of society (Livermore and Revesz, 2013).

Despite of these disadvantages the cost-benefit approach is commonly used for analyzing financial returns of tree plantations. The analysis of forest management practices was pioneered by the works of von Carlowitz (1713). Faustmann (1849) presented the first ever a model-based

[4] Chapter 3 builds on Djanibekov, U., Khamzina, A., Djanibekov, N., Lamers, J.P.A., 2012c. How attractive are short-term CDM forestations in arid regions? The case of irrigated croplands in Uzbekistan. Forest Policy and Economics 21, 108-117.

analysis that considers the optimal management practices of tree plantations, according to which trees should be harvested when its marginal revenue equals its marginal cost. Later on, a study by Hartman (1976) analyzed the value associated with the standing trees, estimating the optimal rotation periods of tree plantations under different tree products and services. Without payments for these goods and services, long-term investments into environmental sustainable land use activities, such as afforestation on marginal croplands, might not be attractive (Pearce, 2001; Engel et al., 2008; Pagiola, 2008; Stenger et al., 2009). Most of the studies that consider multiple benefits of tree plantations developed the model proposed by Hartman (1976) by including various environmental services provided by trees such as carbon (C) sequestration, water purification, biodiversity increase, and considering rotation of trees. For example, the study conducted by Creedy and Wurzbacher (2001) for the Thomson Water Catchment in Australia examined optimal management strategies and estimated that the profits of the catchment were maximized through a high water yield and C sequestration, as opposed to solely timber profits. In the Mediterranean region, Croitoru (2007) estimated that the annual returns from multiple non-timber products such as fuelwood, cork, fodder, mushrooms, honey and others constituted about a quarter of the total value of forests. Besides, the inclusion of protein-rich tree leaves into the feeding ration of dairy cows has the potential to both increase the nutritional value of the milk produced and reduce feed costs (Djumaeva et al., 2009). Additional ecosystem services resultant from tree plantations include irrigation water saving (as trees mostly rely on groundwater), a considerable increase in soil nutrient stocks and an accumulation of C in soil (Khamzina et al., 2012).

Other studies have specified this idea by including C sequestration into the model, focusing on the optimal rotation length of plantations or the cost efficiency of C forestry projects (Richards and Stokes, 2004; Manley and Maclaren, 2010). Olschewski and Benitez (2010) applied NPV and estimated that the joint production of timber and C extends the rotation of tree plantations, increases financial benefits and contributes to the mitigation of climate change. Comparable estimation of tree products was conducted in the context of Certified Emission Reductions (CERs) of Clean Development Mechanism Afforestation and Reforestation (CDM A/R) (Galinato and Uchida, 2010; Guitart and Rodriguez, 2010). Based on the analysis of the impact of three credit schemes on the amount of C captured and plantation management, Köthke and Dieter (2010) concluded that optimal rotation period varies depending on the C price level. Moreover, several researches pointed at substantial benefits when substituting fuelwood derived from short-term rotation tree plantations for fossil fuels, as opposed to using tree plantations only for sequestering C in tree biomass (Kaul et al., 2010).

C forestry projects established on marginal lands have been previously studied using the cost-benefit analysis, yet provided controversial results. While some studies have concluded that tree planting would be an attractive climate change mitigation option under current policies (e.g., Parks and Hardie, 1995; Niu and Duiker, 2006), others have claimed that such projects could only be attained at significant costs and would require a substantial change in present climate agenda regulations (e.g., Van Kooten, 2000; Krcmar et al., 2005; Tal and Gordon, 2010). However, both opinions have not considered CDM A/R with multiple uses, neither with factors influencing the land value. Furthermore, on-going debates in forestry studies have not conclusively resolved concern over determining the price for C stored in wood. The C-wood price in voluntary and regulated markets ranged from 0.65 to more than 50 USD per ton of CO_2 (tCO_2) (Hamilton et al., 2010). The C price is currently fluctuating, and its determination depends on the agreements made between the developing (seller) and industrialized (buyer) countries. Since the start of the CDM A/R offset mechanism, prices for CER averaged 6.72 USD, with the highest value being 9.85 USD in 2007 (Hamilton et al., 2010). Oslchewski et al. (2005) estimating the NPV of forest and crops, advocated the importance of relating the CER value to land productivity, concluding that the minimum CER supply price would be 0.3 USD for land suitable for forestry and 2.5 USD for land with lower suitability. Benítez and Obersteiner (2006) related the C-wood price to the productivity of agricultural land, postulating that profitable C forestry projects would be an unlikely activity on low productive lands. In irrigated drylands, one of the important factors in determining the feasibility of converting marginal croplands to tree plantations would be the opportunity cost of land (revenues from crop cultivation) and revenues from CDM afforestation. In this respect, the response of crop yields to different input levels, such as water, fertilizer, labor activities, will have an effect on the CER price, which would render CDM afforestation project at least as attractive as crop cultivation. To the author’s knowledge, there has been no study to relate the C price with the level of irrigation water applied a factor of high importance for irrigated agricultural settings, as well as inclusion into the analysis of tree plantations producing various non-timber tree products (e.g., fuelwood, fruits, and nutrient rich leaves as fodder). Given these research gaps, estimating financial returns of afforestation on marginal croplands in irrigated areas and determining C sequestration price to initiate such land use require prior analysis.

3.2 Empirical methodology

3.2.1 Data sources

The surveys were designed as multi-topic by collecting data on various aspects that could influence decision-making and the livelihoods condition of rural population in the study area. The objective of the surveys was to identify the living standards of rural people, with a focus on the agricultural interrelationship between farms and rural households. To achieve this aim, two types of surveys were conducted for each type of agricultural producer, i.e., for farms and rural households. For this analysis a data from the commercial farm survey was used[5]. To ensure the availability of farmers for the survey, and also to gain support from the local institutions in conducting the surveys, prior to the interviews me and enumerators visited the district mayor office and/or the district department of Ministry of Agriculture and Water Resources, the district department of Land Cadastre, and offices of Machine Tractor Park. All of the aforementioned organizations assisted in finding farmers and ensuring their availability, and did not interfere during the surveys.

A structured questionnaire was used for the farm surveys, developed over two months based upon expert opinions and reviewing questionnaires from previous farm surveys in the Khorezm region. The questionnaire was pre-tested in the Khorezm region by interviewing 10 randomly selected farms, which helped to identify relevant and irrelevant questions (e.g., irrigation water application level for crops), and possible problems that may occur during interviews. After pre-testing and finalizing the questionnaire, the farmers were randomly selected from the cross-sectional data on farmers in the study area, with around 12 farmers surveyed in each district. Overall, 160 farms were surveyed in the study area.

To capture farms that may possess marginal croplands and address the overall effect on different farm production, the farms were randomly selected from each district depending on their typology (Table 3.1). Accordingly, the survey of farms was planned to be conducted among all existing farm types in the study area. Seven main farm types were identified and surveyed, i.e., cotton-grain, livestock rearing, horticulture, vegetables and melons, sericulture, fishery, and poultry keeping. However, given that some farm types do not exist in some districts, e.g., poultry keeping, fishery, and vegetables and melons, the surveys for these types were targeted at those existing in certain towns, and consequently the size of surveyed farm types was uneven. In the case when a farmer could not be interviewed, he was replaced with the next farmer from the sample.

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[5] The survey data used in this chapter is documented here: http://data.zef.de

Table 3.1: Distribution of farm surveys conducted in the study area between June 2010 and March 2011.

Farm type	Actual number of farmers	Sample share in total farm numbers, %	Sample size
Cotton-grain	3,040	3	80
Livestock	666	3	20
Horticulture	1,884	2	30
Others	1,579	2	30

Farm survey questions were addressed to the farm owner and/or manager. The survey was mainly focused to obtain information concerning the net returns of crops and livestock, and collect per farm data on crop yields and prices, the number of animals and their market prices, input application levels and their purchase prices, the amount of fodder given to animals and fodder prices, the number and remuneration of hired labor, the level of state target production for cotton, and the distance to markets from the farm. To observe changes in farm size and crop area as a result of previous agricultural policies, questions were addressed related to the farmland size at present and prior to last land consolidation process (in year 2008). This information was also supplemented with farm's household characteristics, such as family size and demography, off-farm working activities, the consumption structure of energy commodities, as well as timber use in construction activities and available agricultural technologies and machineries. To understand the perception of farmers in afforesting marginal croplands the questions were addressed on the area of marginal croplands, farmers' willingness to plant certain tree species and/or crops on these lands, the expected benefits of these new land uses, and reasons why these land use practices are not currently followed. During the farm surveys, it was identified that mainly cotton-grain growing farms possess marginal croplands, and thus this farm type was also selected for analysis in this study. The information on the crops' inputs usage and prices collected from the farm surveys are summarized in Table B in Appendix B.

The costs related to tree plantations of the first two years were obtained from the study by Lamers et al. (2008), while the costs related to the annual land taxes and labor were based on the experimental site, and the labor hours derived from the survey observations. Tree leaves were considered as fodder products within the study, and therefore, as suggested by Lamers et al. (2008), the prices of leaves of the selected tree species were calculated based upon the foliar crude protein content, compared to that of marketed dry alfalfa hay. Accordingly, the derived price of leaves was 53.3 USD t^{-1} for *E. angustifolia,* 32.7 USD t^{-1} for *P. euphratica* and 38.8 USD t^{-1} for *U. pumila* leaves. Because of farmers' lack of knowledge concerning irrigation application levels per hectare on marginal, average, good and highly productive croplands and the respective yields of cotton, wheat, rice, maize and vegetables, this information was obtained from the crop water-yield responses developed by MAWR (2001).

To gather necessary data on prices, in addition to farm survey, the weekly surveys were conducted at four types of markets, i.e., food, fodder, fuelwood and timber. The fuelwood market surveys were only conducted between the months of November and April, given that the market for these products only operated during this period of the year. The food, fodder and fuelwood market surveys were performed on Sundays of every week, while the timber market surveys were conducted on Saturdays of every week. At the initial stage of the market surveys, the markets were visited in the southern districts of the Autonomous Republic of Karakalpakstan, although they were later ceased due to logistical complications. During these surveys, the sellers of the commodities were asked about the price of the traded good.

In addition to the survey, the annual data on tree growth on marginal croplands for the period 2003-2009 was obtained from the study conducted by Khamzina et al. (2008; 2009b). In March 2003, the mixed tree plantation consisting of *Elaeagnus angustifolia* L.*, Populus euphratica* Oliv. and *Ulmus pumila* L. was established on a marginalized cropping site of 2 ha. Each treatment was repeated four times, with a total of 36, 105 m^2 sized experimental plots (3 species, 3 irrigation modes, 4 replications) established. At the onset, one-year-old saplings were spaced 1.75 m between the rows and at 1 m within the rows, giving a stand density of 5,714 trees ha^{-1}. These tree species were drip and furrow irrigated with respective quantities of 800 and 1,600 m^3 ha^{-1} $year^{-1}$ during the first two years following plantation establishment. All plots were irrigated for two years, from 2005 onwards, before irrigation was stopped and the trees relied entirely on groundwater. As farmers in the study area do not typically practice drip irrigation, only the amount of water applied through furrow irrigation for the tree plantations was considered in this study, i.e., 1,600 m^3 ha $year^{-1}$ for the first two years. The dry matter was measured each year according to tree bio-fractions, i.e., fruits, foliage, stem, twigs, and coarse roots. The concentration of total C content (%) in each woody fraction was analyzed annually after finely grounded samples were combusted in an elemental analyzer. The carbon stocks in plantations (t ha^{-1}) were estimated based upon the wood biomass and the stand density. The results were converted into CO_2 equivalents by applying a factor of 3.67, accounting for the atomic weights. Data on the current tCER price was 4.76 USD, as reported in Hamilton et al. (2010). Given that the CDM afforestation has not yet been implemented in Uzbekistan, transaction costs of 105,000 USD were assumed, as estimated by Schlamadinger et al. (2007). The information on tree products biomass used for the study is presented in Table A in Appendix A.

3.2.2 Financial evaluation of afforestation of marginal croplands

Emission reductions are reversible in CDM forestry projects due to the non-permanent nature of trees. To address this aspect of non-permanence, the CDM has defined temporary and long-term CERs (tCERs and lCERs) that must be replaced by a specific time in the future. In the estimates of tCERs within the analysis, the 7-year project length was assumed. The short-term project duration can be justified by the land tenure insecurity that prevents long-term investments in forestry land use (for a description on land tenure insecurity see Section 2.4.2). The tree species considered in this study may have longer standing period, however the observations on tree growth beyond the studied period were not available (see Khamzina et al., 2009b). For the similar reason of the data scarcity, the study considered only one observed management practice of tree plantation. To identify optimal rotation, mixed species and density of tree plantations, and related economic values, the cost-benefit analysis can consider an estimated response function of tree growth or several alternatives of plantation management practices. This is only possible after such information becomes available from the field experiments and simulations made in a tree growth model.

Furthermore, it was also assumed that agreements on the crediting period can be negotiated between buyers and sellers. To obtain tCERs, certain eligibility criteria have to be met. For instance, the ‘additionality’ requirement implies that more C should be sequestered in comparison to the baseline scenario of C levels in marginal croplands without afforestation. A constant C stock in the cropland was assumed because the entire above-ground crop biomass is annually harvested. Given the complexity in accounting for C accrual in agricultural soils, only C sequestered in stem, twigs and coarse roots of the three studied tree species, i.e., *Elaeagnus angustifolia* L., *Populus euphratica* L., and *Ulmus Pumila* L. was considered for estimating tCERs. Throughout the empirical analysis of this study, the marginal croplands are defined as those with a *bonitet* level lower than 41 (see Section 2.2.1).

A small-scale CDM afforestation was considered in this study. To reduce the costs and encourage farmers' participation, simplified modalities and procedures were adopted for the small-scale CDM A/R projects, which were defined as those annually sequestering less than 16,000 tCO_2 (UNFCCC, 2007). Accordingly, the CDM transaction costs per hectare were identified by considering the land area that would annually sequester not more than 16,000 tCO_2 based upon the uptake potential of tree species. The CO_2 uptake rate was estimated as an average annual uptake observed in tree plantations during the seven year period since planting.

To estimate the benefits of CDM afforestation on marginal croplands, the net present value (NPV) was calculated for each land use activity, i.e., the annual crop cultivation, conventional afforestation, sole tCER payments, and CDM afforestation, as follows:

$$\mathrm{NPV}^{\mathrm{A}} = \sum_{t=1}^{T} \frac{\mathrm{P}_t^{\mathrm{A}} \mathrm{Y}_t^{\mathrm{A}} - \mathrm{C}_t^{\mathrm{A}}}{(1+\mathrm{d})^t} \qquad (3.1)$$

$$\mathrm{NPV}^{\mathrm{F}} = \sum_{t=0}^{T} \frac{\mathrm{P}_t^{\mathrm{F}} \mathrm{Y}_t^{\mathrm{F}} - \mathrm{C}_t^{\mathrm{F}}}{(1+\mathrm{d})^t} \quad \text{and } \mathrm{C}_t^{\mathrm{F}} = \mathrm{L}_t + \mathrm{E}_t + \mathrm{M}_t + \mathrm{H}_t \qquad (3.2)$$

$$\mathrm{NPV}^{\mathrm{tCER}} = \sum_{t=0}^{T} \frac{\mathrm{P}_t^{\mathrm{tCER}} \mathrm{Y}_t^{\mathrm{tCER}} - \mathrm{C}_t^{\mathrm{tCER}}}{(1+\mathrm{d})^t} \quad \text{and } \mathrm{C}_t^{\mathrm{tCER}} = \mathrm{L}_t + \mathrm{E}_t + \mathrm{M}_t + \mathrm{TC}_t \qquad (3.3)$$

$$\mathrm{NPV}^{\mathrm{CDM}} = \sum_{t=0}^{T} \frac{\mathrm{P}_t^{\mathrm{tCER}} \mathrm{Y}_t^{\mathrm{tCER}} + \mathrm{P}_t^{\mathrm{F}} \mathrm{Y}_t^{\mathrm{F}} - \mathrm{C}_t^{\mathrm{CDM}}}{(1+\mathrm{d})^t} \quad \text{and } \mathrm{C}_t^{\mathrm{CDM}} = \mathrm{L}_t + \mathrm{E}_t + \mathrm{M}_t + \mathrm{H}_t + \mathrm{TC}_t \qquad (3.4)$$

where superscript *A* stands for crop cultivation, *F* for conventional afforestation, *tCER* for tree plantation aiming solely at tCER revenues, and *CDM* for CDM afforestation. Subscript *t* stands for the analyzed (0, 1, 2, …, *T*) years, with *T* equal to 7 years.

NPV is the net present value of all revenues and costs related to any land use activity [USD ha^{-1}]. P is the price of crops, crop by-products, tree products, and tCER [USD t^{-1}]. Y is the yield of the main crop products (i.e., raw cotton, wheat, rice and maize grain, and vegetables), crop by-products (i.e., cotton stem, wheat and rice straw and maize stem), tree products of *E. angustifolia*, *P. euphratica* and *U. Pumila* (i.e., leaves, fruits and fuelwood), and carbon sequestered in tree biomass (i.e., stem, twigs, and roots) [t ha^{-1}]. The yield of crop by-products is obtained using their ratio from the yield of the main crop product. Therefore, the yield of cotton stem is 1:1 with the yield of raw cotton, the yield of wheat and rice straw is 1:1 with their respective grain yields, the yield of maize stem is 1.5:1 with the yield of maize grain, while vegetables do not produce by-products. Leaves and fuelwood only accounted in year seven, when the tree plantations are cut and these products harvested. Only *E. angustifolia* produces fruits, providing yields starting from year three. C pertains to all costs related to an activity, such as crop cultivation, annual land tax and two-year payments for irrigating the tree plantation (*L*), establishing the tree plantation (including saplings, machinery use, labor use for field preparation and planting) (*E*), maintaining the tree plantation (*M*), harvesting and transportation costs of tree products (i.e., leaves, fruits and fuelwood) (*H*), as well as transaction costs of the small-scale CDM A/R (*TC*) (i.e., project design, registration, verification, and monitoring) [USD ha^{-1}]. As afforestation of marginal croplands is not practiced by farmers, introduction of such innovative land use may require an information and extension component. This may imply additional costs related to the training of farmers on various benefits (e.g., on C revenues or preparation of livestock feed mix with tree foliage) and management practices (e.g., preparation of field, trimming, harvest) of tree plantations (Kan et al., 2008). Currently, the local administration organizes annually farm exhibitions that usually precede the start of the sowing season to update farmers on crop cultivation techniques and technologies (Shtaltovna et al., 2012). The trainings on tree plantation management can be integrated into these existing exhibition events at rather low costs. Therefore, in this study the costs related to information and extension are not considered. It was assumed that farmers use conventional technologies for annual crop cultivation, and consequently there are no investments in crop cultivation at t=0 in the calculations. d is the estimated real interest rate that represents the difference between the observed nominal interest rate (22%) and a consumer price index (ca. 8%; ADB, 2011) in Uzbekistan in 2009. Accordingly d is equal to 14% in this study. The NPV of crops on marginal, average, good and high productive lands was estimated to gain an overall understanding of the costs and benefits of crops based on the land productivity level. Since afforestation is conducted on marginal croplands the NPV of this land use was only estimated for marginal lands. After estimating average gross margins and the NPV of crops to observe the variability in returns, their first (lowest 25%) and third quartiles (highest 25%) were also calculated. In estimating the quartiles, the crop yields and irrigation rate to achieve the certain crop yield remained constant, and the changes in quartile values depended on the land productivity level, costs of inputs and prices of outputs. The assumption regarding the same water-yield response in each quartile was made due to farmers in the study area lack information on crop water-yield

response. Therefore, as developed by MAWR (2001), crop water-yield response on different soil productivity levels was used (see Figure 2.4 in Section 2.2.2). In terms of estimating crop gross margins, yields were considered at the optimal water-yield response level. In the NPV and further simulation analysis, crop yield response varies with respect to irrigation level and soil productivity that is grouped into four classes. Incorporation of crop yield response functions to fertilizer application, labor and machinery uses can provide more detailed insights on the constraints and impacts of afforestation on farm economy. In addition, due to lack of data on groundwater availability and its usage in agriculture, the groundwater use was not considered in the study.
In addition, the internal rate of return (IRR) was calculated for the conventional afforestation, solely tCER payments, and CDM afforestation, offering the possibility to analyze the returns on investments without arbitrarily choosing a discount rate. The solution is obtained by computing a new discount rate for which (NPV^{F}), (NPV^{tCER}), and (NPV^{CDM}) in Eqs. (3.2)-(3.4) should be equal to zero. According to the IRR, an investment would be financially rational if the computed discount rate is greater than the real interest rate (14% in this study), although the IRR does not reveal any information concerning the volume of finances involved.

A land use change towards CDM afforestation is worthwhile when (NPV^{CDM}) is greater than the NPV from crop production (NPV^{A}), which is expressed as follows:

$$\mathrm{NPV^{CDM}} = \sum_{t=0}^{T} \frac{P_t^F Y_t^F - C_t^F}{(1+d)^t} + \sum_{t=0}^{T} \frac{P_t^{tCER} Y_t^{tCER} - TC_t}{(1+d)^t} \geq \mathrm{NPV^{A}} \tag{3.5}$$

Using the Eq. (3.2), the Eq. (3.5) can be modified as follows:

$$\mathrm{NPV^{CDM}} = \mathrm{NPV^{F}} + \sum_{t=0}^{T} \frac{P_t^{tCER} Y_t^{tCER} - TC_t}{(1+d)^t} \geq \mathrm{NPV^{A}} \tag{3.6}$$

According to Eq. (3.6), the total NPV of the conventional afforestation and revenues from tCER less the transaction costs should be greater than the NPV of crop production.

3.2.3 Carbon price with respect to irrigation water

In the arid climate, the availability of irrigation water determines farmers' decisions regarding crop cultivation, in addition to the need for fulfilling the crop production targets set by the state. Irrigation water availability can be spatially heterogeneous given that croplands located near a water source (e.g., main irrigation canal or a river) are better endowed with irrigation water, whereas tail-end areas further away from water sources may have less stable water supplies. This variability results in different economic values from crop cultivation in different locations. Assuming that P_t^{tCER} does not change over the seven-year examined period (t), the minimum level of P^{tCER} that would motivate the farmer's decision to shift from annual cropping to CDM afforestation can be calculated from Eq. (3.6) as follows:

$$\mathrm{P^{tCER}} = \frac{\mathrm{NPV^A - NPV^F}}{\sum_{t=0}^{T} \mathrm{Y_t^{tCER}}(1+d)^{-t}} + \frac{\sum_{t=0}^{T} \mathrm{TC_t}(1+d)^{-t}}{\sum_{t=0}^{T} \mathrm{Y_t^{tCER}}(1+d)^{-t}} \qquad (3.7)$$

Eq. (3.7) shows that the value of P^{tCER} depends on the level of irrigation water availability for marginal croplands. This is reflected in crop yields (Y^A) in NPV^A that are calculated as quadratic water-response functions. According to Eq. (3.7) the value of P^{tCER} would increase with increasing differences between NPV^A and NPV^F and decrease with increasing carbon sequestration potential (Y^{tCER}). P^{tCER} would also increase with increasing transaction costs of establishing a small-scale CDM afforestation (*TC*). When deriving P^{tCER} the demand side conditions (buyer of tCER) were not considered. This is in line with other studies performed for identifying price of C sequestered in trees (e.g., Olschewski and Benítez, 2005; Benítez and Obersteiner, 2006; Guitart and Rodriguez, 2010). Furthermore, given the low irrigation demand of tree plantations observed in contrast to crop water demand (Khamzina et al., 2009b), the CDM afforestation on marginal croplands can be considered as an incentive for supplying irrigation water not used on marginal lands to more productive ones on farm. According to Eq. (3.7), higher prices of tCER would lead to reduced irrigation inputs because areas devoted to crops that require a great deal of water (e.g., rice) would be reduced in favor of tree plantations. Assuming different values of P^{tCER}, the water-saving potential of a CDM could be estimated as the difference between the economic optimum rates of crop irrigation and tree irrigation. While afforestation can provide other services such as land rehabilitation, biodiversity enhancement, and water purification (Ninan and Inoue, 2013), the data scarcity did not permit to extend the economic analysis of environmental services of tree plantations beyond C and water saving environmental services.

3.3 Results

3.3.1 Costs and benefits of crops

According to the estimates of five major crops cultivated on marginal lands, i.e., cotton, wheat, rice, maize and vegetables, the most profitable was rice, followed by vegetables and maize, with respective average gross margins of 1,952 USD ha^{-1}, 561 USD ha^{-1} and 420 USD ha^{-1} under optimal irrigation rates (Table 3.2). In contrast, the cultivation of cotton and wheat on marginal croplands brought average annual losses of 77 USD ha^{-1} and 17 USD ha^{-1}, respectively. Given that cotton and wheat are under the state procurement policy in Uzbekistan, according to which farmers have to allocate certain areas and deliver certain output (see Section 2.4.1), in the study area farmers still cultivate these crops in approximately half of marginal lands. The private farm losses were mainly caused by the low prices set by the procurement policy for these two crops. For example, half of the wheat harvest is procured by the state at prices below the local market price. If wheat prices paid to farmers were adjusted to the local market levels, wheat cultivation on marginal lands would become profitable, given the high levels of subsidies for inputs such as fertilizers, fuel, and the use of machinery (Djanibekov, 2008).

Table 3.2: Average annual gross margins of crops on marginal lands.

Parameter	Units	Cotton	Wheat	Rice	Maize	Vegetables
Irrigation water requirement	10^3 m^3 ha^{-1}	5.98	5.38	26.59	5.3	8.6
Crop yield*	t ha^{-1}	1.6	2.4	4.45	3.2	5.7
Crop by-product yield	t ha^{-1}	1.6	2.4	4.45	4.8	n.a.
Crop market price	USD t^{-1}	n.a.	227**	682	227	260
Crop procurement price	USD t^{-1}	227***	108***	n.a.	n.a.	n.a.
Crop by-product price	USD t^{-1}	32	30.4	30	27.4	n.a.
Crop revenue	USD ha^{-1}	415	475	3,168	858	1,487
Total variable costs	USD ha^{-1}	492	492	1,217	438	926
Gross margins (+ profits/ - losses)	USD ha^{-1}	-77	-17	1,952	420	561

Note: *Crop yields are derived based on the water-yield response norms of MAWR (2001); **Farmer can sell half of harvested wheat grains at the market price; ***All the harvested raw cotton and half of the harvested wheat grains are purchased by the state; n.a. is not applicable: selling cotton in rural market; state procurement price for rice, maize and vegetables; by-products for vegetables.

Table 3.3 presents mean, first and third quartiles of gross margins and net present values (NPV) over seven years of crops on marginal (*bonitet* level is 40), average (*bonitet* level is 60), good (*bonitet* level is 80) and highly (*bonitet* level is 100) productive lands. Considering the changes in land productivity level, i.e., from marginal to highly productive lands, and remaining constant the irrigation application level and level of input costs and output prices, the most profitable crops were still rice and vegetables. Despite the same yields assumed on all land productivity levels (see Section 2.2.2), rice is the most profitable crop on marginal, average and good productive lands. Vegetables had the second highest return after rice, whereas vegetables resulted in the highest gross margins and NPV among other crops on highly productive lands. The returns from maize also increased according to the land productivity level, and generated the highest returns among crops after rice and vegetables. On average productive lands, the crops following the state procurement, i.e., cotton and wheat, started generating profits for farmers. The financial attractiveness of crops was different when considering the variability in their returns. To observe variability in gross margins and NPV, their first and third quartiles were considered. On marginal lands in the third quartile, wheat was the most profitable crop due to lower input costs. In comparison, cotton still resulted in losses in the first and third quartiles, with losses in the first quartile being the highest among other modeled crops. Furthermore, maize had the highest difference in quartiles, and in some instances it was more profitable than the most economically attractive crops – rice and vegetables. For instance, the gross margins of cultivating maize on highly productive lands were higher than those of rice in the third quartile. Following maize, variability in profits were the highest in case of vegetables, while the variability in profits of wheat was the lowest.

Table 3.3: Average, first and third quartiles of crop gross margins for one year and the net present values (NPV) over seven years of crops on marginal, average, good and highly productive lands.

Crops	Yield, t ha^{-1}	Gross margins, USD ha^{-1}			NPV, USD ha^{-1}		
		Q1	Average	Q3	Q1	Average	Q3
Marginal productive land							
Cotton	1.6	-130	-77	-22	-557	-330	-94
Wheat	2.4	-53	-17	18	-227	-74	77
Rice	4.5	1,831	1,952	2,088	7,852	8,369	8,954
Maize	3.2	241	420	614	1,033	1,800	2,633
Vegetables	5.7	390	561	720	1,673	2,405	3,088
Average productive land							
Cotton	2.4	72	130	300	309	556	1,286
Wheat	3.6	176	220	260	755	945	1,115
Rice	4.5	1,831	1,952	2,088	7,852	8,369	8,954
Maize	4.8	581	849	1,138	2,492	3,642	4,880
Vegetables	7.5	786	1,021	1,222	3,371	4,376	5,240
Good productive land							
Cotton	3.2	265	336	423	1,136	1,441	1,814
Wheat	4.8	403	458	501	1,728	1,962	2,148
Rice	4.5	1,831	1,952	2,088	7,852	8,369	8,954
Maize	6.4	922	1,278	1,656	3,954	5,482	7,101
Vegetables	10.0	1,364	1,669	1,931	5,849	7,159	8,281
Highly productive land							
Cotton	3.9	442	517	615	1,895	2,216	2,637
Wheat	6.0	636	695	742	2,727	2,979	3,182
Rice	4.5	1,831	1,952	2,088	7,852	8,369	8,954
Maize	7.8	1,218	1,654	2,116	5,223	7,093	9,074
Vegetables	12.7	1,975	2,370	2,716	8,469	10,164	11,647

Note: Q1 and Q3 are respectively the first and third quartiles of crop gross margins for one year and crop net present values over seven years; Crop yields are derived based on the water-yield response developed by MAWR (2001); Rice has the same yield and response to irrigation water on all types of land productivity (see Section 2.2.2).

3.3.2 Costs and benefits of afforestation of marginal croplands

Investments in tree plantations predominantly would occur at the launch of the CDM afforestation project, and when tree harvesting took place (Table 3.4). The cost structure of the CDM afforestation revealed that depending on tree plantations the initial CDM transaction costs (i.e., project design, document preparation, registration and validation) amounted to 122-214 USD ha^{-1}, with plantation establishment costs amounting to 637-793 USD ha^{-1}, with these two components constituting the highest share of costs. The costs of tree plantations were also high in the final year, when the trees are clear cut, and fuelwood and leaves are harvested. Considering a possible highest annual CO_2 uptake rate of 16,000 tCO_2 defined for small-scale CDM A/R projects, the size of such CDM afforestation project would be 476 ha for *E. angustifolia*, 303 ha for *P. euphratica* and 533 ha for *U. pumila*.

In the analysis of this section it was assumed that the tCERs expire after the seventh year of the project, with farmers able to choose whether to extend them. In this case, potential buyers of tCERs could use the generated credits to reduce emissions by 235.5 tCO_2 with *E. angustifolia*, 369.2 tCO_2 with *P. euphratica* and 210.0 tCO_2 with *U. pumila*. Sequestering C on marginal lands through tree plantations would result in higher C stock than cultivating crops on such lands, given that the entire above-ground crop biomass is harvested annually (Scheer et al., 2008). When estimating using the tCER price of 4.76 USD, as presented in Hamilton et al. (2010), the returns solely from the tCERs would be 448 USD ha^{-1} for *E. angustifolia*, 702 USD ha^{-1} for *P. euphratica* and 399 USD ha^{-1} for *U. pumila*. These returns alone are insufficient to cover the initial investments of CDM afforestation.

Table 3.4: Annual discounted benefits and costs over seven years for the tree species examined in Clean Development Mechanism (CDM) afforestation.

	Costs, USD ha^{-1}	Revenues, USD ha^{-1}				Net returns of CDM afforestation, USD ha^{-1}
		Fruits	Leaves	Fuelwood	tCER	
E. angustifolia						
0	774	0	0	0	0	-773
1	381	0	0	0	0	-381
2	335	0	0	0	0	-334
3	149	407	0	0	0	258
4	118	2,267	0	0	0	2,148
5	76	1,423	0	0	0	1,347
6	45	828	0	0	0	783
7	422	339	134	2,248	448	2,747
Total	2,300	5,263	134	2,248	448	5,794
P. euphratica						
0	1,007	0	0	0	0	-1,006
1	381	0	0	0	0	-381
2	335	0	0	0	0	-334
3	129	0	0	0	0	-129
4	5	0	0	0	0	-5
5	5	0	0	0	0	-5
6	4	0	0	0	0	-4
7	591	0	258	3,389	702	3,759
Total	2,457	0	258	3,389	702	1,894
U. pumila						
0	837	0	0	0	0	-836
1	381	0	0	0	0	-381
2	335	0	0	0	0	-334
3	129	0	0	0	0	-129
4	5	0	0	0	0	-5
5	5	0	0	0	0	-5
6	4	0	0	0	0	-4
7	392	0	75	2,336	399	2,419
Total	2,088	0	75	2,336	399	724

Note: Temporary Certified Emission Reduction (tCER) price is 4.76 USD as presented in Hamilton et al. (2010).

When considering other tree products from trees, the largest share of the revenues came from an annual harvest of fruits in *E. angustifolia* stands (5,263 USD ha^{-1}). The second main income-generating tree product was fuelwood, particularly from the other two species of trees that do not bear fruit. For instance, the revenue from fuelwood of *P. euphratica* equaled 3,389 USD ha^{-1}, making it a vital source in covering the entire costs of the CDM afforestation. The highest potential revenues from foliage were observed for *P. euphratica*, and did not exceed 258 USD ha^{-1}. The highest annual returns came from fruits of *E. angustifolia*, which generated substantial profits and led to the highest internal rate of return (IRR) value among the studied tree species (Table 3.5). The IRR calculations over seven years illustrated that land use under only CDM with tCER payments would bring negative IRR for all three tree species, and thus investment in such activities should be avoided. However, IRR estimates showed that planting trees with *E. angustifolia* is more profitable under a conventional afforestation scheme (65%) than a CDM afforestation scheme (61%), given that the annual benefits from fruits contribute to the large share of total revenues. In contrast, *P. euphratica* and *U. pumila* had the highest IRR under the CDM afforestation scheme, with 28% and 21%, respectively.

Table 3.5: Internal rate of return (IRR) in the conventional, only the temporary Certified Emission Reduction (tCER) and Clean Development Mechanism (CDM) afforestation scheme.

Tree species	IRR over 7 years under conventional afforestation	IRR over 7 years under tCER scheme	IRR over 7 years under CDM afforestation
	%	%	%
E. angustifolia	65	-10	61
P. euphratica	26	-4	28
U. pumila	19	-12	21

Note: Temporary Certified Emission Reduction (tCER) price is 4.76 USD as presented in Hamilton et al. (2010).

The NPV estimations that only included tCER at the price of 4.76 USD showed that tCER payments would be insufficient to cover even the costs related to CDM project, tree plantation establishment and management. However, when considering conventional or CDM afforestation schemes, their NPV would be positive. The difference in the NPV of conventional land use and CDM afforestation are unsubstantial. This is because in the study the short-rotation tree plantations were considered, during which only unsubstantial tCER revenues could be generated. Considering the NPV of both tCER and revenues from the tree products, *E. angustifolia* would have higher NPV than cotton, wheat, maize and vegetables (compare the NPV on marginal lands of crops in Table 3.3 and trees in Table 3.6). These tree species have the highest NPV among other trees mainly due to the annual harvest of fruits. *P. euphratica* would be more profitable than cotton, wheat and maize. At the same time, under CDM afforestation land use option *P. euphratica* would have the highest gains from tCER among tree species, owing to its biomass obtained during seven years and consequently sequestered CO_2 (for the data on biomass production of tree species see Table A in Appendix A). The change in land use towards short-rotation tree plantations would bring positive returns under conventional afforestation or CDM afforestation. Only rice was far more profitable crop than trees, assuming the economically optimal rates of water application.

Table 3.6: Net present value (NPV) of trees over seven years.

Trees	NPV over 7 years under conventional land use USD ha^{-1}	NPV over 7 years under tCER scheme USD ha^{-1}	NPV over 7 years under CDM afforestation USD ha^{-1}
E. angustifolia	5,516	-1,221	5,794
P. euphratica	1,459	-1,219	1,894
U. pumila	477	-1,329	724

Note: Temporary Certified Emission Reduction (tCER) price is 4.76 USD as presented in Hamilton et al. (2010).

3.3.3 *Benefits of CDM afforestation in irrigated drylands*

Access to irrigation water is one of the main determinants of agricultural production by farmers in the study area. Availability of irrigation amount would affect crop yields and as a result increase the opportunity cost of CDM afforestation (see Tables 3.3 and 3.6). Hence, to determine the tCER prices at which afforestation under the CDM framework would become competitive with the studied crops at the economic optimum rates of irrigation, the tCER prices were differentiated according to the levels of irrigation water availability for five analyzed crops (Figure 3.1).

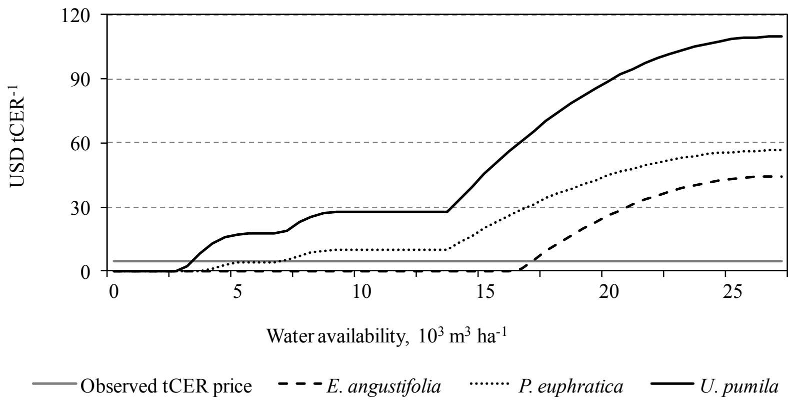

Figure 3.1: Change in temporary Certified Emission Reduction (tCER) prices depending on irrigation water availability.
Note: The observed temporary Certified Emission Reduction (tCER) price is 4.76 USD as presented in Hamilton et al. (2010).

At a level of seasonal irrigation water availability below 3,200 m^3 ha^{-1}, all three tree species were competitive with the studied crops. Above this threshold value, some of the crops would become more profitable than trees, considering the current price of tCER of 4.76 USD. Increasing the tCER price up to 110 USD $tCER^{-1}$ would trigger the adoption of CDM afforestation with *U. pumila*. Afforestation with *P. euphratica* remained competitive with cotton, wheat and maize crops at the current price of tCER, when water supplies did not exceed 6,800 m^3 ha^{-1}. With greater water availability, vegetables would become more profitable than *P. euphratica* plantations. A further increase in irrigation water availability would make rice the most profitable crop. In the case when irrigation water availability is at the level of 26,500 m^3 ha^{-1}, the level which is required to achieve highest rice yield, the tCER prices would need to be 57 USD $tCER^{-1}$ to initiate CDM afforestation with *P. euphratica*. By contrast, due to revenues from fruit production, relatively smaller increases in tCER prices would be needed for afforesting marginal croplands with *E. angustifolia* in lieu of rice cultivation. An increase up to 44 USD $tCER^{-1}$ would be needed for *E. angustifolia*, if irrigation water availability ranges between 16,900 m^3 ha^{-1} and 26,500 m^3 ha^{-1} Although these high amounts of water are not usually available for marginal croplands, they should still be taken into account for the purpose of indicating the points when short-term afforestation becomes competitive with crop cultivation.

Given the much lower irrigation demand of trees, the difference in total water use of annual cropping and afforestation over seven years can be considered as irrigation water saving in a sense that the water not used at afforested marginal lands can be used on more productive lands. The latter can vary in response to considered tCER prices (Figure 3.2). The trend lines in Figure 3.2 were derived based on the trend lines presented in Figure 3.1 after subtracting irrigation water demand for tree plantations, i.e., 1,600 m^3 ha^{-1}. The present price of 4.76 USD $tCER^{-1}$ would allow farmers to get involved in CDM afforestation while not using between 1,600 m^3 ha^{-1} and 15,300 m^3 ha^{-1} of irrigation water each year on marginal lands. CDM afforestation with *E. angustifolia* that has a much higher tCER price (44 USD), could annually supply productive croplands with an irrigation water of about 25,000 m^3 ha^{-1}. In contrast, *P. euphratica* and *U. pumila* would necessitate substantial increase in tCER prices to achieve the same potential of irrigation water saving for more productive lands.

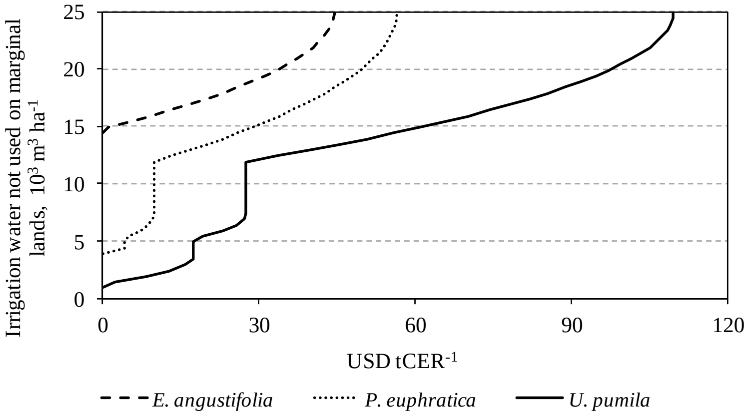

Figure 3.2: Amount of irrigation water saved by afforestation of marginal croplands with respect to temporary Certified Emission Reduction (tCER) prices.

4. Risk managing option and value of services of afforestation on marginal farmland[6]

This chapter addresses the second specific objective of the study: to investigate the impact of afforestation of marginal croplands on farm income and determine price of temporary Certified Emission Reductions (tCER) of such land uses under uncertainty. For this, the study considers a field (1 ha) and whole farm scales, and takes into account various uncertainties. Section 4.1 presents a review of the relevant literature on studies of agriculture and forestry related to uncertainties and risks. Following this, Section 4.2 provides a description of the database and methods used for investigation of the impact of afforestation on farm income under uncertainty, derivation of tCER price under revenue variability, and the potential of afforestation to manage land use revenue risks. Section 4.3 presents the model results at a field and whole farm levels. First, field level estimation results of the financial returns of afforestation and the required price of tCER to initiate afforestation considering the uncertainties in land use revenues are given. Afterwards, this section provides the farm level estimation results of tCER prices required to initiate afforestation, and risk management options and impact on farm income of afforestation under land use revenue uncertainties.

4.1 Literature review

Agricultural production and forestry activities are subject to various uncertainties and risks affecting farmers' profits. The variability in prices and yields of land uses necessitates considering different outcomes that would influence decisions on environmentally sustainable land uses such as afforestation (Knoke et al., 2011; Castro et al., 2013). Risk in land use planning comprises a set of undesired events that could negatively affect livelihoods, i.e., by involving the probability of reduced crop yields, negative effect of resource supply, and others (Hardaker et al., 2004). Uncertainty in land use planning occurs when the farms output is unknown and results in different outcomes that may positively or negatively affect farmers' incomes (Hardaker et al., 2004). However, risk and uncertainty could be interchangeably used in land use analysis, due to the subjective assessment of probabilities and distributions (Hazell and Norton, 1986).

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[6] Chapter 4 builds on Djanibekov, U., Khamzina, A., under 2nd review. Valuation of goods and services from afforestation of marginal irrigated farmland in drylands under revenue uncertainty. Environmental and Resource Economics.

The first studies on uncertainty in farming started with the works on the estimation of risk preferences (Just, 1974), employment of labor in farming activities (Stiglitz, 1974), resolving decisions among risky alternatives (Lin et al., 1974), and theoretical foundations in agricultural decision analysis (Anderson et al., 1976). The previous studies for assessing environmental services of land uses usually capture a portion of their value (Mendelsohn and Olmstead, 2009). In addition, these previous studies often compared opportunity cost of land uses, such as C forestry and crop cultivation, to derive the payments for environmental services (PES) (e.g., Olschewski et al., 2005; Djanibekov et al., 2012c), and only few accounted for the uncertainties related to them (e.g., Knoke et al., 2011; Johnson et al., 2012; Castro et al., 2013). The evaluation of farm forestry activities with uncertainties in revenues mainly dealt with the assessment of forest deforestation (Coomes et al., 2008; Knoke et al., 2009b; Pelletier et al., 2012), and considered optimal rotations under C price uncertainty (Romero et al., 1998; Chladná, 2007). Uncertainty analysis could provide deeper insights on land user's behavior and risks affecting the revenue, and determine PES incentivizing C sequestration and other environmental services.

The description of the various methods used in risk and uncertainty analyses in agriculture and forestry economics are given in Table 4.1. From these methods, the stochastic dominance (SD) can be a suitable method to assess uncertainty in revenues of afforestation on marginal croplands and order risky activities when the preference function is unknown, while also integrating the randomly generated numbers from the Monte Carlo simulation. The Monte Carlo simulation is commonly applied in exploring the impact of economic uncertainty on land use revenues, and allows generating a large number of different scenario alternatives that leads to different outcomes, by considering certain model values to be randomly selected and with a possibility to correlate them (Hardaker et al., 2004). In SD, only limited information on risk preferences is required (Hardaker et al., 2004), and this approach is mainly applied for the comparison of several land uses based upon the full distribution of outcomes of each production activity. Benítez et al. (2006) using SD derived the conservation payments for shaded coffee plantations, indicating that the conservation payments should be higher when considering various revenue risks than under the deterministic option to preserve these land uses. According to Johnson et al. (2012) despite high variations in ecosystem service values, fluctuations in the opportunity cost of land could determine trade-offs in land use preferences. The farm production constraints (e.g., irrigation water and land availability) are not considered in SD, as such an approach is lacking in discriminatory power (Castro et al., 2013). Moreover, farmers' land use decisions involve many alternative options, which renders the identification of optimal land use at a whole farm level impossible with SD, and thus necessitate to consider the model that involve decisions at the whole farm level (Hardaker et al., 2004).

The evaluation of afforestation activities may be extended to farm planning (Knoke et al., 2009a). In this respect, mathematical programming is a suitable approach to support farm planning activities (Hardaker et al., 2004). This approach is an effective instrument for understanding the complexity of human and environmental systems, while deriving optimal decisions for farmers under production constraints. Mathematical programming model allows for simultaneously considering various land uses and estimate values of environmental service payments from introducing afforestation on marginal croplands (Castro et al., 2013). The commonly used mathematical programming approaches addressing uncertainty in land uses are utility maximization objective, $E(U)$, and expected value-variance, $E(V)$ (Von Neumann and Morgenstern, 1947; Markowitz, 1959). These approaches can integrate the randomly generated numbers from the Monte Carlo simulation. While both the $E(U)$ and $E(V)$ methods are widely used in agricultural economics, the main shortcoming of $E(V)$ approach is that the mean is considered as the relevant target and risk is accordingly quantified using the magnitude of deviations from this target (Berg and Schmitz, 2008).

Table 4.1: Methods addressing risk and uncertainty in the fields of agricultural and forestry economics.

Methods	Description
Stochastic simulation	
Stochastic dominance	Differentiation of efficient and inefficient sets of investments. The increase in stochastic dominance degrees increases the restrictive assumptions with respect to the utility function.
Objective function risks	
Expected value-variance E(V)	Quadratic objective function with risk aversion parameter. Assumes that returns are normally distributed.
Expected utility model with state contingent approach	Linear or non-linear utility objective function with different states of nature.
Safety first	Linear objective function. Imposes a minimum constraint on certain outcomes.
Minimization of total absolute deviations (MOTAD)	Linear objective function with an absolute deviation to measure risks. Model depicts tradeoffs between expected income and the absolute deviation of income.
Right hand side risks	
Chance constrained programming	Linear objective function. Imposes risk on right-hand-side of the model.
Quadratic programming	Non-linear objective function. Combines E(V) and chance constraint programming. Imposes risk aversion parameters in both objective function and right-hand-side.
Technical coefficient risks	
Merrill's approach	Non-linear constraints with the mean and variance of the inputs into the constraint matrix.
Wicks and Guise approach	Linear constraints. Based on MOTAD and Merrill's models. Approach converts an absolute deviation into an estimate of standard deviation, using a variant of the dispersion factor.

Source: McCarl and Spreen (1997); Hardaker et al. (2004); Gong and Löfgren (2007); Blanco-Fonseca et al. (2011); Hildebrandt and Knoke (2011).

Previous research conducted on uncertainties and risks affecting crop cultivation and afforestation in farm systems in irrigated agricultural settings has focused on the attitude of farmers towards risks, identifying their optimal production plans, income generation and rotation practices (Kingwell, 1994; Teague et al., 1995; Insley, 2002; Abdulkadri, 2003; Berg, 2003; Cabrera et al., 2006; Riesgo and Gomez-Limon, 2006; Bell et al., 2008). In addition, in farm scale analysis a wide variety of possibilities can be captured that allow analyzing the risks influencing livelihoods and risk smoothing (management) mechanisms. According to Berg and Kramer (2008) the risk management instruments can be classifided into on farm risk management instruments (i.e., risk prevention/reduction, diversification, and holding reserves), and market based/risk sharing instruments (i.e., risk pooling (insurance), risk transfer via contract). For example, Bobojonov (2008) using the expected value-variance and chance constrained programming explored the potential of risk reducing strategies for farmers, while accounting for their economic and environmental benefits in the Khorezm region. He showed that the laser leveling and drip irrigation technologies would allow farmers to mitigate farm production risks by increasing crop yields, although achieving this at high initial costs. According to Hardaker and Lien (2001) financial reserves (e.g., borrowing possibility) can create a risk bearing potential that may compensate the effects of events that would negatively affect the livelihood, yet such system of financial reserves may not be well functioning for farmers in the developing countries. The insurance is widely used mechanism among farmers to reduce the effects of risks, for example in Germany and Spain about 60-70% of farmers apply this instrument (Palinkas and Szekely, 2008). However, if the damage of risks are unsubstantial and recurrent the loss adjustment costs reduce the attractiveness of insurance, and when the risks are positively correlated the pooling principle would preclude the insurance because the insured farmers might claim indemnities at the same time and hence lead to high premium loading factors (Berg and Kramer, 2008). One of the options for farmers to mitigate the positively correlated risks could be through the contractual arrangements and/or by using financial derivatives with other agricultural actors in the market (Berg and Kramer, 2008). Another risk management strategy can be land use diversification, that allows farmers to select the strategies combining several land uses that have independent net revenue fluctuations that may become an effective buffer to reduce the repercussions of revenue risks (Knoke et al., 2011). For instances, Babu and Rajasekaran (1991) evaluated the introduction of two agroforestry systems in irrigated farming systems, analyzing changes in cropping pattern, input use, income generation, risk attitude and nutrient availability. They argued that the adoption of agroforestry systems needs to consider risk attitudes and resource constraints of farmers, and would diversify farming activities and revenues. In addition, Di Falco and Perrings (2005) argued that considering whole-farm revenue risks was important for valuing environmental services of land uses. Diversification of cropping activities with forestry may lead to supply of various environmental services (Khamzina et al., 2012; Villamor et al., under review) with the possibility to identify appropriate PES values, while mitigating revenue risks and increasing incomes of farmers (Castro et al., 2013).

Previous studies on the effects of farm diversification from introducing new land use practices such as afforestation have missed to simultaneously address different sources of uncertainties affecting land use revenues in irrigated agricultural settings (Babu and Rajasekaran, 1991; Berg and Schmitz, 2008; Knoke et al., 2009b; Baumgärtner and Quaas, 2010; Knoke et al., 2011; Johnson et al., 2012; Castro et al., 2013). Furthermore, such studies have not addressed the risk coping option of multiple product tree plantations. Given these research gaps, there is a need to analyze the monetary value of CER payments from afforestation under uncertainty, and to identify the farmland diversification and risk managing options of afforestation.

4.2 Empirical methodology

4.2.1 Data sources

In this study, a data from commercial farm survey were used, such as farm size, crop cultivation area, input and output prices, production practices and costs, labor requirements, and transportation costs[7]. The prices of crop and tree products were collected through a weekly market survey. To capture variability of crop prices and yields and irrigation water availability, data on these parameters were obtained from the Statistical Committee of Khorezm and the Ministry of Agriculture and Water Resources of Uzbekistan for the period 2001-2009 (MAWR, 2010; Statistical Committee of Khorezm, 2010). Correlations of crop yields and prices and irrigation water availability are presented in Table D1 in Appendix D. Correlations values of tree product prices are presented in Table D2 in Appendix D.

Yields of crops were estimated based on water-yield response function using official irrigation rate recommendations for four classes of cropland productivity, i.e., marginal, fair, good, and high (MAWR, 2001; Land Resources, 2002). Information on product yields from tree plantations over a 7-year rotation period was obtained from an afforestation trial conducted on

[7] The survey data and model used in this chapter are documented here: http://data.zef.de

degraded cropland in the Khorezm region (Khamzina et al., 2008; 2009b).The detailed information on the farm and market surveys, and afforestation site is given in Section 3.2.1.

4.2.2 Uncertain crop and tree values

In this study the uncertain parameters for crop and tree product yields and prices, and irrigation water availability for a farm were generated using a Monte Carlo simulation. Monte Carlo simulation allows generating a large number of values by considering certain model values to be randomly selected and with a possibility to correlate them. To prevent biasing the simulation results, a stochastic dependency between crop yields and prices, and irrigation water availability was considered by allowing their multivariate normal distribution, which was generated based on the data from official statistics for the period 2001-2009 (MAWR, 2010; Statistical Committee of Khorezm, 2010). As the price of raw cotton yield and half of the wheat yield are set by the state, their levels were considered as deterministic (for the description of smoothing cotton procurement prices see Section 2.4.1). Yields of tree products of each species were correlated between their products and generated in normal distribution, whereas their prices were independently normally distributed. Since the data for the yield of tree products relies on experimental study, correlations between tree yields and prices were not considered. In the same manner, correlations between tree and crop parameters, as well as tree parameters and irrigation water availability were not considered, and were assumed to be identically distributed so that the occurrence of one state does not influence the probability distribution in another period. Thus, in the analysis, the intra-annual variability in yield, price and irrigation water availability is identically distributed over the years. This does not allow considering yearly trend and different variability levels. To address this issue an approach such as Brownian motion can be applied (Dixit and Pindyck, 1994). However, its application may complicate the intended investigation of the impacts of afforestation by relying on the outcomes produced subject to the arbitrary generated parameters which are difficult to motivate.

The Shapiro-Wilk[8] test was applied to accept or reject the null hypothesis that the generated parameters by Monte Carlo simulation are normally distributed (Table 4.2) (Royston, 1982). This test provides information on p-values for each generated parameter and on accepting or rejecting

[8] An alternative for testing normal distribition is Kolmogorov-Smirnov, Anderson-Darling, Skewness-Kurtosis, Lilliefors tests.

the null hypothesis with a given confidence interval. The test results show that the p-value is very small for the generated yield of fuelwood of all three tree species and fruits of *E. angustifolia*. Consequently, the null hypothesis is rejected for these parameters, thus implying that they are not normally distributed. At the same time, the correlations of these parameters were close to those observed (compare Table D2 with the correlations of generated tree yield parameters in Table D3 in Appendix D), and thus generated parameters by Monte Carlo simulation were acceptable for the analysis. The distribution of yield of leaves of *E. angustifolia* does not result in the rejection of hypothesis that the generated data is normally distributed, with a 99% confidence level. The test results showed a 95% confidence level that the generated by Monte Carlo simulation the crop yields and prices, irrigation water availability and other tree product yields and prices were normally distributed.

Table 4.2: Shapiro-Wilk test results.

	Shapiro-Wilk test for normal data			
Parameter	W test	Covariance	Z test	P-value
Crop yields				
Cotton	0.997	0.710	-0.803	0.789
Wheat	0.997	0.724	-0.759	0.776
Rice	0.997	0.745	-0.691	0.755
Maize	0.997	0.684	-0.891	0.813
Vegetables	0.997	0.726	-0.750	0.773
Crop prices				
Wheat	0.996	0.915	-0.208	0.582
Rice	0.996	0.894	-0.263	0.604
Maize	0.996	0.763	-0.635	0.737
Vegetables	0.997	0.746	-0.689	0.754
Irrigation water availability	0.993	1.519	0.981	0.163
Tree product yields				
Fuelwood of *E. angustifolia*	0.981	4.011	3.260	0.001
Fuelwood of *P. euphratica*	0.961	8.302	4.968	0.000
Fuelwood of *U. pumila*	0.984	3.400	2.873	0.002
Leaves of *E. angustifolia*	0.989	2.243	1.896	0.029
Leaves of *P. euphratica*	0.994	1.254	0.532	0.297
Leaves of *U. pumila*	0.995	0.995	-0.011	0.504
Fruits of *E. angustifolia*	0.962	8.126	4.918	0.000
Tree product prices				
Fuelwood of *E. angustifolia*	0.995	1.051	0.116	0.454
Fuelwood of *P. euphratica*	0.996	0.881	-0.298	0.617
Fuelwood of *U. pumila*	0.995	1.111	0.247	0.402
Leaves of *E. angustifolia*	0.995	1.128	0.284	0.388
Leaves of *P. euphratica*	0.995	1.005	0.012	0.495
Leaves of *U. pumila*	0.994	1.176	0.380	0.352
Fruits of *E. angustifolia*	0.995	1.034	0.078	0.469

The descriptive statistics of tree product yields are provided in Table A in Appendix A. The coefficients of variation of tree product prices, crop yields and prices, and irrigation water availability are given in Table C in Appendix C.

Given the stochastic parameters, the NPV of CDM afforestation and crops ($N\tilde{P}V$) can be estimated as follows:

$$N\tilde{P}V = \sum_{t=0}^{T} \frac{\tilde{Y}_t \tilde{P}_t - C_t}{(1+d)^t} \qquad (4.1)$$

where $\tilde{Y}_t$ and $\tilde{P}_t$ are the uncertain values of yields and prices, respectively. C_t is the cost of the land uses in period t, including the costs of crop cultivation, establishing and maintaining the tree plantation, harvesting and the transportation costs of tree products, and the transaction costs of the small-scale CDM afforestation [USD ha^{-1}]. d=14% is the actual interest rate in Uzbekistan in 2009. The costs were assumed to be deterministic. Since the government purchases half of the wheat harvest, the wheat price is an average value of market and state procurement prices.

4.2.3 Uncertainty in land use revenues at the field level

In the land use change from annual crop cultivation to afforestation, a farmer has to decide whether to invest into CDM afforestation under N possible outcomes corresponding to different levels of returns from different tree species and crops. Stochastic dominance (SD) method orders uncertain activities when the preference function is unknown, comparing them in terms of the distribution of outcomes. SD approach was applied to investigate the distribution of land use returns and identify the required tCER price to initiate CDM afforestation on marginal croplands. In this case, profits from CDM afforestation, NPV^{CDM}, would dominate the profit of crop cultivation, NPV^{A}, if and only if:

$$\sum_{n=1}^{N} [NPV^{CDM} - NPV^{A}] \geq 0 \text{ for all NPV outcomes} \qquad (4.2)$$

In SD criterion, distributions of outcomes of land uses on a field scale of 1 ha are compared based upon the areas under their cumulative distribution function, requiring that the cumulative curve of more profitable land use is below and to the right of the corresponding curve for the less profitable land use (Hardaker et al., 2004). The comparison of NPV distributions applies to situations where land use alternatives are mutually exclusive. However, this approach does not account for constraints in land use decision making, and hence the irrigation water availability and land area were not limiting inputs for crop cultivation. Accordingly, crop yields were considered at the optimal water-yield response levels (see Figure 2.4 in Section 2.2.2).

In cases when returns from tree products are lower than those of crops, the minimum level of tCER that would motivate a farmer's decision to shift from annual cropping to CDM afforestation on marginal land can be calculated by the modified version of Eq. (3.7):

$$\tilde{\mathrm{P}}^{\mathrm{tCER}} = \frac{\mathrm{N\tilde{P}V^{A}} - \mathrm{N\tilde{P}V^{CDM}}}{\sum_{t=0}^{T} \tilde{\mathrm{Y}}_{t}^{\mathrm{tCER}}(1+\mathrm{d})^{-t}} + \frac{\sum_{t=0}^{T} \mathrm{TC}_{t}(1+\mathrm{d})^{-t}}{\sum_{t=0}^{T} \tilde{\mathrm{Y}}_{t}^{\mathrm{tCER}}(1+\mathrm{d})^{-t}} \tag{4.3}$$

Eq. (4.3) shows that the value of $\tilde{P}^{tCER}$ depends on the yield and price variability of crops and trees, reflected in $N\tilde{P}V^{A}$ and $N\tilde{P}V^{CDM}$. According to SD, when the returns from CDM afforestation of marginal cropland are lower than those of crops (i.e., have higher cumulative distribution area), tCER price needs to be increased to the level whereby the returns are at least equal. Due to the absence of yield and price correlations of tree and crop products, to derive tCER prices that would incentivize CDM afforestation on marginal croplands the minimum and maximum NPV^{A} and NPV^{CDM} were considered, based upon which a range of tCER prices were determined. Moreover, when deriving P^{tCER} the demand side conditions (buyer of tCER) were not considered. This is in line with other studies performed for identifying price of C sequestered in trees (e.g., Olschewski and Benítez, 2005; Benítez and Obersteiner, 2006; Guitart and Rodriguez, 2010).

4.2.4 Farm plans under uncertainty

SD approach can be used to order risky choices in farm activities and identify environmental payment levels by the opportunity cost of land. However, SD lacks in discriminatory power and thus may result in overly large values for tCER, which would be unrealistic to implement (Knoke et al., 2008; Castro et al., 2013). Furthermore, the on-farm afforestation of degraded cropland also involves farm planning that considers constraints in resources availability. In this case, the mathematical programming model allows for solving the problem in a farming system context (Hildebrandt and Knoke, 2011; Castro et al., 2013). In this study, using a mathematical programming model, a situation of afforestation of a farm's marginal lands in the CDM framework (CDM) is compared with the business-as-usual (BAU) situation, where the current cropping practices were followed. One widely used method that addresses uncertainty via mathematical programming is the expected utility approach, $E(U)$. The $E(U)$ implies that the utility of farm profits of all land uses, NPV_n^{FARM}, can be calculated depending on the degree of risk aversion, r, and the distribution of NPV_n^{FARM}. Negative exponential function, which is among the frequently applied utility functional forms (Meyer, 2010), was used in this study and expressed as follows:

$$\mathrm{MaxE(U)} = \sum_{n=1}^{N} \mathrm{U}(\mathrm{NPV}_n^{\mathrm{FARM}}, \mathrm{r})\pi(\mathrm{P}_n) = 1 - \mathrm{e}^{-\mathrm{rNPV}_i^{\mathrm{FARM}}} \tag{4.4}$$

where U is the utility function evaluated for the selected values of risk aversion, r, with respect to the expected NPV from the land uses. $\pi(P_n)$ is the probability for state of nature n simulated using the Monte Carlo approach, where each outcome has the same probability and N is the number of states of nature. This approach allows the representation of uncertainty by differentiating various states of nature, which utility sums into 1.

Ordering each outcome by utility values will be the same as ordering by the certainty equivalents (CE). CE expresses values in money terms, which is the sure amount of returns that a decision maker would rate with a risky prospect (Lien et al., 2007):

$$\mathrm{CE} = \mathrm{U}^{-1}(\mathrm{NPV}_n^{\mathrm{FARM}}, \mathrm{r}) \tag{4.5}$$

In the model, a risk aversion degree, r, addressed the reluctance of a farmer to accept a bargain with uncertain land use profits rather than another with more certain yet lower profits (Hardaker et al., 2004). According to Arrow (1971), in this study it is assumed that the coefficient of absolute risk aversion remains constant when profits of activities are maximized. The risk aversion levels considered in the model were not elucidated from the surveys and hence subjective risk aversion levels were considered. In real life, the risk aversion degrees of farmers may vary depending on their characteristics. The risk aversion values, r, were estimated based on the constant risk aversion with respect to the NPV of the risk-neutral farmer, $N\bar{P}V^{neutral}$, in the range from 0.5 (hardly-risk averse at all) to 4 (extremely risk-averse), as follows:

$$\mathrm{r} = \frac{\mathrm{rr}}{\mathrm{N\bar{P}V^{neutral}}} \tag{4.6}$$

Accordingly, to estimate the risk aversion values of a farmer, the model was run without the risk aversion levels (risk-neutral case) and considering the NPV over seven years of a farmer following crop cultivation.

A cotton-grain farm type was analyzed, owing to its dominant number and size in the study area (State Statistical Committee of Uzbekistan, 2010). The model is subject to constraints of resource endowments. The farmer is endowed with 100 ha arable land, q, of which 23 ha are marginal, 56 ha average productive, 20 ha good productive and 1 ha is highly productive, where this land, X, can be allocated to either j crops or trees. This distribution of land productivity classes corresponds to that observed in the Khorezm region in 2005 (Khorezm Region Land Cadastre, 2006). Crops could be cultivated regardless of the land productivity scale, whereas trees are restricted to marginal lands:

$$\sum_{j} X_j \leq q_j \tag{4.7}$$

A farm cultivates crops such as cotton, wheat, rice, maize and vegetables. Given that fruit orchards, mulberry plantations for silkworm rearing, and fodder crops (e.g., alfalfa) only occupy a small share of land in the selected farm type in Uzbekistan, they were thus excluded from the analysis. Farm crop cultivation followed the cropping calendar: occupation of land by cotton in March-November; wheat in October-June; rice and maize in July-October; and vegetables in April-October.

With respect to water availability constraint, a farm assigned the irrigation water for j cropped and afforested areas, X, at respective irrigation rates, h, which should not exceed the varying amount of water available for the farm, $\tilde{w}_n$:

$$\sum_{j} hX_j \leq \tilde{w}_n \tag{4.8}$$

Average annual irrigation water availability for the whole farm was assumed to be 1,200,000 m^3 (MAWR, 2010). For tree plantations, irrigation water was allocated only during the first two years following afforestation.

The cotton policy constraints were included to depict the cotton production policy in the model. Under the BAU scenario (1) at least 50% of farmland, X, is allocated for cotton cultivation, F, (Eq. 4.9), and (2) according to the quantity-based target, the cotton production on the whole farm should not be less than that set by the state of 120 t (Eq. 4.10). In the CDM scenario, the cotton cropped area was not fixed yet the same yield target remained:

$$X_{cotton,t} \geq F_{cotton,t} \tag{4.9}$$

$$\sum_{j} \tilde{Y}_{cotton,t} X_{cotton,t} \geq ST_{cotton,t} \tag{4.10}$$

To determine the tCER payment level required to initiate CDM afforestation on marginal croplands, sensitivity analysis was applied by changing tCER prices under five scenarios: no value for the tCER, 4.76 (average price of tCER in 2009 as reported in Hamilton et al. (2010)), 20, 70 and 120 USD $tCER^{-1}$. The model was programmed in the General Algebraic Modeling System (GAMS).

The limitation of the expected utility approach is as tree plantations are perennial crops the dynamic model could give better overview to the problem. Furthermore, due to data scarcity and computational limits, the analysis in this chapter does not consider possible effects of afforestation of marginal farmland on environmental changes, such as improvement of soil quality, and externalities such as impacts on other groups of rural population. Besides, due to data availability the other sustainable land use options on marginal farmlands and risk management instruments were not considered.

4.2.5 Validation of the model

To validate the model, the expected utility model results on the cropping pattern in the BAU scenario with the extremely risk-averse case were compared with the observed values during the surveys in the cotton-grain farm types and rural households (Table 4.3). Accordingly, when the BAU model's results are close to the share of cropping pattern of cotton, wheat, rice, maize and vegetables the model is valid. Given that perennial crops such as fruit trees and mulberry plantations for silk production, and other fodder crops only use a marginal share of land in cotton-grain farm types, their production is not included in the validation. According to the validation procedure, the cropping pattern of the BAU scenario is close to the observed values during the surveys. The major differences in the cropping pattern of the model were found in the share of cultivated area of cotton, maize and vegetables.

Table 4.3: Comparison of cropping pattern under the business-as-usual (BAU) scenario in the extremely risk-averse case of the expected utility model with that observed during the surveys in the cotton-grain farm type.

Producer	Crops	Observed*	BAU of the expected utility model
		%	%
Farm	Cotton	40	37
	Wheat	29	28
	Rice	14	14
	Maize	11	17
	Vegetables	6	4

Note: *Is the land use pattern of cotton-grain farm type observed during the surveys in 2010-2011.

4.3 Results

4.3.1 Stochastic value of land uses and carbon price

As the land uses are subject to various uncertainties the stochastic dominance (SD) analysis of crops and trees allowed to identify the most and least risky land uses on a field scale (Figure 4.1). According to the SD analysis, the overall range of NPV for crops were between -2,971 USD ha^{-1} and 20,424 USD ha^{-1} on marginal croplands, and between -588 USD ha^{-1} and 21,753 USD ha^{-1} on highly productive ones. Due to the state procurement policy and the smoothing of cotton price (see Section 2.4.1 for the description of cotton procurement policy), that crop has the least variable returns and the main risk on NPV stems from its yield. For example, the NPV over seven years of cotton was between -1,041 USD ha^{-1} and 346 USD ha^{-1} on marginal croplands. In a similar manner, the NPV of wheat also has low variability, as the half of its harvest is purchased by the state. Rice has the highest returns on marginal lands compared to other crops, despite requiring the highest irrigation amount. Rice dominates other crops on average productive lands, whereas vegetables and rice dominate other crops on good productive lands, and vegetables are the most financially attractive crop on highly productive lands. The cumulative probability function of rice depicts that the NPV of this crop can have a 20% chance of being lower than 4,650 USD ha^{-1}, a 40% chance of being lower than 7,300 USD ha^{-1}, a 60% chance of being lower than 9,500 USD ha^{-1} and an 80% chance of being below than 11,500 ha^{-1}. At the same time, the variability in NPV of rice and vegetables are highest among all modeled crops. This could be explained by the high correlations between the yields and prices of these crops (see Table D1 in Appendix D).

When considering the NPV of tree species, in Figure 4.1 (a), the curve of *E. angustifolia* is located at the right side of the curves of cotton, wheat, maize and vegetables, except for rice. This implies that it would be more preferable for the farmer to plant this tree species than these crops on marginal lands. The minimum NPV of *E. angustifolia* without tCER payments would be -962 USD ha^{-1}, the average one would be 5,346 USD ha^{-1}, and the highest NPV could reach up to 11,634 USD ha^{-1}. *U. pumila* would be the least profitable among tree species, yet along with *P. euphratica* it would have the least uncertainty in returns. For instance, the NPV of *U. pumila* can have a 20% chance of being lower than -350 USD ha^{-1}, a 40% chance of being lower than 120 USD ha^{-1}, a 60% chance of being lower than 650 USD ha^{-1} and an 80% chance of being below than 1,000 ha^{-1}. The highest and the most varying NPV of *E. angustifolia* among other tree species is due to the annual production of fruits (Djanibekov et al., 2012c).

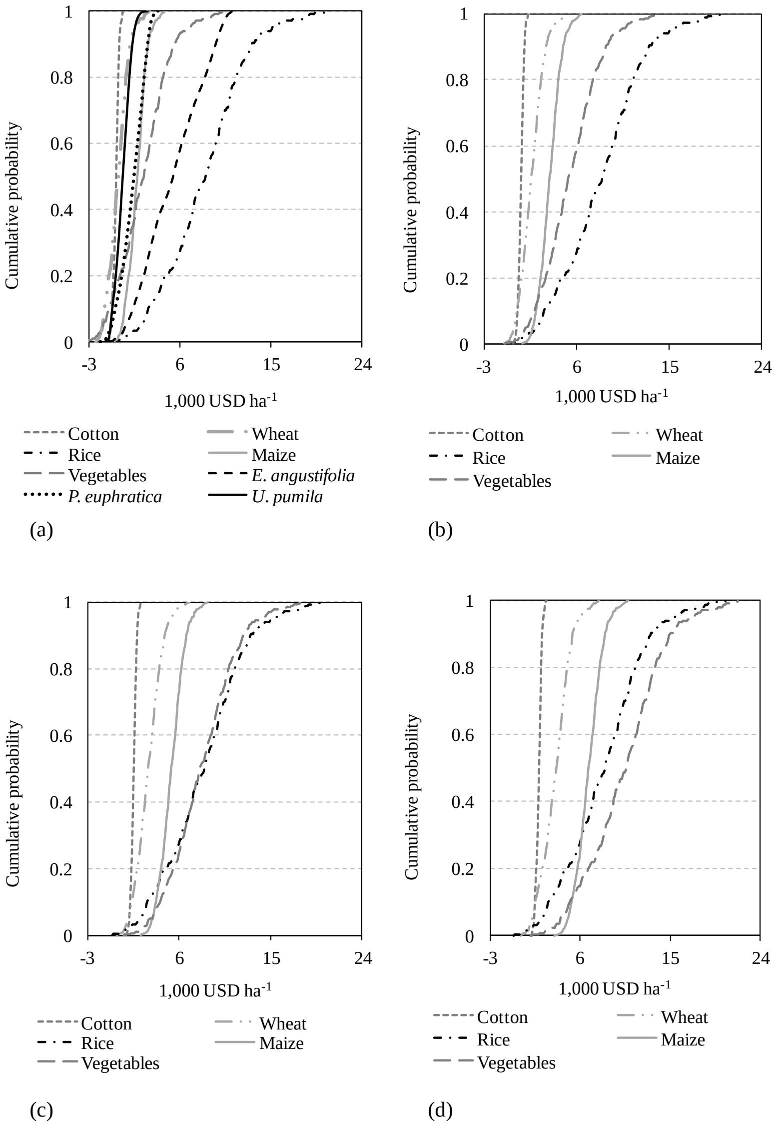


Figure 4.1: Stochastic dominance of the net present value over seven years of trees on marginal lands (a), and crops on marginal, average (b), good (c) and highly (b) productive lands.
Note: revenues from temporary Certified Emissions Reduction (tCER) are not considered.

Although the study results showed that afforestation of marginal croplands in Uzbekistan is a financially attractive land use option, additional payments in the form of the tCER may be required to outweigh the profits of rice, vegetables and maize in order to initiate such a land use. Hence, the tCER prices were derived considering the uncertainties in the NPV of trees and crops grown on marginal lands. Since the data on the correlations of farm forestry and crop cultivation does not exist, to derive tCER prices, a range of values was selected that would make the NPV of tree plantation equal to its opportunity cost, i.e., crops (shaded areas in Figure 4.2). Depending on the highest NPV of trees and the varying NPV of crops, the tCER price would need to be adjusted up to 68 USD $tCER^{-1}$ for *E. angustifolia*, 103 USD $tCER^{-1}$ for *P. euphratica*, and 133 USD $tCER^{-1}$ for *U. pumila*. Given that *E. angustifolia* has the largest NPV among other trees, this species would require the least increase in tCER price to initiate CDM afforestation on marginal croplands. In the riskiest case, when tree plantations would bring the lowest profits, due to the low yields of tree products and their market prices, and in the case, when crops would bring the highest profits, due to their high yields and market prices, the tCER price would necessitate a substantial raise in its level to increase the financial attractiveness of CDM afforestation. For instance, at the lowest NPV of *U. pumila* and the highest NPV of crops, the tCER price level might require an increase up to 540 USD $tCER^{-1}$ to establish CDM afforestation on marginal lands.

However, analysis with SD criteria is lacking in discriminatory power, such as constraints in irrigation water and land, thus explaining why tCER payments were so high (Hardaker et al., 2004). According to Castro et al. (2013), identifying conservation payment prices based upon opportunity cost of land was almost twice of a method that accounts for the whole farm planning. Hence, identifying tCER prices to initiate afforestation on marginal croplands by considering the opportunity cost of land may lead to its unrealistically high prices.

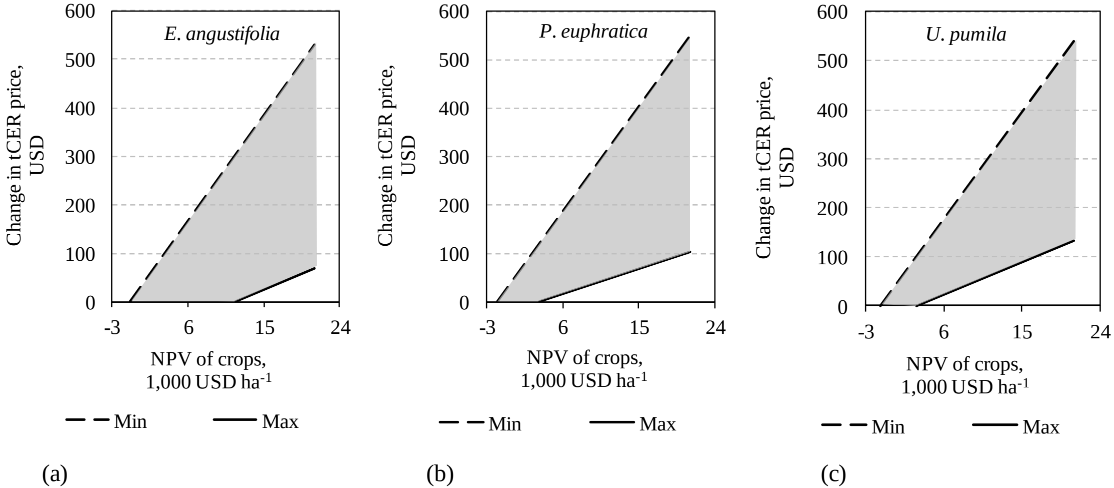


Figure 4.2: Prices of temporary Certified Emission Reduction (tCER) under uncertainty of net present values (NPV) of *E. angustifolia* (a), *P. euphratica* (b) and *U. pumila* (c) and crops over seven years.

Note: Min is the prices of temporary Certified Emission Reduction (tCER) based on simulated lowest net present values of respective tree species; Max is the prices of temporary Certified Emission Reduction (tCER) based on simulated highest net present values of respective tree species.

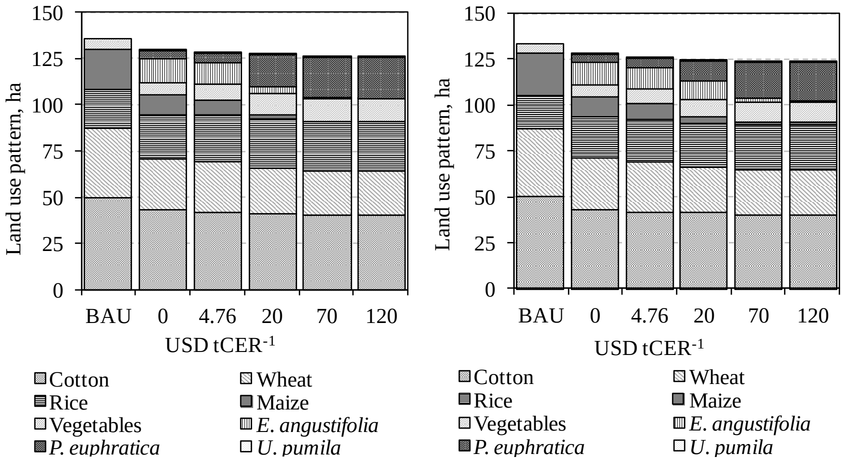
4.3.2 Land use diversification

As can be seen from Section 4.3.1, using the SD approach to identify tCER prices, which would motivate farmers to establish CDM afforestation, necessitates a considerable increase in the current price of tCER (i.e., 4.76 USD). However, afforestation at farm is subject to various constraints, which would also affect land use decisions. The diversification possibility of land use practices on farm can require a minor adjustment of tCER prices to initiate planting trees under the CDM framework.

To estimate the tCER price and the impact on farm income under uncertainty using the expected utility approach, the NPV of the risk-neutral farmer was initially estimated. In this case, the NPV of the risk-neutral farmer over seven years was 353,000 USD. Consequently, using the NPV of the risk-neutral farmer and Eq. 4.6, the risk aversion levels of farmer were derived (see Section 4.2.4), which were in the range of 0.0000014-0.000011. For the simplicity of results interpretation, were presented only hardly (0.00000014) and extremely (0.000011) risk aversion levels of the model output. Accordingly, the overall land use pattern of a farmer under both risk aversion levels is presented in Figure 4.3 (a) and (b). In the case of following the practices of business-as-usual (BAU) scenario, the hardly risk-averse farmer would at first place fulfill the cotton production target, i.e., allocate about half of his land for cotton cultivation and produce 120 t of raw cotton. After cotton cultivation, the farmer would mainly prefer to plant wheat, followed by maize and/or rice, while the least cultivated crop would be vegetables. The same trend of land use activities would be followed by an extremely risk-averse farmer, albeit with the farmer having less cropped area than the hardly risk-averse farmer due to the susceptibility to risks present in the production system. In particular, the cultivated area of rice and vegetables would be less in the case of the extremely risk-averse farmer, owing to the high variability in returns of these crops.

A farmer that can plant trees on marginal croplands would increase the cultivation area of both rice and vegetables in comparison to the BAU case. For example, the area of vegetables would almost double when trees are planted on marginal lands under the current tCER price (4.76 USD), while the area of rice would increase by about 35% in contrast to the BAU scenario. Even when tCER payments are not accounted, the area of rice and vegetables would still increase due to high returns from other non-timber products (e.g., fuelwood, fruits, and leaves as fodder). These land use changes could be explained by less water requirements of tree plantations compared to crops cultivated on marginal lands. Hence, irrigation water not used on the afforested marginal lands can be delivered to more productive lands. The increase in the area of rice and vegetables would be at the expense of the decline in the area of maize. The raise in tCER price would further reduce the area of maize, until it stops being cultivated for the hardly risk-averse farmer at the tCER prices starting from 70 USD $tCER^{-1}$. In contrast, the extremely risk-averse farmer would diversify land uses to avoid repercussions of risks, and continue to cultivate maize despite such high price levels of tCER.

When analyzing the land use pattern of afforestation without considering tCER payments, *E. angustifolia* would be the most preferred trees to plant on marginal croplands. Whereas, *U. pumila* species due to its lower returns and biomass production (Khamzina et al., 2008; 2009b; Djanibekov et al., 2012c) compared to other two tree species, would have the smallest occupied area at the farm. In such a scenario, the afforested area of marginal lands would be around 17 ha. In case when the tCER prices started to increase from 70 USD $tCER^{-1}$ to 120 USD $tCER^{-1}$, then as *P. euphratica* showed higher biomass increase in experimental site (for the data on biomass production of tree species see Table A in Appendix A), the area of this tree species would expand, while the area of *E. angustifolia* would reduce. Under the current tCER price level of 4.76 USD, *E. angustifolia* species would still remain the most preferred tree plantations on marginal lands, followed by *P. euphratica*. Moreover, when the price of tCER is about 70 USD and 120 USD, *P. euphratica* would occupy the largest area on marginal lands, and the area of *E. angustifolia* plantations would be negligible. Starting from these tCER price levels, the marginal lands would be completely afforested. To reduce the impacts of land use risks, farmer would prefer to diversify marginal lands, and thus would still plant all these tree species. Depending on the tCER price, the area of *U. pumila* on the farm would be in the range of 0.02 ha to 0.7 ha, and the tree planting patterns of both the hardly and extremely risk-averse farmer would be close. These results show that even without revenues from tCER, farmers would plant trees under the uncertainties in profits, thus contradicting the results presented in Section 4.3.1.



(a) (b)

Figure 4.3: Land use pattern of the hardly (a) and extremely risk-averse farmer (b) under the scenario of business-as-usual (BAU) and Clean Development Mechanism (CDM) with the change in prices of temporary Certified Emission Reduction (tCER).

4.3.3 Afforestation under uncertainty in irrigation water availability

Given the lower irrigation requirement of tree plantations on marginal lands in contrast to crops (Khamzina et al., 2012), a farmer would opt to plant trees on marginal lands to mitigate the income risks due to reduced irrigation water availability. For example, Figure 4.4 shows the distribution of land use pattern under the different levels of irrigation water availability of an extremely risk-averse farmer who has an option to establish CDM afforestation on marginal croplands with the tCER price of 4.76 USD. This figure shows that the variability of irrigation water availability would influence the area of afforestation. In the scenario of lower than average level irrigation water availability, i.e., lower than 12,000 m^3 ha^{-1}, trees are preferred over crops on marginal lands, in contrast to the situations of water abundance. When the irrigation amount is at the simulated minimum of 4,000 m^3 ha^{-1} with a frequency of occurrence of about 1% and considering the tCER price of 4.76 USD, a farmer would entirely afforest marginal croplands, preferring to plant *E. angustifolia* on 17.1 ha, *P. euphratica* on 4.7 ha, and *U. pumila* on 1.2 ha. The rest of the farmlands would be mainly cultivated with cotton, in order to fulfill the state production policy. Due to the low cotton yields in such scenario of irrigation water availability, the cotton production target of 120 t would require that the area of cotton is large. As the reduction in irrigation water availability affects crop yields, in this scenario the main returns would come from tree plantations. Furthermore, under lower than average irrigation water availability, a farmer would opt for crops that have high water productivity, such as maize, as well as for cotton and trees. In the scenario of the abundant irrigation water availability of 21,000 m^3 ha^{-1} with a frequency of occurrence of about 1%, tree would be planted on around 4.5 ha of marginal lands, and the main tree species would be *E. angustifolia*. Besides, in this scenario, rice, wheat and vegetables would occupy the largest area of farmland, while at the expense of maize cultivation and tree planting. Also, the area of cultivated cotton would be lower than in the scenarios of lower irrigation water availability, due to its reallocation to more productive lands that would ensure higher cotton yields.

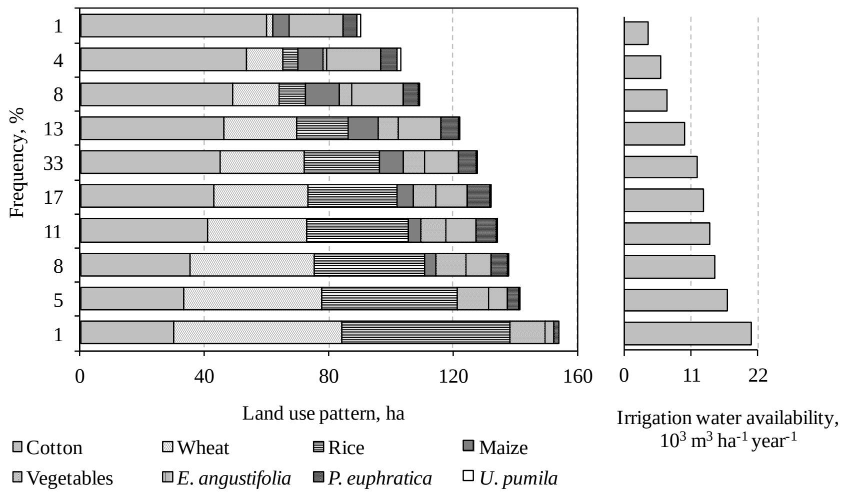


Figure 4.4: Frequency of land use pattern under different irrigation water availability of the extremely risk-averse farmer under the scenario of Clean Development Mechanism (CDM) with the temporary Certified Emission Reduction price of 4.76 USD.

4.3.4 Farm income under uncertainty

Diversification of land use by planting trees can become an effective buffer against the risks affecting farm incomes in irrigated areas (see Section 4.3.3). The Certainty Equivalent (CE) values of the NPV depending on the degrees of risk aversion of the farmer following only cropping practices and the one that is planting trees would lead to different outcomes (Figure 4.5). As expected, the CE shows the clear decreasing tendencies with increasing risk aversion levels. The lower values imply that depending on a risk aversion degree a farmer would select less risky activities to avoid possible risks of negative returns from land uses. Under the BAU case, the NPV of the hardly risk-averse farmer over seven years would be around 350,000 USD, whereas it would be 325,000 USD for the extremely risk-averse farmer. In contrast, in the CDM scenario with the tCER price of 4.76 USD, the hardly risk-averse farmer would have 470,000 USD, and extremely risk-averse farmer would receive about 435,000 USD. The higher CE in the CDM scenario is due to increased profits from marginal croplands, and would also be triggered by the allocation of irrigation water unused on marginal fields towards more productive lands. When the tCER price level is substantially increased to the level of 120 USD, the farm's total NPV would be almost twice as large as under the current tCER price level. In such a scenario, the main return would be derived from unrealistically high tCER prices.

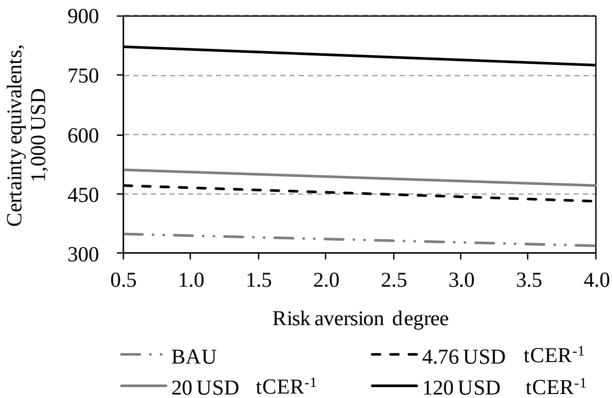


Figure 4.5: Farm certainty equivalents over seven years with different degrees of risk aversion under the scenarios of business-as-usual (BAU) and Clean Development Mechanism (CDM) with the change in prices of temporary Certified Emission Reduction (tCER).

Uncertainties in different parameters affecting land use activities, i.e., yield, prices and irrigation water availability, would lead that farm profits would substantially vary (Figure 4.6). For example, the extremely risk-averse farmer following current land use practices on marginal lands would have a farm NPV over seven years in the range of 15,000 and 930,000 USD. These low profits would be due to the reduced crop yields and prices, and irrigation water availability. In contrast, high profits could be attributed to the increased crop yields and prices, and irrigation water availability. Under the CDM scenario, the NPV of farmer that established tree plantations on marginal lands and receives tCER payments of 4.76 USD would range between 80,000 and 1,170,000 USD. In the lowest NPV case, due to the low levels of irrigation water availability, crop yields and prices, the farm profits would mainly come from tree plantations. However, in the case when the NPV of the farm is the highest, i.e., 1,170,000 USD, such high profits would be attributed to the increased crop yields and prices. Since tree product yields and prices are not correlated with the crop yields and prices, the increase in tree product yields and prices would as well lead to high NPV levels.

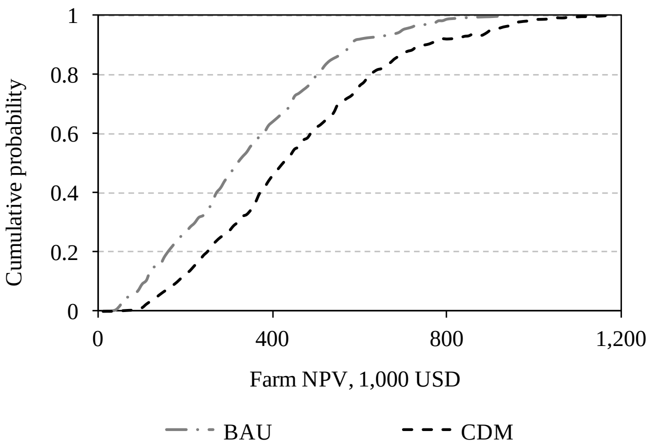


Figure 4.6: Cumulative distribution of the net present value (NPV) over seven years of the extremely risk-averse farmer under the scenarios of business-as-usual (BAU) and Clean Development Mechanism (CDM) with the temporary Certified Emission Reduction (tCER) price of 4.76 USD.

5. Impact of afforestation on rural livelihoods in a bimodal agricultural system[9]

Introducing new land use practices such as afforestation on marginal croplands at farm may have spillover effects on rural livelihoods through the agricultural contracts established between farm and rural households employed at this farm. Accordingly, this chapter addresses the third and fourth specific objectives of the study: to investigate direct and indirect impacts on rural livelihoods from shifting crop cultivation on marginal lands to tree plantations; and to identify rural development policies that may be efficient for land use change, including shifting crop cultivation on marginal lands to tree plantations. Section 5.1 provides the literature review on the impacts on livelihoods of afforestation, a discussion of structure and role of agricultural contracts in rural areas. Section 5.2 describes the data, and the model that is used to analyze the impacts of afforestation on rural livelihoods. The model explicitly considers the interdependencies between one farm and various types of rural households through the agricultural contracts. This section also presents a method that is used to classify heterogeneous rural households into distinct groups. Section 5.3 provides a description of identified types of rural households, based on their income and expenditure sources, as well as a description of observed types of agricultural contracts. Section 5.4 presents the model results on the impacts of afforestation of marginal croplands on incomes, land use, farm employment, energy use, and rural household expenditures for energy resources and livestock fodder.

5.1 Literature review

Introducing afforestation on farms' marginal croplands is among the effective land uses that could increase incomes, cope with agricultural revenue risks, improve environment and enhance carbon sequestration (Hildebrandt and Knoke, 2011; UNEP, 2011). Some studies have considered the potential of C forestry activities for supplying multiple products and services that impact not

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[9] Chapter 5 builds on:
Djanibekov, U., Djanibekov, N., Khamzina, A., Bhaduri, A., Lamers, J.P.A., Berg, E., 2013b. Impacts of innovative forestry land use on rural livelihood in a bimodal agricultural system in irrigated drylands. Land Use Policy 35, 95-106.
Djanibekov, U., Van Assche, K., Boezeman, D., Djanibekov, N., 2013c. Understanding contracts in evolving agro-economies: *Fermers*, *dekhqans* and networks in Khorezm, Uzbekistan. Journal of Rural Studies 32, 137-147.

only agricultural production and income, but also employment and energy consumption of rural population. The incorporation of bioenergy production within forest C offset projects could decrease household fossil energy expenditures and CO_2 emissions (Kaul et al., 2010). Tree leaves are protein-rich fodder that may improve forage ration of livestock (Djumaeva et al., 2009; Lamers and Khamzina, 2010). However, published findings on the sustainable development objectives of C forestry are few and bring contrasting conclusions. Palm et al. (2009) analyzed the prospects for establishing CDM A/R in India, and argued that short-term plantations with multiple tree products and environmental services are attractive for farmers. Shuifa et al. (2010) argued that C forestry projects would lead to increase of job opportunities in China. Also for China, Xu et al. (2007) showed that such projects have the potential to alleviate poverty. In contrast, Glomsrød et al. (2011) using the general equilibrium model reported for Tanzania that CDM A/R have limited ability to reduce poverty and mainly the non-poor rural and urban households would benefit, despite contributing to the mitigation of climate change. Sedjo and Sohngen (2000) using the dynamic timber supply model analyzed the effects on welfare from expanding the forest area for C sequestration. They concluded that the large-scale C forestry might have impacts on the world timber market, and thereby reduce the incentives of suppliers to invest into the forest management practices. Alig et al. (1998) used an interlinked model of the US forest and agricultural sectors to investigate the economic and ecological impacts of a minimum harvest age and a reduced harvest forest policies. The results of their study reveled that these policies would enhance the wildlife and C sequestration, yet would lead to higher prices for forest land and tree products. The study by Paul et al. (2013) concluded that even though the employment generated by afforestation on marginal lands tends to be less than many agricultural enterprises, any jobs generated from C forestry on marginal lands would be additional and result in overall increase of economic returns.

Afforestation of marginal croplands at farms in the bimodal farming system that is present in Central Asian and Central and Eastern European countries (Kostov and Lingard, 2002; Lerman et al., 2004), would impact not only this type of agricultural producers but also would have a spillover effects on rural households through their agricultural contract relationship. In this study, it is considered that farms and rural households are linked through the labor employment of the latter at farms. Large-scale farms are typically unable to manage their farms through their own labor inputs, and consequently hire nearby residing rural households. To accomplish farming activities farmer and rural households form a contractual arrangement (Roumasset, 1995).

The literature on agricultural contracts has focused on fixed (cash, in kind and land rent) and flexible (sharecropping) contractual forms between farms and rural households (Cheung, 1969; Roumasset, 1995; Agrawal, 1999). Huffman (2001) and Shively (2001) used an agricultural household model to examine rural labor markets, production, and consumption decisions, highlighting that farmers tend to hire labor with mixed wage and rent contracts. In farm employment, a significant amount of redistribution occurs in kind, which could be an effective mean of providing support to the subsistence smallholders' consumption (Gahvari, 1994; Slesnick, 1996), which could be also via multiple tree products. According to Roumasset (1995), if material determinants influence production to labor shirking then the fixed form of contract is preferred. Meanwhile, Cheung (1969) discussed that sharecropping might emerge as the dominant contractual arrangement in the presence of both agricultural risks and transaction costs. Sharecropping is the trade-off between risk sharing and incentive provision (Stiglitz, 1974; Fafchamps and Gubert, 2007), moral hazard (Ghatak and Pandey, 2000; Zhao, 2007), or limited liability (Ray and Singh, 2001; Jacoby and Mansuri, 2009). Stiglitz (1974) emphasized that the share tenancy contract could bring higher returns to the farmer (i.e., commercial farm in this study) than wage contracts. Sharecropping is the dominant form of the contractual arrangement in India, where large-scale and rich farmers store the output to take advantage of price variation (Sharma, 1997). According to Otsuka et al. (1992) use of both fixed and flexible contracts would improve agricultural production. Research on agricultural contracts has focused on the role of various factors affecting contracts, including risk sharing, moral hazard, capital constraints and transaction costs (Cheung, 1969; Stiglitz, 1974; Laffont and Matoussi, 1995; Roumasset, 1995; Sen, 2011). The combination of contracts between farmer and rural households changes according to agricultural policies and land use change, farm size, wealth of farmer and rural households, capital constraints, uncertainties in returns, transaction costs, land quality, resource availability, as well as controllable and non-controllable inputs (Murrell, 1983; Laffont and Matoussi, 1995; Roumasset, 1995).

As an example, based on the study by Taslim (1990), Figure 5.1 presents a graphical interpretation of land contractual arrangements, such as sharecropping, between farmer and his workers (rural households) under uncertainty in farm production. The figure gives an overview of land use interdependencies, and how changes in organizations (payments) could affect their incomes. Considering total farmland (*0L),* the total output of the sharecropping land is shown in ray *0A* of panel 1, while ray *0B* shows the expected output share of the farmer that brings him expected profit I_e. Panel 2 depicts the *0C* farm profit curve derived if there is no uncertainty in production.

Hence, CI_e is the profit that farmer would receive if there is no uncertainty. The curve *DEF* in panel 3 shows the profit derived under various levels of uncertainties reflected by values of variance (v_1 and v_2). The curve is assumed to be concave considering the farm profit received under different levels of uncertainty. Panel 4 depicts the relationship between variance (v) and the number of labor employed at farm (l) receiving farmland under a sharecropping payment structure. The ray *0G* in panel 5 derives the number of employed labor (l) considering the various uncertainties in farmland (v) to the horizontal axis in panel 6. For deriving the relationship between farm profit and number of labor obtaining land under sharecropping arrangement, vertical lines are drawn at v and according to the number of l. The intersection points *J* and *K* between the horizontal and vertical lines through l are the profit derived for farmer when his land is divided among several labor. Accordingly, the curve *0JK* is the profit derived from dividing the land among labor under various levels of uncertainties. Thus, the more risky the farming activity, the more sharecropping arrangements would prevail (Taslim, 1990).

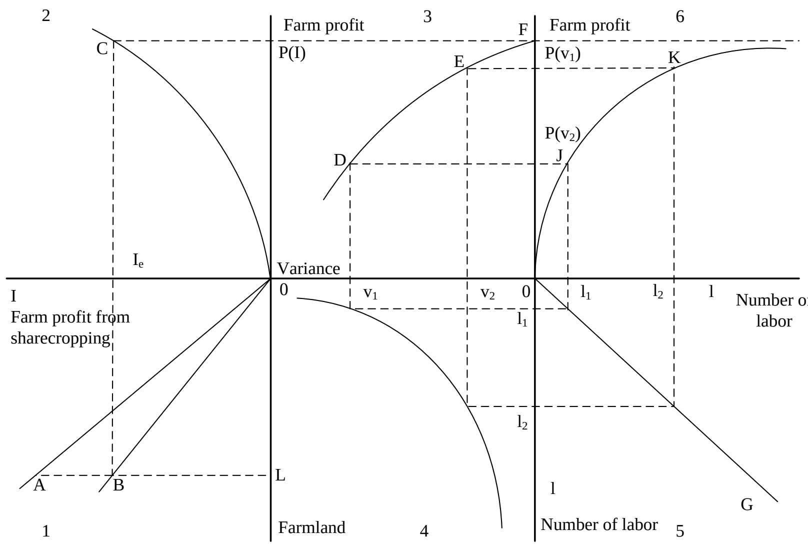


Figure 5.1: Sharecropping arrangement between farmer and his workers (rural households).
Source: Adapted from Taslim (1990).

Building on the concepts and theories on agricultural contracts presented above (Murrell, 1983; Laffont and Matoussi, 1995; Roumasset, 1995; Jacoby and Mansuri, 2009; Sen, 2011), these type of agricultural transfers between farmer and rural households are necessary to achieve an efficient allocation of resources preferred by everyone, considering that no one is willing to sacrifice their own income and consumption for the finite increase of others. In this way, a labor market in agriculture can provide useful information in examining the link between rural economies. Interpersonal relationships between large-scale farm producers and rural households forms the rural economy exchange and agrarian institutions (Roumasset, 1995). In the bimodal farming system of Uzbekistan, the introduction of afforestation on marginal croplands at farms could affect the organization of farm and rural household interdependencies. Therefore, in contrast to the previous approaches addressing the impact of tree plantations on rural incomes (Babu and Rajasekaran, 1991; Xu et al., 2007; Glomsrød et al., 2011; Knoke et al., 2011; Paul et al., 2013), the bimodal agricultural system, consisting of farms and rural households in the model, explains the impact of land use change on different groups of rural population by considering various aspects such as income, production, employment, energy use, and land use decisions.

5.2 Empirical methodology

5.2.1 Data sources

In this study the data of farm and rural household, as well as market surveys were used[10]. The detailed information on the farm and market surveys is given in Sections 3.2.1 and 4.2.1. For the rural household survey, to ensure the availability of rural household members, and also to gain support from the local institutions in conducting the surveys, prior to the interviews myself and enumerators visited the district mayor office and/or the district department of Ministry of Agriculture and Water Resources, Water Consumers Associations, and the Village Citizens' Centers. These organizations assisted in ensuring availability of rural households, and did not interfere during the interviews.

For the rural households' surveys, the structured questionnaire was developed over six weeks based on expert opinions, reviewing questionnaires from previous rural household surveys in the Khorezm region, with a pre-test conducted in this region by interviewing 15 randomly

[10] The survey data and model used in this chapter are documented here: http://data.zef.de

selected rural households. This pre-test helped to include necessary questions and remove those that may create complications for both the enumerator and respondent. After finalizing the questionnaire, the 40 villages were randomly selected from the list of the districts' mayor office. Overall, 400 rural households were surveyed in the study area. Due to the complications in surveying rural households, leaders of the Village Citizens' Centers and staff of the Water Consumers Associations assisted in visiting them. Furthermore, given the unfamiliarity with villages, the need to overcome difficulties in overlapping with neighboring villages, problems with logistics, as well as avoid those households that may not be willing to respond to the questionnaire (e.g., social events such as weddings and funerals may prevent respondents from providing reliable answers), the representatives from these organizations assisted in selecting the village area to start the rural households' surveys. After selecting the initial household in the village to start the survey, the systematic sampling was preformed, with every fifth household surveyed in the village. In the case when the household was absent, the next fifth household from the village was interviewed. The rural households' questionnaire comprised different parts, with the main target of this survey to capture smallholders' dependency on agricultural activities. Accordingly, questions related to employment at farms were emphasized during the interviews. Information was gathered on the number of household members working on the farm, the type of work conducted, the time when work was undertaken, the employment period and agricultural contract arrangements. This survey also included information on household composition, non-agricultural employment and expenditures, consumption structure, timber use in construction activities and the availability of assets, e.g., machinery and livestock. The questions were addressed to the head of the household, assuming that decisions in his/her household depend on his/her capacities and knowledge.

Furthermore, the prices of crop and tree products were collected through a weekly market surveys, as well as obtained from the Statistical Committee of Khorezm and the Ministry of Agriculture and Water Resources of Uzbekistan for the period 2001-2009 (MAWR, 2010; Statistical Committee of Khorezm, 2010). Yields of crops were estimated based on water-yield response function using official irrigation rate recommendations (MAWR, 2001; Land Resources, 2002). Information on tree plantations over a 7-year rotation period was obtained from Khamzina et al. (2008; 2009b). The detailed information on the afforestation site is given in Section 3.2.1. Given the lack of data for Uzbekistan, initial values for own- and cross-price elasticities of demand were obtained from the WATSIM[11] model's base-run dataset on the rest of the world. The initial

[11] WATSIM data on demand elasticities of the rest of the world. http://www.ilr1.uni-bonn.de

(uncalibrated) values of income elasticities were generated as presented by Djanibekov (2008). Data on per capita energy resources consumption was adopted according to the study by Kenisarin and Kenisarina (2007), and was assumed to be 24,700 MJ $person^{-1}$ $year^{-1}$. The nutrient content of maize and crop by-products was obtained from Djumaeva et al. (2009) as metabolizable energy (ME) and crude protein (CP). The greenhouse gas emissions from combustion of energy resources, which are commonly used in the study area, are 2.3 tCO2 t^{-1} for coal, 1.5 tCO2 t^{-1} for liquefied petroleum gas (LPG) (Carbon Trust, 2011) and 0.9 tCO2 t^{-1} for cotton stem (Cao et al., 2008).

5.2.2 Classification of rural households

While rural households in the study area do not possess the majority of arable area, their number is substantial. Thus, classifying rural households is important to provide clues about the main factors that categorize or classify households' types and reduce the aggregation bias when studying land use change. Principal component (PCA) and cluster analysis (CA) were applied to identify representative rural households from the survey (Hair et al., 1998). PCA was performed to condense information from a large number of original variables of rural households, obtained from the surveys to consider dependency on agricultural and non-agricultural activities, into new composite components with minimal loss of information. If these variables are correlated, their properties would be overvalued in the clustering process. The variables with a Kaiser-Meyer-Olkin that are higher than 0.5 (unacceptable level) are included as a measure of sampling adequacy. This is a common measure which describes the degree of interrelationship between the variables, and the variables with higher loadings per identified component (>0.5) were selected. Also, in PCA, the Varimax rotation and Kaiser Normalization techniques were conducted to remove components with *eigen* values below 1.0.

After obtaining scores from PCA, the CA can be performed, with the K-mean method used to minimize the heterogeneity of each cluster by moving cases between clusters. The K-mean method allows dividing observations into clusters in which each observation belongs to certain cluster. The number of clusters is based upon exploratory use of K-means clustering. For further information about the estimation of PCA and CA, see Hair (1998) and Villamor (2012).

5.2.3 *Description of farm-household model*

An integrated model of farm and rural household decision making (farm-household model) was developed using the stochastic dynamic nonlinear programming approach to investigate the impact of the afforestation of marginal croplands under the CDM framework on rural livelihoods. The farm-household model supports the farm and rural households' choice of optimal production plans that maximizes respectively their annual profit and money metric utility in two situations: (1) business-as-usual (BAU) and (2) CDM afforestation introduced on farm's marginal croplands (CDM). Under the BAU scenario, 50% of farmland is cultivated annually with cotton, according to the area-based production target. Furthermore, farmer should fulfill the quantity-based target of cotton policy, producing at least 120 t of raw cotton. In the CDM scenario, the area-based production target is removed and farmer only has to fulfill the cotton output target. The model includes: (1) annual farming activities, i.e., the production, storage and selling of agricultural products; (2) consumption of food, fodder and energy products; (3) labor use on own plots and hired labor for on-farm field activities as well as leisure time consumption; (4) structure of payments from the farm to rural households during labor remuneration. The model links production and consumption decisions at the smallholder level. Given that the CDM afforestation can be implemented for 20 or 30 years, three seven-year rotations were considered in the farm-household model. The additional seven years were considered in the model to analyze the impact after the cease of CDM afforestation on rural livelihoods, and hence the model was simulated for 28 years. After the cease of CDM afforestation, the cotton policy is restored at farm.

A cotton-grain farm type with an area of 100 ha, which is around the average size of such a farm type in the study area, was analyzed (State Statistical Committee of Uzbekistan, 2010). The share of the farm's marginal croplands was assumed to be 23 ha, average productive 56 ha, good productive 20 ha, and highly productive 1 ha, which are close to the regional average in Khorezm (Khorezm Region Land Cadastre, 2006), whereas it was assumed that rural households only possess good productive lands. Farm and rural households cultivate crops such as wheat, rice, maize and vegetables. In addition, farm also cultivates cotton. Since fruit orchards, mulberry plantations for silkworm rearing, and fodder crops (e.g., alfalfa) only occupy a small share of land in selected cotton-grain farm type in Uzbekistan, such land uses were excluded from the analysis. Cropping activities are specified according to their seasonal production process and followed intra-year rotations, i.e., the occupation of land by cotton in March-November, wheat in October-June, rice and maize in July-October, and vegetables in April-October.

The following products were considered in the model:

- Main crop products are wheat and rice grains and vegetables, as well as maize grain used as a livestock fodder. In addition, farm produces raw cotton that is purchased by the state;

- Crop by-products, namely wheat and rice straw and maize stem are used as livestock fodder, and cotton stem is used by households as a domestic energy product;

- The main tree product is temporary CER (tCER) traded through CDM by farm;

- Tree by-products are fruits, leaves used as a livestock fodder, and fuelwood used as a domestic energy product;

- The consumption of rural households includes wheat and rice grains, vegetables, meat, eggs, milk, and aggregated groups of other food and non-food products, energy products such as liquefied petroleum gas (LPG), coal, cotton stem and fuelwood, and time spent on leisure activities.

The model includes the following constraints: (1) the cropping area of farm and rural households; (2) annual cash availability for purchasing the inputs; (3) labor availability of rural households; (4) irrigation water availability; (5) rural households' food, fodder and energy consumption requirements; (6) the production targets for cotton; and (7) weight carriage for products purchased and sold. The annual weight carriage for the farm was assumed to be 1,000 t, and 2 t per person of the rural household member. The maximum storage period of crop and tree products was assumed to be six years, while raw cotton and vegetables are not stored. Furthermore, it was assumed that only 80% of the stored products can be used next year[12]. The model assumed fixed input and output prices.

The cultivation of crops relies on the employment of members of nearby residing rural households, and accounted in terms of total person-hours. For each working hour of a hired rural household member, the farmer made payments in cash, kind, and/or land given for crop cultivation. Payments in kind included crops and their by-products, except raw cotton, as well as tree by-products, except tCER. For the simplification of the model the value of farm wages was assumed to be fixed. In the model sharecropping and land rent contractual arrangements were not considered. Moreover, differences in type of labor employed on the farm, i.e., temporary, seasonal and permanent, were not taken into account. The characteristics and number of employed labor from

[12] The value obtained based on personal communication with farmers.

rural households were estimated based upon the PCA and CA analysis (see Section 5.2.2). Each household operated their own household plot of 0.2 ha of arable land. Households' food, energy and livestock feed requirements were satisfied by products purchased from markets, received as payment in kind from employment on the farm, and produced on their own household plots and fields received from farmer as part of the payment for labor services provided. The interdependencies between the modeled farm and rural households are depicted in the farm-household model (Figure 5.2).

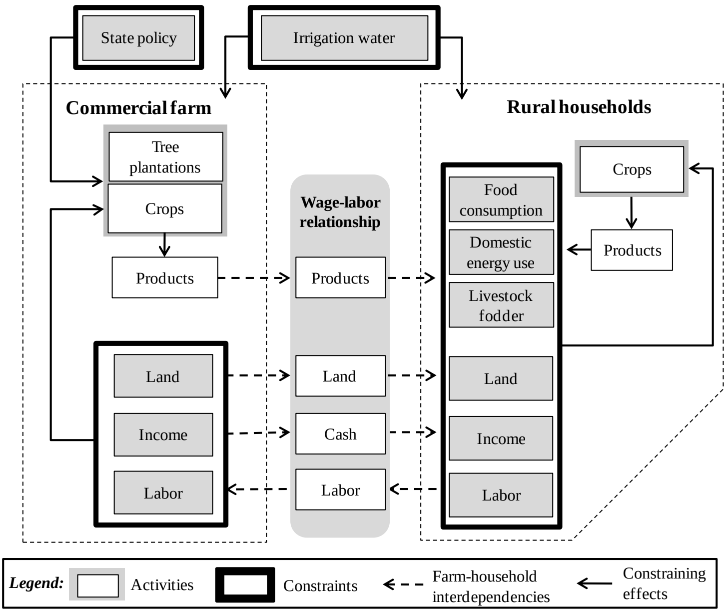


Figure 5.2: Farm-household model structure.
Source: Adapted from (Djanibekov et al., 2013b).

In such a farm-rural household interdependent system, engaging large farms in CDM would affect the consumption structures of rural population by changing their income levels (Pagiola et al., 2005; Hedge and Bull, 2011). Accordingly, the model comprises a module of rural household consumption of food, non-food and energy products and leisure time, with levels responsive to household's incomes. Empirical observations have demonstrated that a pronounced variation of income, typical for transition countries such as Uzbekistan, could not be captured by linear Engel curves (Frohberg and Winter, 2001). In contrast, quadratic Engel curves are able to reflect the driving influence of ample income changes on demand, more aligned with empirical evidence and suitable for a policy analysis (Frohberg and Winter, 2001). Therefore, a demand system was employed that reflects the influence of income changes on consumption patterns, namely the Normalized Quadratic–Quadratic Expenditure System (NQ-QES). Developed by Ryan and Wales (1999), this demand system encompasses a modified version of the Normalized Quadratic Reciprocal Indirect Utility Function (NQRIUF), which proved to be reliable with respect to the forced theoretical conditions, and convenient for the parameterization without imposing a computational burden (Diewert and Wales, 1988; Ryan and Wales, 1999). Rural households sell the surplus of the products to supplement their incomes.

Using the approach presented by Frohberg and Winter (2001), a set of initial (uncalibrated) demand elasticities were modified prior to the parameterization of the demand system to render it consistent with the following theoretical requirements: adding-up, homogeneity, symmetry and the curvature condition, as discussed in Diewert and Wales (1988) and Ryan and Wales (1999). The parameterization of the demand system ensured that demand functions of food products have a negative curvature and positive slope, i.e., concave through their estimated quadratic terms. This indicates that the levels of per capita food consumption increase as the per capita income rises, until it reaches a certain saturation point. The per capita consumption of non-food products and time for leisure rises with growing prosperity, showing Engel curve-relationships with increasing positive slopes within a meaningful range of household income level (Djanibekov, 2008).

The mathematical presentation of the farm-household model is provided in section 5.2.4. The model was programmed in the General Algebraic Modeling System (GAMS).

The important limitations of the model are related to its joint farm and household objective function, scale such as price exogeneity, as well as the ones presented in previous analytical chapters, such as tree growth parameters for seven years, single tree management practices, and constant inter-annual uncertainty values.

5.2.4 Mathematical representation of the farm-household model

The stochastic dynamic farm-household model supports the choice of optimal production planning of interdependent farm and rural households that maximizes their total expected utility, $E(U)$, over the period of 28 years:

$$\text{Max } E(U) = \sum_{n=1}^{N} \sum_{t=1}^{28} U(W_t^{Farm,HH}, r)\pi(P_n) \tag{5.1}$$

where, $W_t^{Farm,HH}$ is the joined utility expressed as profits of farm (Farm) and money metric utility of rural households (HH). $\pi(P_n)$ is the probability for n simulated state of nature, where each outcome has the same probability, N is number of states of nature, and utility sums into 1. When assessing policies targeted towards population the joint maximization problem could be a suitable approach, as it considers the changes in overall livelihoods, and by specifying each actor (through including constraints and balance equations) it is possible to observe gains and losses of such policies (Just et al., 2004). At the same time, the joint maximization of farmer and rural household profits can be argued as the limitation of the model. Farmers may design an incentive scheme for his labor (rural households), which is different from his objective function given that this creates strategic advantages (Viaggi et al., 2009). Different equilibriums may appear as a result of bargaining for labor compensation schemes between farmer and rural households, and through the bargaining the optimal contract arrangement is identified. This contractual bargaining can be captured through the game theory models where farm and rural households are treated as individual actors each with its own objective function. The application of game theoretical model for dynamic decision making of land use change while considering covariate risks raises complications in programming. Another approach to treat the decisions of farms and rural households separately is an optimization of farm decisions first to identify optimal farm plans and labor demand. Following this, the rural households land use decisions and the payment structure for provided labor are optimized given the estimated farm output and associated labor demand. The main drawback of this approach is that it would not allow capturing the feedback of rural households' labor use decisions on the land use decision of the farmer, but rather would treat his decisions as exogenous to the household activities. An alternative approach can be multiple objective programming, where the model maximizes objectives of farmer and rural households in one objective function by putting different weights for these two actors (Janssen and van Ittersum, 2007). However, identification of weights requires focus group discussions, which would have necessitated conducting additional extensive survey, and/or the use of assumptions for weights. Hence, in this study to observe the impacts of afforestation of marginal croplands on rural livelihoods it was assumed the joint maximization of incomes of farm and rural households.

The negative exponential function was used to estimate the utility of farm and rural households:

$$W_t(\mathrm{Farm}, \mathrm{HH}) = 1 - e^{-rV, V^{o}{}_{i}^{\mathrm{FARM,HH}}} \tag{5.2}$$

where, (V) is the farm's annual profits and (V^o) is the rural households' money metric utility at their respective risk aversion levels, r. The risk aversion degree, r, was derived based on the constant absolute risk aversion, rr, with respect to the risk-neutral profits of farmer, $V^{neutral}$, and money metric utility of rural households, $V^{o^{neutral}}$, in the range of 0.5 (hardly risk-averse at all) to 4 (extremely risk-averse) as follows:

$$r = \frac{rr}{V^{neutral}} \tag{5.3}$$

$$r = \frac{rr}{V^{o^{neutral}}} \tag{5.4}$$

Consequently, for estimating the initial profits of farmer and money metric utility of rural households the model was run without the risk aversion levels (risk-neutral case), and considering that farmer follows the crop cultivation over 28 years.

Farmer's profit value comprises the marketed amount of i crop (S) and z crop/tree by-products $(\bar{S})$, c sequestered wood-carbon (tCER), amount of used a production inputs (E) multiplied with their respective prices ($\tilde{p}$, $\bar{p}$, $\check{p}$, $\bar{\bar{p}}$ and $\dot{p}$) where main product prices vary according to the values simulated by the Monte Carlo approach, as well as other costs related to growing j crops/trees (u) on farmland (X), and cash paid for hired labor (R):

$$V_t = \sum_i \tilde{p}_i S_{it} + \sum_z \bar{p}_z \bar{S}_{zt} + \check{p}tCER_t - \sum_a \bar{\bar{p}}_a E_{at} - \sum_j u_j X_{jt} - R_t \tag{5.5}$$

Rural households' money metric utility comprises the value of marketed and purchased i crop products (S^o,B^o) and z crop/tree by-products ($\bar{S}^o$, $\bar{B}^o$), a purchased inputs (E^o), e purchased energy resources ($\bar{\bar{B}}^o$) at their respective prices ($\tilde{p}$, $\bar{p}$, $\bar{\bar{p}}$ and $\dot{p}$) where main product prices vary according to the values generated by the Monte Carlo approach, income from non-agricultural activities (M) at wage rate ($\bar{s}$), cash received from working at farm (R) as well as other costs of j crop cultivation activities (u^o) on household plots (X^o) and on land received from farmer ($\bar{X}^o$), and expenses for consumption commodities (D_{it}^o):

$$V_t^o = \sum_i \tilde{p}_i(S_{it}^o - B_{it}^o) + \sum_z \bar{p}_z(\bar{S}_{zt}^o - \bar{B}_{zt}^o) + \bar{s}M_t + R_t - \sum_a \bar{\bar{p}}_a E_{at}^o - \sum_e \dot{p}_e \bar{\bar{B}}_{et}^o - \sum_j u_j^o(X_{jt}^o + \bar{X}_{jt}^o) - D_{it}^o p_{i,z,a,e} \tag{5.6}$$

The farm's labor balance defines that the farm uses its own labor (b) and labor hired from households (N) for growing j crops/trees (X) that demands labor hours (k):

$$\sum_j k_j X_{jt} \le b_t + N_{ht} \tag{5.7}$$

In this respect, households' labor balance defines their interaction with the farmer: households can use their available labor hours (b^o) to cultivate j crops (X^o) requiring a certain working hours (k^o), to be hired for farm activities (N) and/or off-farm activities (M), and consume part of their time for leisure activities ($D_{leisure,t}^o$ is leisure consumption per capita, and pop is number of household members):

$$\sum_j k_j^o(X_{jt}^o + \bar{X}_{jt}^o) + N_t + M_t + popD_{leisure,t}^o \le b_t^o \tag{5.8}$$

The interactions between farm and rural households are further determined by the households' labor hours hired (N) at agreed wage (s) and the structure of payments which includes cash (R), i crop products in kind (C), z crop/tree by-products in kind ($\bar{C}$), and land (G) at their respective prices ($\tilde{p}$, $\bar{p}$, g):

$$sN_t = R_t + \tilde{p}_i C_{it} + \bar{p}_z \bar{C}_{zt} + \tilde{g} G_t \tag{5.9}$$

The land constraint of the farm defines that the land available (q) can be used for j crop/tree growing activities (X) and/or given as remuneration (G) for hired labor to households for all t:

$$\sum_j X_{jt} + G_t \leq q_t \tag{5.10}$$

Each household operated its own household plots of 0.2 ha of arable land. Accordingly, the total area of household plots (q^o) determines j crop cultivation area (X^o) for all t:

$$\sum_j X_{jt}^o \leq q_t^o + G_t \tag{5.11}$$

The irrigation water constraint applies to the entire modeled system: water used on farms fields (X), household plots (X^o), household operated farm fields (G) at respective irrigation rates (W, W^o and $\bar{W}$) should not exceed the varying amount of water available in the system ($\tilde{w}_n$):

$$\sum_j W_{jt} X_{jt} + \sum_j W_{jt}^o X_{jt}^o + \sum_j \bar{W}_{jt} \bar{X}_{jt}^o \leq \tilde{w}_n \tag{5.12}$$

The cotton procurement policy is incorporated via two constraints: according to the area-based target, the farm's cotton cultivation area (X) should not be less than the area set by the state (F):

$$X_{\text{cotton,t}} \geq F_{\text{cotton,t}} \tag{5.13}$$

According to the quantity-based target of the cotton procurement policy, the farmer should produce a certain amount of cotton that is not less than the amount determined by the state (ST):

$$\sum_i \tilde{Y}_{\text{cotton,it}} X_{\text{cotton,t}} \geq ST_{\text{cotton,t}} \tag{5.14}$$

The farm's product balance requires that i crop products are at varied harvested yields ($\tilde{Y}$) with respect to the water application rate (W) and cultivated area (X) can be marketed (S), used as payment in kind to households (C) or stored (H) for the next period:

$$\sum_{j} \tilde{Y}_{jit} X_{j} = S_{it} + C_{it} + H_{it} - H_{it-1} \tag{5.15}$$

The households' product balance defines that i crops harvested on household plots and on land received from farm at varied yields ($\tilde{Y}^{o}$, $\bar{\bar{Y}}^{o}$), which depend on water application rate (W^{o}), and cultivated area (X^{o}, $\bar{X}^{o}$) as well as received as payment in kind (C) and purchased (B^{o}) can be sold (S^{o}), consumed (D^{o}) or stored for the next period (H^{o}):

$$\sum_{j} Y^{o}_{jit} X^{o}_{jt} + \sum_{j} \bar{Y}^{o}_{jit} \bar{X}^{o}_{jt} + C_{it} + B^{o}_{it} = S^{o}_{it} + popD^{o}_{it} + H^{o}_{it} - H^{o}_{it-1} \tag{5.16}$$

A similar equation applies to the rural households' crop/tree by-product balances.

In this respect, the energy use balance defines that the amount of energy products received from farmer as payment in kind (C), reserves from previous periods and purchased ($\bar{\bar{B}}^{o}$) can be consumed (D^{o}), stored (H^{o}) and/or sold (S^{o}) when converted into energy units via their energy content parameters (d, $\bar{d}$):

$$\sum_{i} d_{i,energy}(C_{it} + H^{o}_{it-1}) + \sum_{e} \bar{d}_{e,energy} \bar{\bar{B}}^{o}_{et} = popD^{o}_{energy,t} + \sum_{i} d_{i,energy}(H^{o}_{it} + \bar{S}^{o}) \tag{5.17}$$

Finally, the rural households' per capita demand function of i products (D^{o}) comprises non-linear (α) and linear (β) terms with respect to the households' per capita net income value (V^{o}/pop):

$$D^{o}_{it} = \alpha_{i} \frac{(V^{o}_{t}/pop)^{2}}{p_{k} \sum(p_{k}\beta_{k})} + \beta_{i} \frac{V^{o}_{t}/pop}{\sum(p_{k}\beta_{k})} \tag{5.18}$$

where D_{it}^{o} is the demand for food, energy and leisure consumption, i is the commodities produced and consumed, α is quadratic and β is the linear parameters of NQ-QES, and $k = i$ for crop/animal products, non-food products, energy and leisure.

Households food, energy and livestock feed requirements were satisfied by products purchased from markets, received as payment in kind, and produced at the households' own plots and fields received from farmer as part of payment for labor services provided, as well as the consumption of meat, milk and eggs from the possessed animals. The households' total consumption expenditure is equal or less than their money metric utility (V_t^o):

$$\mathrm{pop}\sum_{i} p_{it} D_{it}^{o} \leq V_t^{o} \tag{5.19}$$

5.2.5 Validation of the model

To validate the farm-household model results, the cropping pattern in the BAU scenario with the extremely risk-averse case were compared with the observed values during the surveys in the cotton-grain farm types and rural households (Table 5.1). Accordingly, when the BAU model's first year results are replicated or close enough to the share of cropping pattern of cotton, wheat, rice, maize and vegetables on the farm, and wheat, rice, maize and vegetables at rural households, the model was considered to be valid. Given that perennial crops such as fruit trees and mulberry plantations for silk production, and other fodder crops (e.g., alfalfa) only use a marginal share of farmland in cotton-grain farm types, their production is not included in the validation.

Considering the land occupation by crops, the cropping pattern of the BAU scenario is close enough to the observed values during the surveys. The major differences in the cropping pattern of the farm model were found in the share of cultivated area of cotton and maize. The land use of rural households in the BAU scenario was close to the real situation, with the only exception being the share of maize and vegetables area.

Table 5.1: Comparison of cropping pattern under the business-as-usual (BAU) scenario in the extremely risk-averse case of the farm-household model with that observed during the surveys in the cotton-grain farm type and rural households.

Producers	Crops	Observed*	BAU of the farm-household model
		%	%
Farm	Cotton	40	38
	Wheat	29	29
	Rice	14	13
	Maize	11	15
	Vegetables	6	5
Rural households	Wheat	33	34
	Rice	29	30
	Maize	5	8
	Vegetables	33	28

Note: *Is the land use pattern of cotton-grain farm type and rural households observed during the surveys in 2010-2011.

5.3 Results on organization of rural households

5.3.1 Classification of rural households

There are several important characteristics that distinguish farms from rural households. The superiority of farms over rural households is explained by their wealth, status, networking, and resulting interactions with traders and financial institutions, providing the managerial ability to make production decisions on the choice of crops, land and water management, the selection and negotiation of timely availability of inputs, as well as the provision of machinery services. The rural households were classified by using the PCA and CA analysis. The Kaiser-Meyer-Olkin measure showed a satisfactory sampling adequacy of 0.617, and Bartlett's test of sphericity was significant (Table 5.2). Components for categorizing rural households' were determined using the rotated component matrix, with twelve variables selected to capture rural households' heterogeneity in terms of the number of members, employment at farm, assets in the form of livestock, and expenditure and revenue characteristics. A total of five principal components were extracted, namely “Non-agricultural activity dependency”, “Dependency on farmland”, “Dependency on cash and crops from farm employment”, “Food commodity purchase expenditure”, and “Dependency on own plot and livestock”. These components generated 74% of the total variance of initial variables (Table 5.3).

Table 5.2: Test scores of the principal component analysis using the Kaiser-Meyer-Olkin measure and Bartlett’s test.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.617
Bartlett’s Test of Sphericity	Approx. Chi-Square	1,365
	df	66
	Sig.	0

Table 5.3: Rotated component matrix using Varimax with Kaiser Normalization.

	Principal Components				
	Non-agricultural activity dependency	Dependency on farmland	Dependency on cash and crops from farm employment	Food commodity purchase expenditures	Dependency on own plot and livestock
Variable	19.10%	17.50%	14.10%	12.90%	10.40%
Household members	0.44	0.02	0.16	0.72	0.16
Household members employed at farm	-0.21	0.60	0.70	0.39	0.11
Household members employed at non-agricultural activities	0.83	-0.06	-0.11	0.14	0.08
Area of land rented, given as payment in kind and sharecropping	-0.10	0.90	-0.10	0.14	0.09
Livestock heads	0.24	0.04	0.14	-0.20	0.79
Food commodity purchase expenditure	0.37	0.03	0.10	0.78	-0.07
Agricultural production expenditure	0.18	0.66	0.48	-0.22	0.13
Other expenditures	0.58	-0.02	0.01	0.18	0.04
Income from marketing livestock and crops from own plot	-0.21	0.09	-0.07	0.32	0.73
Income from crops and cash payments from farm employment	-0.06	0.02	0.90	0.03	-0.02
Income from land rented, given as payment in kind and sharecropping	-0.07	0.91	-0.03	-0.02	-0.01
Income from non-agricultural activities	0.87	-0.03	-0.10	0.12	-0.10

Using the PCA, the extracted “Non-agricultural activity dependency” component is related to variables of non-agricultural employment (loading 0.83), expenditure (loading 0.58) and revenue (loading 0.87) of rural households. The variables of non-agricultural employment and revenue are related to the remittances from Russia and Kazakhstan, social payments (e.g., pension), work at government organizations, or entrepreneurship. Meanwhile, the variable “Other expenditures” are related to the transportation, health care, education, and the construction and purchase of commodities unrelated to agricultural production, with this factor having a total variance of 19.1% of the original dataset. The second principal component is “Dependency on farmland”, which relates to variables of income from land given as payment in kind, sharecropping arrangements and rent. Variables significantly contributing to these components include the number of household members employed at farm (loading 0.60), the area of land in these contracts (loading 0.90), income from farmland (loading 0.91), and expenditure for agricultural production (loading 0.66). This factor has a total variance of 17.5% of the original dataset. “Dependency on cash and crops from farm employment” represents the third principle component, with a variance of 14.1%, and variables distinguishing this factor include the number of rural household members employed at farm (loading 0.70), and income from being employed by the farmer (loading 0.90). The next component in the PCA is the “Food commodity purchase expenditure”, which relates to food purchase expenditure, comprising variables of households’ size (loading 0.72) and food expenditure (loading 0.78) with the total variance of 12.9% of the original dataset. The final principle component, “Dependency on own plot and livestock” accounts for 10.4% of the total variance of the original dataset, and describes the availability of livestock (loading 0.79) and household income from marketing livestock and crops from attached and distanced household plots (loading 0.73).

The K-mean cluster analysis was employed using the standardized scores of the five principle components, resulting in $k = 3$ with three rural households groups from a total sample size of 400. According to the K-mean cluster analysis, group 1 contains 200 rural households, while group 2 has 112 and group 3 has 88 (Table 5.4). The first and third groups are those whose main income stems from farm employment, which relate to temporary, seasonal and permanent working activities. Group 1 has the smallest household size (6 people) and the lowest revenues from non-agricultural activities. Furthermore, households in this group have the lowest share on “other expenditures”, namely costs comprising construction, transportation, purchasing clothes and others. This is due to fewer household members being employed in non-agricultural activities, and thus most of the costs are related to agricultural production. Group 2 mainly consists of rural households, whose main income and expenditure sources are related to non-agricultural activities. This type of income includes remittances from Russia and Kazakhstan, social payments, employment at the government, and entrepreneurship. Consequently, the largest share of costs is also spent for these activities. Given that households in this group are less employed by farmers than in other household groups, they rely less on farm payments. Accordingly, food expenditure is also high, which can be explained by receiving fewer food products from the farmer as payment in kind, as well as less rented land area from the farmer than other types of rural households. Rural household group 3 has the smallest number of households, yet the largest household size. In these households, the main and largest source contributing to the households' income among other groups is the revenue generated from agricultural activities. This group also has the largest number of livestock in comparison with the other two groups. In terms of energy expenditures, the lowest are related to groups 1 and 3, due to possibly obtaining energy products as payment in kind from farmers.

Table 5.4: Descriptive statistics of categorizing variables for each classified rural household group.

Variable	Group 1	Group 2	Group 3
Household members	6	7	9
Household members employed at farm	2.6	2.3	4.7
Household members employed at non-agricultural activities	1.8	2.9	2.3
Land rented, received as payment in kind and sharecropping from farmer, ha	0.2	0.1	0.1
Livestock, head	3.6	2.3	3.8
Share of food purchase expenditure, %	34.1	36.2	32.7
Share of energy purchase expenditure, %	3.8	4.2	3.1
Share of agricultural production expenditure, %	28.8	16.1	30.2
Share of other expenditures, %	33.3	43.5	33.8
Share of revenue from marketing livestock and crops from own plot, %	26.6	19.6	26.0
Share of revenue from cash and crops as payments in kind from farm employment, %	13.5	8.2	16.4
Share of revenue from land rented, given as payment in kind and sharecropping, %	20.6	11.8	24.1
Share of revenues from non-agricultural activities, %	39.3	60.4	33.6

5.3.2 Typology of agricultural contracts

The livelihoods of most rural households is connected to the economic performance of farms (Veldwisch and Bock, 2011), with various forms of labor relations and payment structures formed between farms and rural households. With respect to the duration of labor relations, it was observed that permanent, seasonal and temporary labor activities are provided by smallholders to farms (Table 5.5). In permanent work, household members perform different working activities with respect to crop cultivation and livestock rearing. In such types of labor relations, large-scale farms also employ tractor drivers whose functions involve driving and maintaining the quality of farm machinery. The seasonal type of work (*pudratchi* in Uzbek) is mainly used for cultivating crops during one season, and involves field activities of a single crop starting from planting until harvesting, e.g., cotton planting, managing and harvesting. Another type of labor employed at farm is that of a temporary nature, whereby households perform certain field operations, e.g., planting rice, cutting twigs of fruit trees, preparing fields for sowing, weeding. Temporary labor is particularly hired for the harvest of cotton and forage crops, harvesting fruits and weeding at rice fields, via piece- or time-rate contracts. Horticulture and other type of farms largely rely on own family members, hiring less labor from rural households. However, by contrast, due to their large size, cotton-grain farms have insufficient labor and capital for production, and hence typically depend on all three types of labor.

Table 5.5: Rural households labor activities at farms.

Type of labor activities	Description of labor activities
Permanent	Related to long-term agreements, several vegetation seasons and several crop types. Comprises several types of activities.
Seasonal (*pudratchi*)	A crop-based working activity, performed from planting until the harvesting period in one crop season.
Temporary	Temporary work is conducted for certain field operations.

Source: Own observation (2011).

Given that farmers cannot directly observe the agricultural productivity characteristics of their workers that possess different skills, they offer them a menu of contracts, and rural households in turn would select contract forms based on their characteristics and needs. Depending on a farms' availability of cash and land size, as well as the characteristics of rural households, contractual arrangements between rural households and farmers are distinguished as fixed wage, fixed rent and flexible (crop share) (Table 5.6). In the fixed wage contract, farmers employ rural households and keep the entire harvest of crop, paying in cash and/or kind of crop main and/or by-products for their provided labor services. In this contractual form, farmers supervise the labor themselves, controlling production and owning the entire output, and this form is mainly practiced during the cotton cultivation. Despite renting out the land being prohibited, the fixed rent contract is widely practiced. In cases when rural households rent land from farmers, the fixed rent is subsequently paid in cash prior to the growing season. In this type of contract, household members cover the entire input costs, providing both management and supervision, and maximize the profits from the harvest. In the study area, this contractual arrangement is preferred by farms residing far from the agricultural area, for whom the monitoring and supervision of contractual agreements is costly. The land is typically rented for one crop season, in a range of 450-900 USD ha^{-1} depending on the rented plot's soil quality and access to irrigation water, and this arrangement is applied for the cultivation of cash crops such as vegetables and rice. The next type of contractual arrangement between farmers and rural households is the flexible contract (sharecropping). According to this agreement, farmers provide management of operation of their fields, while employed household members provide labor and share the output according to input use. The pure sharecropping implies the situation when farmers and smallholders share the input and output of production. By providing the opportunity for specialization in abilities and resources in which farmers and rural households have an advantage, sharecropping emerges as their decision to pool skills and resources to achieve an output that they would not be able to achieve if performing individually (Roumasset, 1995). This arrangement is commonly used in the cultivation of wheat and crops with high market value, such as rice and vegetables. Farms and smallholders often use simple fractions of crop output to economize on measurement costs, such as buckets of grain harvester in the case of wheat production.

Table 5.6: Existing agricultural contracts between farmers and rural households.

Type of contractual agreement	Description of contract
Fixed wage	Arranged for a specific task in which farmer bears all production costs and keeps the entire harvest for own discretion, in return paying in cash and/or kind.
Fixed rent	Rural households rent land from farmer for a certain amount of cash paid prior to the sowing season. Rural households bear all production costs and keep the entire harvest.
Flexible (sharecropping)	Farmer bears most of production costs, while employed rural household members provide labor, and they both share the harvest according to their contribution to the production costs.

Source: Own observation (2011).

Table 5.4 showed that the payments from farm to rural households play an important role in the livelihoods of households. For rural households for whom food security and access to land is an issue, agricultural work may be more attractive than non-agricultural work if agricultural wages are paid in commodities and land. The highest income reliance of households from the three types of contracts was observed in terms of fixed wage contracts (Table 5.7). The most observed payment structure to the rural population is in the form of crops and crop by-products as payment in kind. Rural household group 3 has the highest dependency on fixed wage payments among the different household groups, and it should be noted that the payment by the main crop is substantially higher in the fixed wage than other groups, and consequently such payments contribute to the income and food security of these households. Land contractual arrangements with farms also play an important role in the livelihoods of rural households, which is mainly observed in group 1, and where all fixed rent payment structures are in the form of cash. The rural household group 2 has the lowest agricultural payment arrangements with the farmer, owing to the group's high dependency on non-agricultural revenues. The rural household group 3 has the highest dependency on agricultural payments from farmers in the form of flexible (sharecropping) arrangements compared to other two household groups. In the sharecropping, the contractual arrangement between farmer and household members is mainly in the form of main crop harvest and its by-products, and complemented with payments in cash. In this contractual arrangement, farmers and rural households often use simple fractions and units of crop output to simplify the measurement; for instance, buckets of the grain harvester as units and 50/50 or 33/67 schemes for crop sharing. Experienced households, who know what crop yield to expect and how much input should be used, typically prefer sharecropping.

Table 5.7: Agricultural contracts observed in rural households.

Payment structure	Fixed wage			Fixed rent			Flexible		
	Group			Group			Group		
	1	2	3	1	2	3	1	2	3
Cases, No	100	75	121	71	55	60	80	55	103
Payment structure, number of observations									
Main crop	100	60	115	n.a.	n.a.	n.a.	80	55	103
By-product	95	68	74	n.a.	n.a.	n.a.	80	55	103
Cash	54	33	58	71	55	60	38	28	50
In land	55	36	60	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Note: In the fixed rent contractual arrangement the rural households rent land from farmers; n.a. is not applicable payment in the contract type.

5.4 Results on impact of introducing farm forestry on rural livelihoods

5.4.1 Land use pattern

In the model were considered the heterogeneous rural households, with their number employed on the farm estimated according to their share of the total surveyed households. Accordingly, it was assumed that rural household groups 1, 2 and 3 consisted respectively of 10, 6 and 4 households that work at farm. The labor available at rural households was according to that observed during the surveys (see Section 5.3.1).

To observe the land use change of a risk-averse farmer and rural households, initially the average annual profits and money metric utility of the risk-neutral farmer and rural households were respectively estimated. The annual profit of the risk-neutral farmer was around 75,000 USD. The annual money metric utility of rural household group 1 was 835 USD, group 2 was 1,442 USD and group 3 was 1,025 USD per households. Afterwards the risk aversion levels were derived according to Eq. 5.3 for farmer and Eq. 5.4 for rural households (see Section 5.2.4). The calculated risk aversion levels of farmer were in the range of 0.000007-0.00005. For the rural households, the risk aversion levels were in the range of 0.0006-0.005 for group 1, 0.0003-0.003 for group 2, and 0.0005-0.004 for group 3. To avoid complicated and extensive explanations of the model results, only the results for the hardly and extremely risk-averse farmer and rural households are presented and interpreted.

According to the model results, in the BAU situation, the cropping pattern of the hardly and extremely risk-averse cases would mainly differ in the cultivation area of rice, maize and vegetables (Figure 5.3). Also, the extremely risk-averse land users would cultivate smaller area of land. In both cases, the main crops cultivated would be cotton and wheat, with the former mainly cultivated due to the state procurement policy (for a description of the cotton procurement policy see Section 2.4.1). Because wheat provides different by-products and can be rotated with rice and maize, the area of this crop is also large. The crop with least area of cultivation would be vegetables because this crop occupies land in two growing seasons, and it is less suitable for cultivation on less-productive lands (for gross margins of crops on different productive lands see Section 3.3.1).

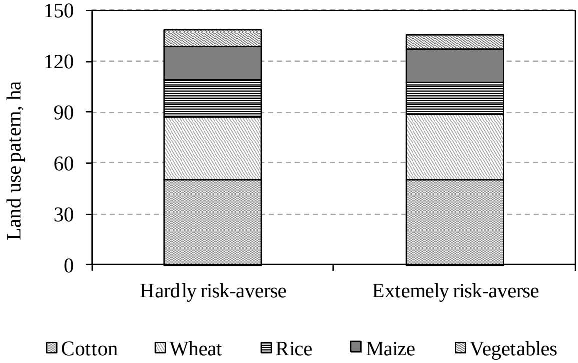


Figure 5.3: Annual land use pattern of the hardly (a) and extremely (b) risk-averse farmer and rural households under the business-as-usual (BAU) scenario.

In the CDM scenario, all three types of tree species would be planted, i.e., *E. angustifolia*, *P. euphratica* and *U. pumila*, with the main planted tree species being *E. angustifolia*, followed by *P. euphratica* (Figure 5.4). The area of *U. pumila* would be respectively 0.1 ha and 0.2 ha in the extremely and hardly risk-averse land users' case. Compared to the BAU scenario, in the CDM the irrigation water not used on marginal croplands at farm due to lower water demand by trees (Khamzina et al., 2012), would be applied for irrigating crops in other fields of this farm. Consequently, the area of more profitable and irrigation water demanding crops, i.e., rice and vegetables, would be larger in the CDM scenario than in the BAU, by around 40%. At the same time the area of wheat and maize would be smaller over the simulated period than in the BAU case. The area of these crops would reduce as the dependency on wheat straw and maize grain and stem would decline as rural households would partly substitute them from animal feeding rations with tree leaves (see Section 5.4.5). Moreover, the area of wheat and maize would reduce due to the expanded area of rice and vegetables. The cease of the CDM and clear cut of trees in year 21 would once again trigger changes in land use pattern. Accordingly, the cotton area policy would be restored and the area of this crop would occupy half of farmland. The area of wheat and maize would also increase. Consequently, the area of the most profitable and irrigation demanding crops, i.e., rice and vegetables, would decline. In year 27 the land use pattern in the CDM scenario would be similar as to the one observed in the BAU.

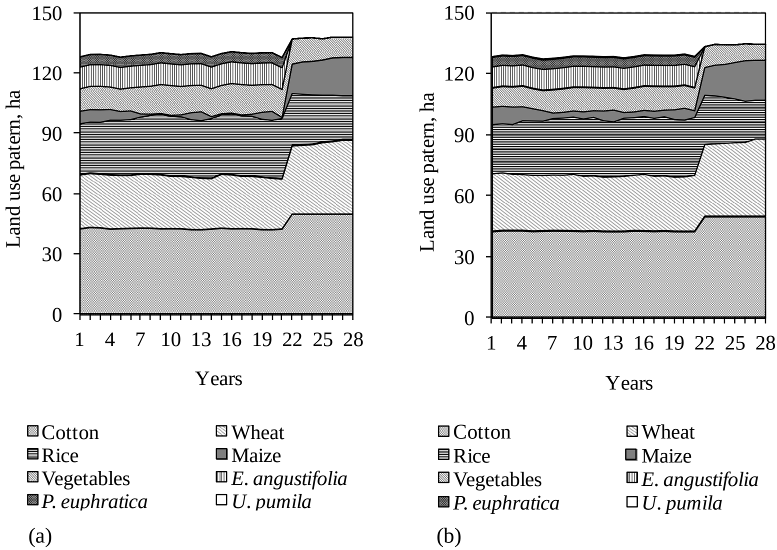


Figure 5.4: Land use pattern of the hardly (a) and extremely (b) risk-averse farmer and rural households under Clean Development Mechanism (CDM) scenario over 28 years.

5.4.2 Farm employment and rural payments

Changes in employment are vital in environmental projects, particularly for non-participating rural population that may have limited means to earn income but depend on farm working activities. According to the CDM scenario, in the years of the tree planting on marginal lands, the employment of rural household members at farm would increase due to the establishment and management activities of tree plantations (Figure 5.5). During the tree plantation harvest periods, i.e., in years seven, fourteen and twenty one, the demand for labor at farm would also increase, with labor-intensive operations performed at tree plantations, including felling and sectioning the woody parts and foliage. This increase in labor demand would consequently provide rural households with an additional source of income. However, given that less labor is needed for tree plantation management than for annual cropping activities, CDM afforestation would result in an agricultural labor discharge for all rural household types between the period of tree planting and harvest, i.e., years two to six, nine to thirteen, and sixteen to twenty. During these periods, in the CDM scenario the labor discharge would lead to lower employment at farm than in the BAU.

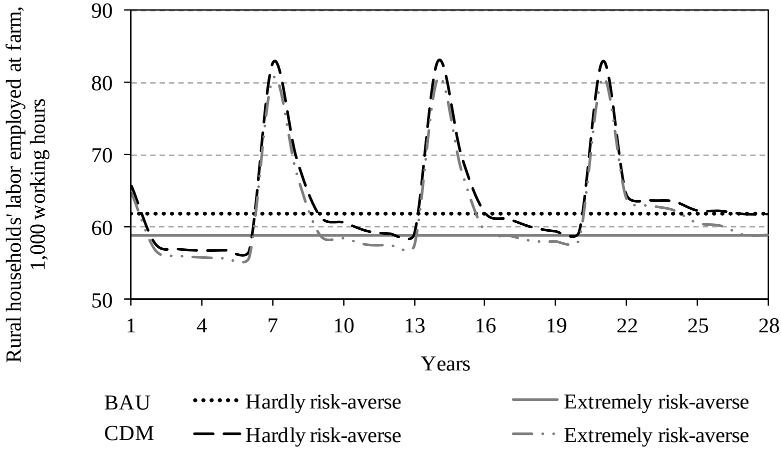


Figure 5.5: Employment structure of rural households at farm in the hardly and extremely risk aversion degrees under the scenarios of business-as-usual (BAU) and Clean Development Mechanism (CDM) over 28 years.

In the bimodal farming system, agricultural contracts between large-scale farms and rural households can represent linkages of the rural economy. Based on the model results in the BAU scenario, the main payment would be in the form of land, followed by grains and cotton stem (Figure 5.6). This payment structure would be selected due to cash availability in farm and weight carriage of both farm and rural households. The least remuneration would be in the form of cash, because of its necessity to purchase inputs and operate large-scale farms. In overall, the patterns of the hardly and extremely risk-averse farmer payments do not differ substantially, with the main difference is in the payments in the form of rice. As in the study area rural households are abundant in labor (see Table 5.4 in Section 5.3.1), operating land received from a farmer would not affect rural households' labor supply.

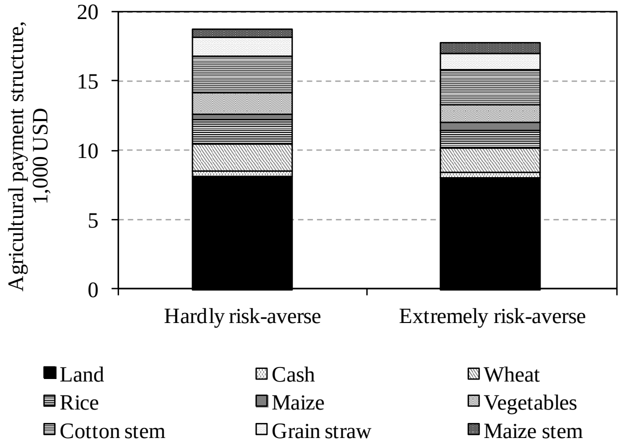


Figure 5.6: Structure of payments from farm to rural households in the hardly and extremely risk aversion degrees under the business-as-usual (BAU) scenario.

The land use change towards CDM afforestation would diversify remuneration in agricultural contracts by inclusion of tree products. The inclusion of tree products in the CDM scenario would shift the structure of agricultural payments, which would differ from year to year, as opposed to the BAU (Figure 5.7). Under the CDM scenario, the value of land allocated to remunerate the household labor would decrease during the tree plantation period, gradually increasing after the tree harvest and reaching the level of the BAU from year 27 onwards. Tree products would be one of the largest payments after land, with fuelwood share of 20%, tree foliage of 3% and fruits of 4% of total payment value. In addition, given that the area of rice and vegetables would be larger in comparison to the BAU scenario, the payments in the form of these crops would substantially contribute to payments in kind. Following the six years since the cessation of CDM afforestation activities (year 27), the payment structure would equalize the BAU levels.

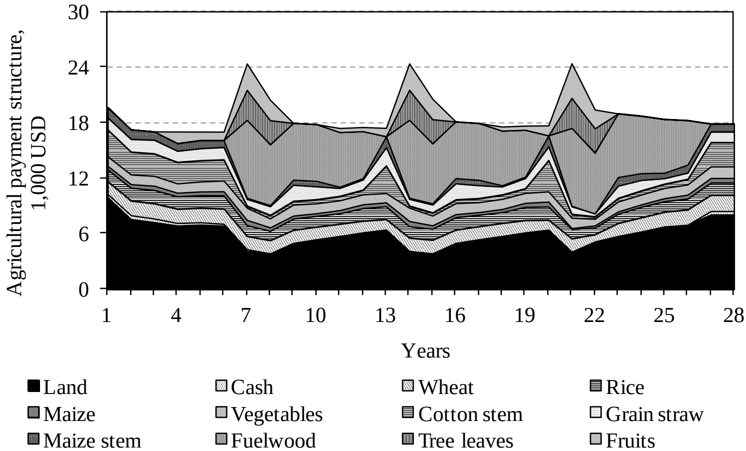


Figure 5.7: The structure of payments from farm to rural households in the extremely risk aversion degree under the Clean Development Mechanism (CDM) scenario over 28 years.

5.4.3 Profits of farm and utility of rural households

The profits of farm and utility of rural households when converted into the money metric utility would not change over the years under the BAU scenario (Figure 5.8 and 5.9). For instance, the annual profits of the hardly and extremely risk-averse farmer would be around 72,000 USD and 69,000 USD, respectively. In contrast, under the CDM scenario, the change in cropping pattern due to afforestation of marginal croplands would have positive impact on farm profits. In this scenario the total farm profit over 28 years would be larger by about 600,000 USD compared to the BAU case. In this scenario, the shifts in cropping pattern towards high-return crops would impact the farm's profit structure. For instance, an increase in the area of rice and vegetables would substantially increase farm profits. Moreover, non-timber products would generate important benefits due to their dominant share in profits in the CDM scenario. Fuelwood, tree leaves, fruits and tCER would generate revenues of around 630,000 USD over 28 years.

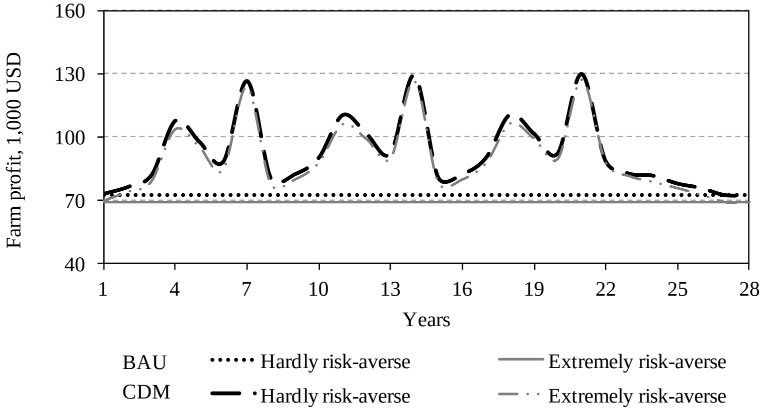
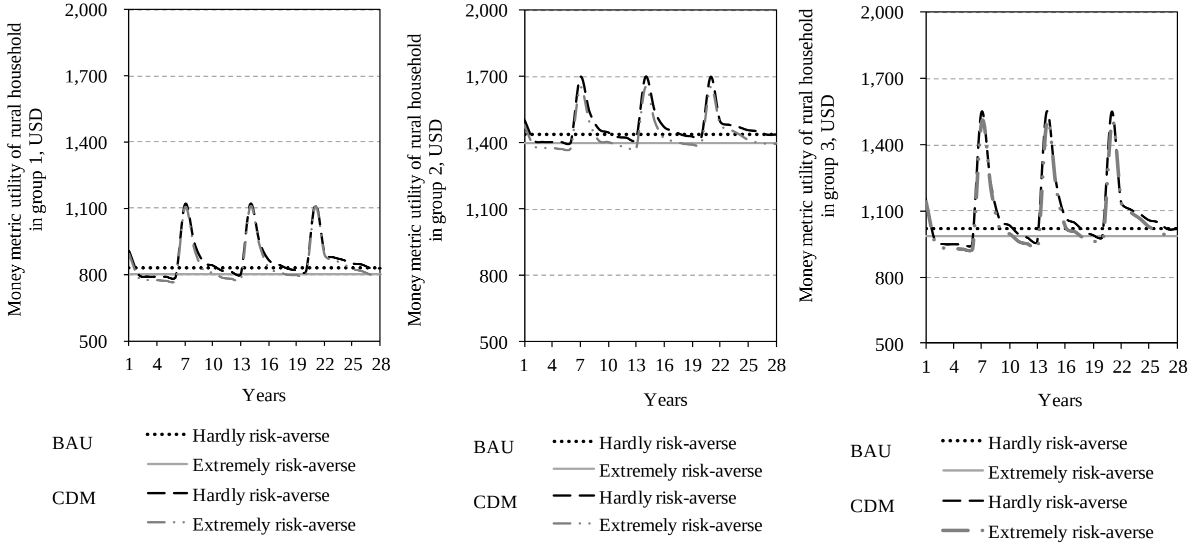


Figure 5.8: Profits of the hardly and extremely risk-averse farmer under the scenarios of business-as-usual (BAU) and Clean Development Mechanism (CDM) over 28 years.

Due to the heterogeneity of rural households' characteristics, their money metric utility would differ for each group, and the largest one observed in group 2 (about 1,400 USD in the extremely risk-averse case) (Figure 5.9). In the CDM scenario, since less labor would be required at farm between the years of plantation establishment and harvest, the money metric utility of rural households employed at farm would decrease. During those periods rural households' money metric utility in total would be lower by about 5,000 USD than of the BAU case. The most affected rural household type would be group 3, because of the high dependency of these household members on activities at farm. However, the harvest of tree plantations would substantially increase their money metric utility. Moreover, during the initial years after cessation of the CDM afforestation, namely years 22 to 26, the money metric utility of rural households would be larger than under the BAU scenario. This could be due to the labor demanding activities at farm, and reduced energy and fodder expenditures by rural households as a result of receiving fuelwood and tree leaves as payment in kind. The largest positive effect would relate to rural households that largely depend on farming activities, i.e., group 3, for whom the total money metric utility over 28 years would increase by around 8% compared to the BAU scenario. As for groups 1 and 2, their money metric utility over 28 years would increase by 5% and 3% respectively, in contrast to the BAU case.

The model results showed that non-timber products can generate important benefits for rural households. For instance, storage by farmer tree foliage and fuelwood and their annual inclusion in the payment structure can substitute or complement respectively grain straw as livestock fodder, and coal and LPG as domestic energy products beyond the duration of CDM afforestation activity. Nevertheless, the return to cropping on marginal lands after year 21 would eventually bring down the profits of farm and money metric utility of rural households to the levels observed under the BAU scenario.



(a) (b) (c)

Figure 5.9: Money metric utility of the hardly and extremely risk-averse rural households in group 1 (a), group 2 (b) and group 3 (c) under the scenarios of business-as-usual (BAU) and Clean Development Mechanism (CDM) over 28 years.

5.4.4 Energy use and CO_2 emission reduction of rural households

The model results showed that the decrease in farm employment between the years two and six would also reduce the cotton stem transfer as payment in kind, and consequently increase the total expenditures for domestic energy use of the extremely risk-averse rural households (Figure 5.10). While expenditure for coal, LPG and cotton stem is high prior to year seven, this pattern would be reversed after the harvest of trees in years 7, 14 and 21. Short-term rotation tree plantations would allow households to reduce energy expenditures via accessing and storing cheaper fuelwood, and thus partially substituting coal and LPG beyond the duration of CDM afforestation activities. In overall simulated period, rural households' energy expenditures would be substantially lower than in the BAU case.

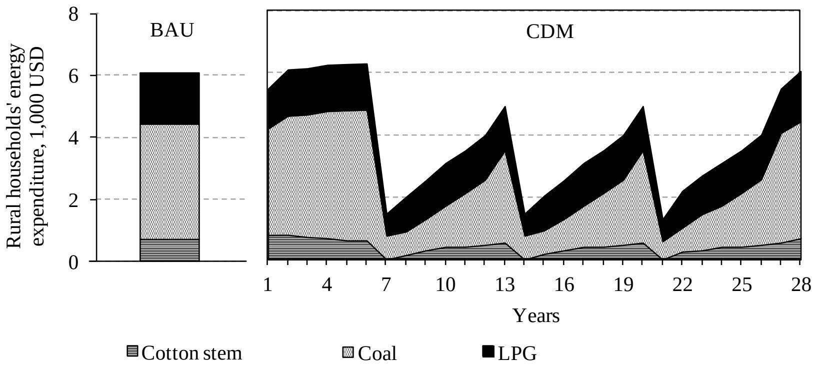


Figure 5.10: The extremely risk-averse rural households' domestic energy expenditure under the scenarios of business-as-usual (BAU) and Clean Development Mechanism (CDM) over 28 years.

The calculations indicate that up to 4,300 tCO_2 can be sequestered every seven-year rotation of tree plantations on marginal croplands. When converted into monetary terms (1 ton of avoided CO_2 emissions = 4.76 USD), this can represent an additional income of 20,500 USD. However, it has already been shown in the previous sections that these returns would be insufficient to cover establishment and transaction costs. At the same time, the possibility of harvesting trees during years 7, 14, and 21 would change rural households' domestic energy expenditures and CO_2

emissions. Accordingly, the inclusion of fuelwood as payment in kind would lead to the positive environmental externality effects through reducing emissions from the combustion of domestic energy products such as coal and LPG. In the CDM scenario, the CO_2 emissions would follow similar pattern as energy expenditure. Hence, before the initial harvest of tree plantations, rural households would receive less cotton stem as payment from farmer and would rely more on coal and LPG. Consequently, households' energy emissions would increase. During the periods of tree plantation harvest, the changes in the energy product consumption would in turn reduce CO_2 emissions from domestic energy products (Figure 5.11). In years 13 and 20, the energy emissions would be close to the BAU level. The main CO_2 emitting product at rural households would be coal, fuelwood and cotton stem, while emissions from LPG would be negligible. This highlights that the short-term CDM afforestation on marginal croplands, which was not aimed for rural households, would lead to a positive environmental externality by reducing CO_2 emissions from domestic use of energy products.

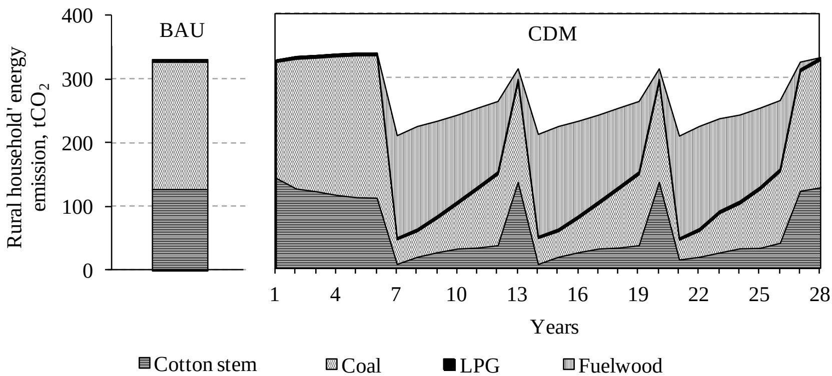


Figure 5.11: The extremely risk-averse rural households' domestic energy emissions under the scenarios of business-as-usual (BAU) and Clean Development Mechanism (CDM) over 28 years.
Note: tCO_2 is the ton of CO_2.

When comparing the reductions in energy emissions among rural household groups, the largest one contributing to climate change mitigation would occur in rural household group 3 (Figure 5.12). At the same time, the highest increase in emissions in certain years (years 6, 13, and

20) would also occur in this group. This could be explained by the decreased labor demand at farm that would reduce payments in the form of cotton stem, and in turn increase usage of more CO_2 emitting energy products such as coal and LPG. Consequently the group that has the highest reliance on farming activities would have the largest changes in emissions. In contrast, the least changes would occur in rural households that have the highest off-farm income, i.e., those in group 2. Thus, there would be a positive externality to the environment from following short-rotation afforestation practices on marginal croplands. When tree growth rates are high and several short-term rotations can be implemented, the opportunities of fossil fuel substitution with fuelwood can act as a C reducing land use strategy. Consequently, to facilitate the sustainable development objective of CDM afforestation, the integration of energy substitution possibilities and benefits transfer to rural population needs to be considered.

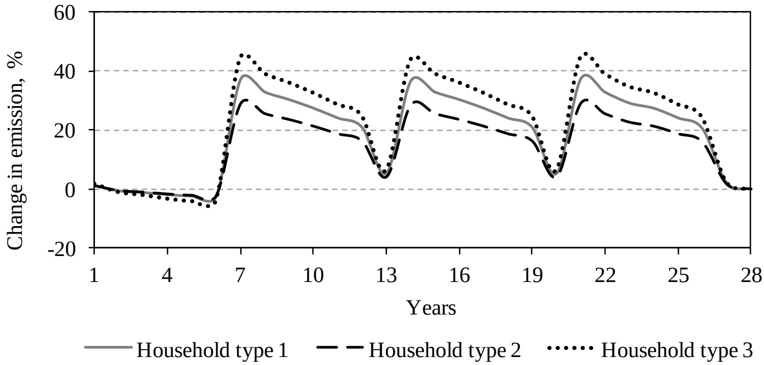


Figure 5.12: Change in the extremely risk-averse rural households' domestic energy emissions under the Clean Development Mechanism (CDM) scenario over 28 years.
Note: 0% is the initial level of energy emissions.

5.4.5 Livestock feeding rations

Rural households are one of the main producers of animal products, with livestock representing an important stock for their income security (see Section 5.3.1). In this way, the improved quality and cheaper fodder rations can contribute to the better livelihoods of rural population. Among the modeled commodities, the main fodder commodities used by smallholders for livestock feeding were rice and wheat straw (grain straw) and maize grain and stem (Figure 5.13 (a)). The possibility to include tree leaves into the payment structure would diversify animal feeding ration practiced in households (Figure 5.13 (b)). In the CDM scenario, between the years of establishment and harvest of tree plantations, the usage of rice and wheat straw, as well as maize grain and stem in animal feeding would increase. During the period of tree harvest, and wood and foliage sectioning the maize usage as livestock fodder would decline to 14% of total fodder use. Accordingly, when trees are harvested the leaves would be one of the main fodder products amounting to 40% of total fodder use. In the mid-term period of tree planting and harvesting, when the maize area increases, the use of maize for livestock feeding would also increase.

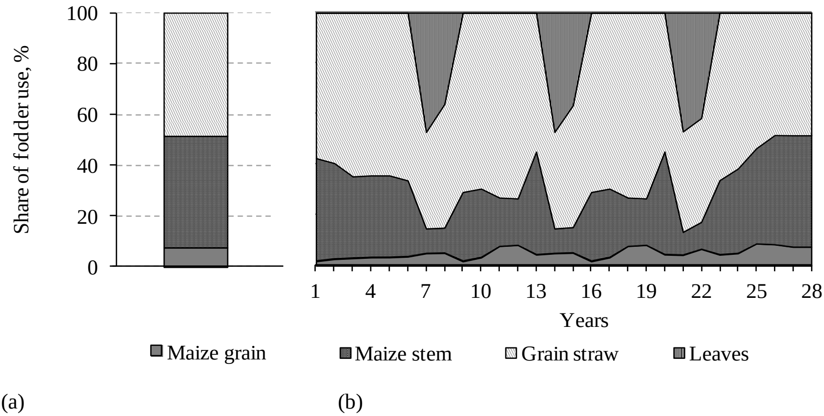


Figure 5.13: Pattern of fodder usage in the extremely risk-averse rural households under the scenarios of business-as-usual (BAU) (a) and Clean Development Mechanism (CDM) (b) over 28 years.

Obtaining leaves as a fodder would not only change the feeding ration of livestock, but also affect the expenditure structure of households, given that it represents a cheap fodder product (Djumaeva et al., 2009; Lamers and Khamzina, 2010). Hence, the possibility of including tree leaves as fodder for livestock would lead to the reduction of fodder expenditure, and for all rural households the fodder expenditures would be reduced by about 15% over the analyzed period of 28 years. Given the high number of rural household members employed at farm, the largest decrease in fodder expenditure was for rural households' group 3.

6. Discussion and Conclusions[13]

This chapter discusses and concludes the results presented in previous chapters by focusing on estimated temporary Certified Emission Reduction (tCER) prices in CDM afforestation (Section 6.1), the co-benefits of non-timber products (Section 6.2), land use revenue risk coping strategies (Section 6.3), the impact on rural livelihoods in the bimodal agricultural system (Section 6.4), the policy relevance of this study's results (Section 6.5), and further research needed to analyze economic viability of afforestation on marginal croplands (Section 6.6).

6.1 Carbon value of tree plantations

Establishing tree plantations on marginal irrigated croplands in Uzbekistan may offer benefits through the carbon (C) sequestration in wood, in the form of temporary Certified Emission Reductions (tCERs) under the short-term CDM afforestation of the Kyoto Protocol (Khamzina et al., 2012). The results showed that short-rotation plantations of the three studied tree species, i.e., *E. angustifolia*, *P. euphratica* and *U. pumila*, endorse the conversion of marginal croplands into small-scale conventional tree planting or CDM afforestation. Non-timber products in the form of fuelwood, leaves as fodder and fruits represent the largest share of revenues from tree plantations, and would account for around 86-94% of the total revenues, depending on the tree species. Accordingly, the revenues solely from tCERs would be 6-14% of the total revenues, which would be insufficient to cover the initial investments and management of a small-scale CDM afforestation. High transaction and establishment costs balanced out the benefits from tCERs, as was previously observed in the review of existing CDM Afforestation and Reforestation (CDM A/R) projects (Thomas et al., 2010). Based upon the case study of dryland afforestation in Israel, similar conclusions were derived by Tal and Gordon (2010) who indicated that, under the present

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[13] Chapter 6 builds on:
Djanibekov, U., Khamzina, A., Djanibekov, N., Lamers, J.P.A., 2012c. How attractive are short-term CDM forestations in arid regions? The case of irrigated croplands in Uzbekistan. Forest Policy and Economics 21, 108-117.
Djanibekov, U., Djanibekov, N., Khamzina, A., Bhaduri, A., Lamers, J.P.A., Berg, E., 2013b. Impacts of innovative forestry land use on rural livelihood in a bimodal agricultural system in irrigated drylands. Land Use Policy 35, 95-106.
Djanibekov, U., Van Assche, K., Boezeman, D., Djanibekov, N., 2013c. Understanding contracts in evolving agro-economies: *Fermers*, *dekhqans* and networks in Khorezm, Uzbekistan. Journal of Rural Studies 32, 137-147.
Djanibekov, U., Khamzina, A., under 2nd review. Valuation of goods and services from afforestation of marginal irrigated farmland in drylands under revenue uncertainty. Environmental and Resource Economics.

prices of CER, the costs of registration and monitoring would prohibit farmers participation in small-scale CDM A/R projects. In contrast, a study on tCER prices in Brazil showed that the current price in the market is economically attractive, and does not necessitate a significant increase in its price for conserving tree plantations (Guitart and Rodriguez, 2010). Moreover, Olschewski and Benítez (2010) argued that CERs can generate substantial income from forestry activities.

As can be seen, the identification of prices for CER are not entirely resolved, and the enhancement of such environmental services valuation in terrestrial systems is needed to highlight socially preferable options and provide guidance on balancing demands for provision of food, fiber and non-market ecosystem products (Johnson et al., 2012). In this study, when considering CDM afforestation in irrigated agricultural settings on a one hectare scale, the tCER price was related to irrigation water availability; given that this is one of the main factors in determining the opportunity cost of tree plantations in irrigated agricultural settings. The estimated increases in tCER prices needed to motivate CDM afforestation under conditions of adequate irrigation water availability do not seem realistic, being around 10 times the actual value of 4.76 USD (see Section 3.3.3).

At the same time, the price for C stored in wood ranges substantially in voluntary and regulated markets from 0.65 to more than 50 USD tCO_2^{-1} (Hamilton et al., 2010). When considering uncertainties in land use revenues the level of the current tCER prices of 4.76 USD may require an increase up to 120 times (see Section 4.3.1). At the same time, appropriately identifying the price of environmental services and scale of benefits reflect important issues. This study showed that analysis at the whole farm level (i.e., single farm with arable land area of 100 ha) of afforestation of marginal croplands, rather than the field level, would result in a more realistic tCER prices to initiate such land use activities, while considering various uncertainties affecting farm revenues. By capturing correlated uncertainties at the farm level, this study provided a broader overview of the valuation of ecosystem services, such as tCERs. The application of the expected utility model in a whole farm context enabled to reveal that the actual price of tCER is sufficient to initiate afforestation on marginal croplands (see Section 4.3.2). In the same vein, the study by Castro et al. (2013) identified payments for environmental services based upon the opportunity cost of land, showing it to be almost twice of method accounting for the whole farm planning. The diversification of land uses in farming could necessitate only minor adjustment of tCER prices to initiate CDM afforestation on marginal croplands. This is because land use diversification is a common practice carried out by farmers in order to hedge land use revenue risks

(Baumgärtner and Quaas, 2010; Knoke et al., 2011). The determination of tCER price may depend on the agreement between the seller of sequestered C (developing country) and its buyer (industrialized country).

Moreover, given that tree plantations established on marginal lands demand less irrigation water than required for crops (Khamzina et al., 2008), relating the tCER prices to the irrigation water supply for marginal croplands could provide scope for increasing the water availability on the whole farm through small-scale short-term CDM afforestation. This might be implemented by adjusting the irrigation water to the negotiated tCER prices by primarily focusing afforestation activities at locations prone to irrigation water scarcity, e.g., farmers located downstream. Accordingly, it might be possible to negotiate an environmental premium for the increase of irrigation water supply in voluntary markets.

6.2 Co-benefits of non-timber products

The results of the study showed that a short-term CDM afforestation would generate benefits from non-timber products in the short run, while also addressing the problem of land tenure insecurity (Djanibekov et al., 2012c). With such a tree management practice, non-timber products are important co-benefits of CDM afforestation, as suggested by their dominant share in the total revenues. In particular, the internal rate of return (IRR) estimates emphasized the attractiveness of conventional afforestation with *E. angustifolia* due to annually recurring benefits from fruits (see Section 3.2.2). For instance, obtaining fruits from *E. angustifolia* would amount to around 70% of the revenues from this tree species. In addition, the energy security of rural population can be strengthened via the production of fuelwood on afforested plots for meeting their energy demand, currently satisfied through the illegal logging of riparian forests and other forest reserves in Uzbekistan (Vildanova, 2006).

Through harvesting trees in the short-term, substantial C benefits can be obtained from substituting or complementing fossil fuels with fuelwood, thus increasing households' incomes and reducing domestic CO_2 emissions. Baral and Guha (2004) argued that large C mitigation benefits can be obtained by substituting coal and gasoline with biomass obtained from short-rotation forestry practices, as compared to only sequestering C in standing trees. When tree growth rates are high and several rotations can be implemented, the opportunities of fossil fuel substitution with fuelwood can act as a C reduction (Kaul et al., 2010). Thus, harvesting fuelwood through short-term afforestation will result in positive externalities of CDM objective through indirectly reducing the C emissions of rural households. Moreover, tree leaves as a fodder could be of interest to livestock holders as an inexpensive, protein-rich supplement to basic feeding stuffs (Djumaeva et al., 2009), despite making up a modest share of the total revenues. In this way, tree leaves would reduce the expenditure for livestock fodder, through supplementing and/or substituting maize and grain straw fodder.

Furthermore, with irrigation water supply frequently fluctuating in the study area, the introduction of afforestation on marginal croplands offers the potential to supply between 1,600 m^3 ha^{-1} $year^{-1}$ and 15,300 m^3 ha^{-1} $year^{-1}$ to more productive croplands, rather than applying these amounts to marginal croplands (Khamzina et al., 2012). Irrigation water not used by afforested plots can be applied to commercially important crops on fertile lands (Khamzina et al., 2012), consequently expanding the impact of afforestation in the CDM scenario beyond the afforested area. In turn, the area of these crops would substantially increase, and likewise farm incomes. As shown in Sections 4.3.2 and 4.3.3, the afforestation of marginal croplands may lead to an indirect effect of improving irrigation water use at farm, and increasing the production of the most profitable crops, i.e., rice and vegetables. Previous studies also showed that integrating farm forestry could increase irrigation water use efficiency (Breman and Kessler, 1997; Ong et al., 2000; Wallace, 2000; Droppelmann and Berliner, 2003) and enhance crop production (Glomsrød et al., 2011).

Consequently, when considering the introduction of CDM afforestation on marginal croplands, it is important to take into account the value of fruits that can be used for income generation, the integration of energy substitution possibilities with fuelwood, the supply of protein rich fodder for livestock, and the increase in irrigation water supply to other more productive farm fields (Gundimeda, 2004; Djanibekov et al., 2012c; Khamzina et al., 2012). The study for the Mediterranean region by Croitoru (2007) indicated that the annual returns from multiple non-timber products would provide an additional value of 25% for the timber of forests. In the same line, the study by Creedy and Wurzbacher (2001) for the Thomson Water Catchment in Australia showed that the profits of the catchment were maximized through a high C sequestration and yield response to irrigation, as opposed to only timber profits. Moreover, the benefits from afforesting marginal croplands could be higher given that this analysis does not account for other environmental services stemming from trees, e.g., soil rehabilitation (Khamzina et al., 2009a), water quality improvement (Neary et al., 2009), biodiversity enhancement (Crossman et al., 2011) and reduced dryland salinity (Townsend et al., 2012). Furthermore, the development of an environmental payment scheme for improved forest management can generate additional economic benefits for rural population, as well as provide environmental goods and services (Bulte et al., 2008).

6.3 Afforestation on marginal farmland as a risk managing strategy

Although afforesting marginal croplands is a financially attractive land use option that can contribute to positive effects on rural livelihoods in the study area (Djanibekov et al., 2013b), a farmer's main problem could be the uncertainty of returns. Irrigated agricultural systems are subject to various risks, e.g., reduction of crop yields, volatility of prices and variability of irrigation water availability (Bobojonov, 2008). Hence, the uncertainties affecting revenues need to be accounted in analyzing the introduction of such new land uses. Land use decisions become complex, since their revenues may change as a consequence of interactions between economic (price) and biological systems (yield) (Faucheux and Froger, 1995). By capturing correlated uncertainties at the farm level, such as variability in crop and tree product prices and yields, as well as irrigation water availability, this study constitutes as one of the first steps in addressing various correlated uncertainties when estimating an economic value of environmental service projects such as CDM afforestation, including the impact of revenue uncertainties on the income of risk-averse beneficiaries in the irrigated agricultural settings.

Adding tree plantations on a farm's marginal croplands in the study area can represent a key strategy to maintain income and manage risks in rural areas. Baumgärtner and Quaas (2010) showed that with increasing risks farmers would diversify land uses with agrobiodiversity. The strategies combining several land uses that have independent net revenue fluctuations may become an effective buffer to reduce the impacts of revenue risks (Knoke et al., 2009b). Mills and Hoover (1982) found that farmers in the U.S.A. investing in forestry benefited from the diversification, as forestry had low correlation coefficients with other land uses. Hence, the concurrent consideration of diverse farming activities is important in analyses of innovative land uses supplying environmental services (Knoke et al., 2011). Di Falco and Perrings (2005) showed that considering farm revenue risks is important for ecosystem conservation, and that depending on the risk aversion levels of farmers the land uses are selected. In the study, an expected utility approach allowed investigating the diversification options of trees established on marginal croplands for hedging the risks of reduced incomes from crop cultivation. This study showed that tree plantations would be the main income source under the situation of decreased irrigation water availability and/or low crop prices and yields, reducing the repercussions of revenue risks (see Sections 4.3.3 and 4.3.4). Due to independent revenues of trees and crops and depending on risk aversion degrees, farmer would select different tree species to diversify land uses, and the most preferred would be *E. angustifolia*. Moreover, the lesser irrigation water demand of tree plantations than crops would allow more efficient use of irrigation water, with that not used on marginal lands supplied to more productive ones, and as a result enhancing grain and vegetable production. During the drought years and when the irrigation water availability is lower than the average level of 12,000 m^3 ha^{-1}, the afforestation practices would represent one of the main land uses on the farm, apart from cotton, which would be cultivated according to the cotton procurement policy. Furthermore, when crops generate low profits due to land use risks, the tree plantations established on marginal croplands can provide one of the main income sources. When considering various uncertainties affecting revenues, the incomes of farmer adopting afforestation practices on marginal croplands would be substantially larger than of farmer practicing business-as-usual land uses. Accordingly, combining the value of land with that of non-timber products and land use diversification options can enlarge the scope for afforestation.

Furthermore, uncertainty in the production and valuation of ecosystem services are important in assessing environmental projects and their impact on land use change (Johnson et al., 2012). The present study showed that determining tCER prices under revenue uncertainties through the whole farm model results in more realistic prices than those identified via the field level analysis, namely only considering the opportunity cost of land (i.e., stochastic dominance approach). Accordingly, taking into account in the analysis the land use diversification option could assist farmers in identifying land uses that mitigate the impacts of revenue risks, and allow buyers and sellers of tCER to assign more realistic prices for tCER to initiate CDM afforestation. Complementing this argument, Knoke et al. (2011) reported that the land use diversification strategies could develop cost-effective compensation policies to avoid the deforestation of tropical forests and emissions of sequestered carbon from the risk-averse farmer perspective.

6.4 Afforestation and rural livelihoods

Policies addressing the combined concerns of climate change, irrigation water scarcity, land degradation and rural income must deal with incentivizing land users to respond positively to them.

Agricultural policies in the post-Soviet countries often focus on improving output and productivity of commercial farms (Pomfret, 2008), which emerged after the fragmentation of the large-scale collective farm (*kolkhoz*) system (Lerman et al., 2004). These farms dominate arable land use and are the main producers of strategic export-oriented crops, such as cotton in Uzbekistan and Turkmenistan, and wheat in Kazakhstan. Yet, it is common that due to a lack of capital and knowledge, these farms are unable to use their land efficiently (Laffont and Matoussi, 1995). They therefore rely on labor and knowledge of local smallholders. At the same time, the livelihoods of virtually all smallholders are closely connected to the economic performance of commercial farms. One can thus speak of existing interdependencies in a bimodal agricultural system of commercial farms and smallholders (Djanibekov et al., 2013c).

The research in agricultural contracts between farmers' and rural households' could be helpful in analyzing the implementation of sustainable land use practices. By capturing the existing interrelations between the large-scale farms and rural households in the bimodal agricultural system via the developed farm-household model, this study provided the assessment of multidimensional impacts of CDM afforestation on the levels of crop production, incomes, agricultural employment, energy use and CO_2 emissions. The application of such a model could be relevant for the bimodal agricultural system to analyzy the impacts of new land uses and policies on rural livelihoods (Djanibekov et al., 2013b). The farm-household model results showed that farm benefits from converting marginal croplands to tree plantations would be transmitted through agricultural contract arrangements to rural households employed at these farms. Thus, revealing dependencies of rural households on land use and commodities produced at farm, as well as the direct and spillover effects on livelihoods.

According to the model results, the new land use will change an employment structure at the analyzed cotton-grain farm. These changes in employment are vital in environmental projects such as CDM afforestation, and especially for non-participating households that may have limited means to earn additional incomes (Pagiola et al., 2005). The CDM promise to mitigate climate change while contributing to sustainable development, such as poverty alleviation (Glomsrød et al., 2011), in case of the bimodal agricultural system could be realized via mixed agricultural contracts between farms and smallholders as an effective mean of supporting the welfare of the rural population. Following the study by Ito and Kurosaki (2009), this present study showed that payment in kind from farm employment could represent the most preferable arrangement (see Section 5.4.2), given that the monetary value of wages paid in the form of crops and tree products is positively correlated with their prices. The annual change in working hours and inclusion of new tree products into the payment structure would diversify contracts, and might reduce the pressure on farm funds. However, given that afforested marginal croplands require less labor than crops between periods of tree plantations establishment and harvest, rural households' employment on the farm would decline. These changes would consequently reduce the payments from farm employment, and likewise the incomes of rural households. Moreover, reduced farm employment prior to initial harvest of tree plantations can also increase the domestic energy costs and CO_2 emissions of rural households, as they would receive less payment in the form of cotton stem, thus relying more on expensive and high emitting fossil fuels. In contrast, Shuifa et al. (2010) reported that C forest sinks can provide a vast potential for increasing job opportunities in the case of China. Paul et al. (2013) stated that although employment from C forestry tended to be lower than from cropping activities, jobs generated from the forestry on degraded or abandoned land can bring additional income

In the study, during the period of afforestation of marginal croplands and the harvest of tree plantations, during which wood and leaves sectioning is performed, the demand for work at farm would increase, raising the farm remuneration to rural households and accordingly overweighing the losses of such land use. This positive change would be primarily derived from the increased employment at farm and improved structure of agricultural contracts. The improvement of agricultural contracts would be due to the inclusion of multiple tree products into the structure of payments in kind, particularly fuelwood and tree leaves. The inclusion of fuelwood and leaves as fodder in the farm payments would reduce the domestic energy and feed expenditures of rural households. Furthermore, fuelwood would reduce rural households' domestic energy emissions, resulting in positive environmental externality contributing indirectly to the climate change mitigation objective of CDM. By accessing cheaper energy products and protein-rich feeding supplements, the rural households would be able to divert part of their capital and resources to other commodities and activities. Besides, the effects of afforestation on marginal croplands would be different depending on characteristics of rural households. The rural households that are most depended on farm income would lose the most when then demand for labor at farm would be reduced, and benefit most when the labor requirement at farm would be increased, and in overall would be the most affected from afforestation on marginal croplands and benefit the most in comparison to other rural household groups. In contrast, the smallholder group that has highest income from non-farm employment would be least affected. Consequently, when considering afforestation of marginal croplands additional policy measures would be required to support rural households' livelihoods during the periods of low demand for labor at farms.

The results of the farm-household model indicate that CDM afforestation on marginal croplands under the irrigated agricultural settings could improve the incomes of both farmers and rural households, and farmers with more land would become the main beneficiaries. While rural households can indirectly gain from the farm CDM afforestation activity through the effect on the wage-labor relationship, the impact on rural households' incomes would be uneven, including fluctuating incomes over the years and an improved structure of agricultural payments. For instance, Guangxi, a Watershed management project in Pearl River Basin, China, which aims to reforest 4,000 ha of degraded lands, is expected that over the years 2006 and 2036 a total income of 21 million USD will be generated: 75% from employment, 15% from forest products (e.g., fuelwood) and 10% from C credits (Zhang et al., 2006). According to Gong et al. (2010), the CDM reforestation the Guangxi Watershed Management project indirectly increased farmers' incomes following the conversion of barren lands to tree plantations. Xu et al. (2007) showed that the economic conditions of the population in another region of China improved after shifting agricultural land to C forest project, and particularly for families with higher incomes and more economic resources, e.g., farms in my case. In contrast, establishing the CDM A/R in Tanzania would be ineffective in fulfilling the objective of poverty reduction and the transfer of incomes to rural areas (Glomsrød et al., 2011). In this respect, the sustainability of CDM afforestation can also be defined by the effect of farm's land use changes on rural households' incomes (Glomsrød et al., 2011; Hegde and Bull, 2011).

6.5 Policy implications

According to the study results, international and local incentives would be essential in fully realizing the environmental and economic potential of afforestation on marginal croplands within the framework of CDM, and also its contribution to sustainable development in irrigated agricultural regions. In particular, legal support for setting aside marginal cropland parcels for small-scale afforestation could lay the foundation for introducing this land use practice. At present, vast areas of the marginal croplands in the study area are used for the cultivation of state procurement crop, i.e., cotton. The flexibility in the area-based target of cotton policy, according to which farmers can decide the area of cotton cultivation and only have to deliver the state-determined production target, can be decisive for initiating afforestation on marginal croplands. Removing the area-based target of cotton production and following only the output-based production target, farmers will have greater flexibility in land use decisions (Djanibekov et al., 2013a) and may opt to plant trees on marginal croplands. Such change in cotton policy would also lead to the more efficient irrigation water use and enhancement of grain and vegetable production, which are important crops for food and income security of rural population (Djanibekov et al., 2013b).

Furthermore, high transaction and establishment costs, ranging between 100,000-610,000 USD per project, reduce the profits of CDM afforestation (Michaelowa et al., 2003; Neeff and Henders, 2007; UNEP, 2007; Thomas et al., 2010). To reduce these costs and encourage farmers to participate, simplified modalities and procedures were adopted for the small-scale CDM A/R projects, which were defined as those annually sequestering less than 16,000 tCO_2 (UNFCCC, 2007). However, even with the simplified modalities, some small-scale CDM A/R projects failed to support the smallholders' livelihoods (Aggarwal, 2012), for instance due to not including multi-purpose tree species, and still high waiting and transaction costs of CDM. Accordingly, land and income tax exemptions for the initial years of tree plantation establishment should be also considered to reduce the initial costs of afforestation of marginal croplands (Kan et al., 2008). Local support is required to cover initial investments and attract farmers to convert marginal croplands into tree plantations. In China and India, where most of the CDM A/R projects were registered, these projects were predominantly government or company-initiated, and sometimes involving collaboration with international non-governmental organizations (Chokkalingam and Vanniarachchy, 2011). In Uzbekistan, land-based projects have been underrepresented on the country's CDM agenda, due to the prevailing skepticism concerning the cost effectiveness of such projects. In the context of Uzbekistan, solely planting trees or within the framework of CDM on farms' marginal croplands could be supported by the Ministry of Agriculture and Water Resources of Uzbekistan, Designated National Authority for CDM, Farmers Associations, Village Citizens Centers, and Water Consumers Associations. These institutions can provide subsidies for farmers to cover initial costs of afforestation of marginal croplands, knowledge on management of tree plantations and organize meetings for farmers and rural households to jointly decide on tree plantation management activities. Training programs on potential costs and benefits of afforestation and its management practices can be integrated at low costs into farm training activities that are currently organized by local administration to update farmers about crop cultivation techniques and technologies (Shtaltovna et al., 2012).

Taking into the account various environmental goods and services from afforestation on marginal croplands, development of payments for environmental services would further boost economic attractiveness of tress and sustainable management practices of tree plantations (Engel et al., 2008; Khamzina et al., 2012). The state support that ensures payments for environmental services and dissemination of benefits and management practices of tree plantations would be required to introduce afforestation on marginal croplands in Uzbekistan. In addition, when accepting small-scale afforestation as a means of improving degraded croplands, as opposed to a competitive land use, this option becomes an example for land use optimization in irrigated regions, providing various non-timber products and in turn increasing rural livelihoods. However, farm employment would decline between the periods of tree plantations establishment and harvest, consequently reducing the incomes of rural households employed at such farms. Accordingly, additional policy measures would be required to support rural households' incomes during the period of reduced employment at farms (McElwee, 2012).

6.6 Further research

The approaches applied in this study represent tools for the economic evaluation of afforestation of marginal croplands at different scales, addressing its multidimensional aspects. However, this study relied on tree growth parameters of seven years, and consequently it was not possible to include different tree plantation management practices. For future research, it is thus proposed to analyze the impacts of afforestation of marginal croplands on rural livelihoods using long-term rotations and different densities. Extension of data would allow considering various environmental services provided by tree plantations such as biodiversity, land rehabilitation, improvement of water quality, pollination, waste treatment, and others (Ninan and Inoue, 2013). These would increase environmental benefits of trees, as well as estimate in more detail tradeoffs and synergies in the provision of such environmental services and goods. For the crops, inclusion of other inputs affecting the yield, such as fertilizer and machinery, would also give better estimations. In addition, different alternative techniques used to increase the productivity of marginal lands, such as laser leveling, conservation agricultural practices, need to be analyzed to identify the most appropriate policies on such lands. The extension of market prices of tree products would allow capturing trend and make projections for the model using different scenarios affecting the welfare of population, e.g., climate change projected by IPCC, population growth projected by UN.

As farmers and rural households may have different objectives, given that this creates strategic advantages (Viaggi et al., 2009), various equilibriums may appear as a result of bargaining for labor compensation schemes between these two actors, e.g., farmers may maximize their profits, while rural households may optimize consumption and production of livestock to buffer agricultural revenue risks. To address this issue multiple objective programming, where the model maximizes one objective by putting different weights for farmer and households can be used (Janssen and van Ittersum, 2007). For identifying weights the focus groups discussions with farmers and rural households should be conducted.

In addition, the change in the land uses from crop cultivation on marginal lands to CDM afforestation may lead to formation of rural institutions, e.g., farm cooperative, where several farmers will participate in CDM afforestation. Farmers may decide to participate in such cooperative to reduce the initial investments required for initiating CDM afforestation (i.e., establishment and transaction costs), and to collectively manage tree plantations. With such cooperation, farmers would share costs and benefits through a joint CDM afforestation project according to their heterogeneous resources and contributions. Moreover, introducing afforestation on marginal croplands may affect the rural demand for some products, e.g., coal and maize, which in turn would affect their supply and that of their complementing and substituting products. As a result, the prices of these commodities may change, thus impacting the regional welfare in the study area. To address these issues, it is important to capture the sectoral effects of introducing afforestation on marginal croplands in the study area.

Appendices

Appendix A

Table A: Dry matter of tree products over seven years since planting.

Years	Tree products, kg ha^{-1}							
	Leaves		Fruits		Stem and twigs		Coarse roots	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
E. angustifolia								
1	1,543	76	0	0	3,045	32	899	46
2	7,428	343	0	0	30,686	269	4,484	225
3	7,542	587	686	285	59,782	785	10,797	811
4	8,457	1,023	4,228	964	64,116	1,726	12,119	1,403
5	5,714	710	3,028	1,061	70,480	1,290	13,736	1,881
6	6,000	1,269	2,000	831	85,710	3,885	25,142	6,381
7	6,285	1,827	914	601	102,216	6,481	35,304	10,881
P. euphratica								
1	171	21	n.a	n.a	318	6	241	26
2	3,486	517	n.a	n.a	9,528	224	3,044	366
3	6,057	1,052	n.a	n.a	25,694	761	8,597	1,298
4	16,971	4,728	n.a	n.a	79,259	3,665	13,463	2,304
5	18,342	2,846	n.a	n.a	101,672	2,581	22,351	4,952
6	19,142	4,023	n.a	n.a	137,136	6,441	34,284	8,084
7	19,713	5,200	n.a	n.a	170,987	10,300	48,001	11,216

Source: Khamzina et al. (2008; 2009b).

Note: Only *E. angustifolia* produces fruits; n.a. is not applicable; SEM is the standard error of the mean.

Table A: Dry matter of tree products over seven years since planting (*continued*).

Years	Tree products, kg ha^{-1}							
	Leaves		Fruits		Stem and twigs		Coarse roots	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
U. pumila								
1	654	63	n.a	n.a	1,202	22	616	53
2	2,889	171	n.a	n.a	10,458	146	4,822	321
3	3,698	550	n.a	n.a	22,583	641	10,249	1,288
4	4,054	763	n.a	n.a	33,283	1,425	17,987	3,660
5	4,707	1,083	n.a	n.a	41,402	1,220	20,873	3,840
6	4,857	1,066	n.a	n.a	59,997	2,003	33,141	6,164
7	4,858	1,049	n.a	n.a	82,611	2,786	45,984	8,487

Source: Khamzina et al. (2008; 2009b).
Note: Only *E. angustifolia* produces fruits; n.a. is not applicable; SEM is the standard error of the mean.

Appendix B

Table B: Descriptive statistics of cropping systems.

		Cotton			Wheat			Rice		
Parameter	Unit	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Crop market price	USD t^{-1}	n.a.	n.a.	n.a.	227	205	364	682	546	909
Crop procurement price	USD t^{-1}	227	145	273	108	82	159	n.a.	n.a.	n.a.
Crop by-product price	USD t^{-1}	32	23	45	30	21	46	30	21	46
Seeds costs	USD ha^{-1}	16	12	20	50	32	71	82	55	120
Labor costs	USD ha^{-1}	152	102	220	105	82	120	127	85	171
Fertilizer costs	USD ha^{-1}	152	108	197	135	100	163	166	120	199
Machinery	USD ha^{-1}	122	85	166	105	69	150	650	574	800
Other costs*	USD ha^{-1}	50	30	82	97	60	145	192	118	269

Source: Djanibekov et al. (2012c).

Note: *Costs related to transportation and payments for accessing rural markets; n.a. is not applicable: cotton is not sold in local markets; rice, maize and vegetable are not part of the state procurement system; vegetables do not produce any by-products.

Table B: Descriptive statistics of cropping systems (*continued*).

		Maize			Vegetables		
Parameter	Unit	Mean	Min	Max	Mean	Min	Max
Crop market price	USD t^{-1}	227	182	364	260	202	900
Crop procurement price	USD t^{-1}	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Crop by-product price	USD t^{-1}	27	12	58	n.a.	n.a.	n.a.
Seeds costs	USD ha^{-1}	80	57	113	257	200	309
Labor costs	USD ha^{-1}	81	58	109	401	325	469
Fertilizer costs	USD ha^{-1}	150	104	200	80	67	100
Machinery	USD ha^{-1}	100	68	131	90	65	110
Other costs*	USD ha^{-1}	27	12	55	98	85	85

Source: Djanibekov et al. (2012c).

Note: *Costs related to transportation and payments for accessing rural markets; n.a. is not applicable: cotton is not sold in local markets; rice, maize and vegetable are not part of the state procurement system; vegetables do not produce any by-products.

Appendix C

Table C: Coefficients of variation of crop yields and prices, irrigation water availability and tree product prices.

Parameters	Coefficient of variation
Crop yields	
Cotton	0.16
Wheat	0.15
Rice	0.22
Maize	0.16
Vegetables	0.11
Crop prices	
Wheat	0.57
Rice	0.40
Maize	0.40
Vegetables	0.20
Irrigation water availability	0.25
Tree product prices	
Fuelwood of *E. angustifolia*	0.11
Fuelwood of *P. euphratica*	0.10
Fuelwood of *U. pumila*	0.12
Leaves of *E. angustifolia*	0.10
Leaves of *P. euphratica*	0.13
Leaves of *U. pumila*	0.12
Fruits (Russian Oliv.)	0.08

Data source: Coefficients of variation of crop yields and prices, and irrigation water availability are for the period 2001-2009 (MAWR, 2010; Statistical Committee of Khorezm, 2010).

Note: As the cotton price is determined by the state its price variability is not considered; As half of wheat yield is purchased by the state determined price its variability is not considered; Coefficient variation of tree products prices are for one year and based upon weekly observation between June 2010 and March 2011; Prices of leaves were derived based on crude protein content of dry alfalfa and subsequently this fodder product market price was assigned (for a detailed description of leaves valuation see Lamers et al. (2008)).

Appendix D

Table D1: Correlation matrix of crop yields and prices, and irrigation water availability between 2001 and 2009 in the Khorezm region. Data source: MAWR (2010), Statistical Committee of Khorezm (2010).

	Yield					Prices				
	Cotton	Wheat	Rice	Maize	Vegetables	Wheat	Rice	Maize	Vegetables	Irrigation water
Yield										
Cotton	1.00									
Wheat	0.59	1.00								
Rice	-0.02	0.45	1.00							
Maize	0.70	0.84	0.53	1.00						
Vegetables	0.17	0.64	0.61	0.53	1.00					
Prices										
Wheat	0.35	0.70	0.02	0.48	0.66	1.00				
Rice	0.07	0.54	-0.03	0.19	0.67	0.02	1.00			
Maize	0.64	0.86	0.25	0.72	0.67	0.48	0.19	1.00		
Vegetables	-0.18	-0.58	-0.60	-0.69	-0.12	0.66	0.67	0.67	1.00	
Irrigation water	0.03	0.14	0.74	0.42	0.03	-0.49	-0.58	-0.19	-0.67	1.00

Data source: MAWR (2010), Statistical Committee of Khorezm (2010).

Table D2: Correlation matrix of observed tree product yields over seven years.

	Wood	Leaves	Fruits
E. angustifolia			
Wood	1		
Leaves	0.65	1	
Fruits	0.50	0.53	1
P. euphratica			
Wood	1		n.a.
Leaves	0.93	1	n.a.
U. pumila			
Wood	1		n.a.
Leaves	0.83	1	n.a.

Data source: Adapted from Khamzina et al. (2009a; 2009b).
Note: n.a. is not applicable to produce fruits.

Table D3: Correlation matrix of tree product yields over seven years generated by Monte Carlo simulation.

	Wood	Leaves	Fruits
E. angustifolia			
Wood	1		
Leaves	0.63	1	
Fruits	0.52	0.55	1
P. euphratica			
Wood	1		n.a.
Leaves	0.89	1	n.a.
U. pumila			
Wood	1		n.a.
Leaves	0.82	1	n.a.

Note: n.a. is not applicable to produce fruits.

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