Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Sciences
Department of Economics

Photovoltaic Installations and Land Allocation under Uncertainty

A Real Option Approach

Ardjan Gazheli

Master's thesis · 30 hec · Advanced level
Environmental Economics and Management, Master's Programme
Degree thesis No 654 · ISSN 1401-4084
Uppsala 2011

Photovoltaic Installations and Land Allocation under Uncertainty
A Real Option Approach

Ardjan Gazheli

Supervisor:	Luca di Corato, Swedish University of Agricultural Sciences, Department of Economics
Examiner:	Karin Hakelius, Swedish University of Agricultural Sciences, Department of Economics

Credits: 30hec
Level: Advanced E
Course title: Independent Project in Business Administration
Course code: EX0536
Programme/Education: Environmental Economics and Management - Master's Programme

Place of publication: Uppsala
Year of publication: 2011
Cover picture: CCLG Energy Srl
Name of Series: Degree project
No: 654
ISSN 1401-4084
Online publication: http://stud.epsilon.slu.se

Key words: Land Allocation, Photovoltaic Installations, Real Option, Renewable Energies, Uncertainty.

Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Sciences
Department of Economics

Acknowledgements

I wish to thank firstly the Swedish Institute for providing me with the funding for this master degree within the scholarship program Master in Sweden for East Europe. Without this financial support, it would be difficult for me to obtain this degree.

In addition, I would like to thank the staff of SLU – Economic Department. I am thankful to all my professors, assistant professors and researchers I worked with and knew in these two years.

Besides, I pass my acknowledgements to Assistant Professor Luca di Corato for the help and patience during this six months trip in math and real options.

Furthermore, I am grateful for the help offered by Gessica and Annica Perini and S.E.D.I Srl in order to obtain all the valuable data needed for this work.

Finally, I would like to dedicate this work to my parents.

Dedikuar prinderve te mi!

Abstract

A real option model is developed to examine the crucial factors affecting the agricultural firms' decision to quit the production and rent out the land to a company building a PV power plant. The public policies in support of investments in renewable energies have created the conditions for a market regarding investments in PV installations in agricultural areas.

The decision to switch offers to the agricultural firm and to society several economical, social and environmental benefits, representing sustainability. However, PV installations in agricultural areas require the allocation of a certain land area. By assigning a part of land to PV installations, thereby the area of land allocated to agricultural production decreases. Using a real option approach the trade-off between these two competing uses is studied. The real option approach is useful for the evaluation of decisions regarding PV installations since it takes into account the uncertainty regarding the agricultural commodities prices and the irreversibility of the decision taken by the agricultural firm.

The results illustrate how uncertainty and irreversibility are important factors and determine the decision of the agricultural firm to switch. These results have implications for the design and implementation of decision-making processes regarding PV installations and land allocation.

Sammanfattning

I denna studie är en verklig alternativ modell framtagen för att undersöka de kritiska faktorerna som påverkar ett jordbruksföretags beslutsförmåga att lägga ner sin produktion för att arrendera ut marken till företag som sätter upp solceller på marken. Marknaden samt och investeringarna för att installera förnybar energi såsom solceller på jordbruksmark är beroende av statliga bidrag.

Beslutet att växla från jordbruksproduktion till solcellsarrendering är ekonomiskt fördelaktigt för jordbruksföretaget och samhället, inte minst ur ett hållbarhetsperspektiv. För att installera solceller på jordbruksmark krävs dock en allokering av mark, som inte kan brukas i till annat jordbruket och andelen areal tillämpad för jordbruksaktiviteter minskar. Genom att använda en verklig alternativ modell utfaller trade-offen för de olika alternativen. En verklig alternativ modell är användbar för jordbruksföretagaren då den utvärderar och inkluderar osäkerheten för framtida jordbruksråvarupriser samt den reversibla beslutsdelen.

Resultaten i studien påvisar att osäkerhets- och reversibelfaktorerna är de viktigaste och avgörande i lantbrukarens beslut för att eventuellt växla sin produktion. Resultaten i studien påvisar att modellen kan användas i en beslutsberäkningsprocess för solcells installering på arrenderad mark samt land allokering.

Abbreviatons

ADF – Augmented Dickey-Fuller

BTP – Multi-year Treasury Bonds

CF – Cash Flows

CRP – Conservation Reserve Program

EBITDA – Earning before interest, tax, depreciation and amortization

EC – European Commission

ECN – Energy Research Centre of the Netherland

EEA – European Environmental Agency

EU – European Union

FAO – Food and Agriculture Organization

GDP – Gross Domestic Product

GHG – Greenhouse gas

GSE – Italian Renewable Energy Market Operator

GW – Giga Watt

IPCC – Intergovernmental Panel on Climate Change

ISTAT – Italian National Institute of Statistics

KW –Kilo Watt

LCC –Life cycle cost

MC –Monte Carlo

MS – Member State

MW – Mega Watt

NPV – Net Present Value

O&M – Operation and maintenance

PV – Photovoltaic

R&D – Research and development

RES– Renewable Energy Sources

RWM – Random walk model

S.E.D.I Srl – Società Elaborazione Dati Impresa

UNFCCC – United Nations Framework Convention on Climate Change

US – United States

List of figures, charts and tables

Table of Contents

1 Introduction

The set of incentives established by the Italian Department for Economic Development jointly with the Department of Environment and the State Regions Joint Conference aims to support the investments in renewable energies (Ministero dello Sviluppo Economico, 2010). The ministerial decree "Conto Energia" is the implementation of the European Directive 2001/77 EC regarding the development of renewable energies from the member states (MS). The decree provides incentives to individuals, private and public companies, which decide to invest in a photovoltaic (PV) power plant with a power greater than 1 kW. In addition, a set of additional benefits are provided to the PV systems that use energy in an efficient way (*ibid*).

As a result of the European policies in support of renewables, the energy consumption from renewable energy sources (RES) in the European Union (EU) almost doubled since 1990 (European Commission, 2010). The share in the energy consumption by RES increased from 7,1% in 2006 to 8,4% in 2008 (*ibid*). Wind energy and PV have played a significant role in this growth. The PV market in Italy had a rapid growth in 2008, increasing by 150-160% with respect to the previous year (www, Aurora, 2011).

Sustained by this set of incentives, the PV installations gained a rapid acceptance within the private and public sector. PV installations can be of two types: rooftop or ground-based. The first category is installed in a large scale in the residential area, shopping malls and industrial sheds, while the second category is generally installed in agriculture (www, Aurora, 2011). Ground-based PV power plants require the destination of a determined amount of land area for the installation of solar panels. Considering that land is the main input for agricultural production, a conflict in land use may emerge. Agricultural firms may directly invest in PV installations by quitting the agricultural production and installing the PV solar panels on the ground. Another option is to rent out the land to a company investing in PV installations.

By renting out the land, the agricultural firm does not pay any investments or other costs connected to the maintenance and insurance against weather conditions or vandalism acts of the PV solar panels. The only cost the agricultural firm has to sustain is the initial switching cost, which includes the transaction costs of finding the counterpart and financial consulting regarding the decisions. The pay-off for the agricultural firm is given by the yearly rent received by the company investing in the PV plant.

The decision making model presented in this thesis examines the factors affecting the decision of the agricultural firm willing to quit the agricultural production and rent out the land to a company building a PV installation. Using a real option approach the aim of this research is to study the profitability between these two competing land uses and determine the optimal use of land. This approach is the most promising since it accounts for the irreversibility of the decision to quit the agricultural production once undertaken, considering that the contracts have a lifetime of twenty – twenty five years, as well as the uncertainty surrounding agricultural commodities markets.

1.1 Problem background

"*To these ends, the ministers have agreed on the following objectives: ...putting more abundant energy at a cheaper price at the disposal of the European economies...*" from the Messina declaration, 1955, p. 1 (www, Eurotreaties, 2011).

The European Commission (EC) (2007) identifies the energy sector as one of the strategic sectors in Europe. This sector is currently facing problems regarding dependence on outside suppliers, the security of supply, competitiveness and sustainability issues. In this respect, since renewable energies may deal with some of the issues above, i.e. reducing greenhouse gas (GHG) emissions and air pollution, increasing the security of supply and competitiveness, they are strongly supported by the EU (European Environment Agency, 2008).

The first step made by the EU in this direction was the publication of the European White Papers in 1997. In this document the EU decided as a common policy for all the MS to increase the renewable energy produced in the Union by 12% by 2010 (European Commission, 1997). In 2007, the EC issued declaration 548 Final in order to increase the target for renewable energy production to 20% of the total energy produced by 2020 (European Commission, 2007). In addition, the EC has set two main objectives for 2020: first to reduce GHG emissions by 20% and second to improve energy efficiency by 20% (European Renewable Energy Council, 2007).

Outside dependence

The energy dependence from outside sources shows the extent to which an economy relies on imports to meet its energy needs (www, Eurostat, 2010). Outside energy dependency in the

EU remained constant from 1990 to 2000, at a level of up to 45%. From 2000, it started growing significantly and reached 55% of the total energy consumed in 2008 (*ibid*). The main energy providers were Russia with 33% of oil imports and 40% of natural gas imports and Norway with 16% and 23% respectively (www, Energy, 2010). These figures show that more than half of the energy needed in the EU is imported. Future forecasts for energy demand are not very encouraging either. According to the EC, by 2030 EU dependency on outside providers will reach 65% of the total energy consumed (European Commission, 2007).

Security of supply

Outside dependence on energy is connected to political and economic risk. To have a secure energy supply, means to have a continuous and uninterrupted availability of the energy supply at the consumer's site (ECN, 2007). The gas crisis between Russia and Ukraine in the end of 2005 and beginning of 2006 highlighted the problem of security of supply related to energy provision in the EU (Spanjer, 2007). Because of disagreement over subsidies in the gas price paid by Ukraine, Gazprom decided to limit the amount of gas transported to Ukraine. This problem turned into a European one because the pipeline going through Ukraine is of vital importance for Europe since it furnishes France, Austria, and Italy with natural gas. As a result, the quantity of natural gas to these countries decreased by levels by 25-30% in France, 33% in Austria and 25% in Italy (*ibid*).

Competitiveness

In order to remain competitive, the EU must work towards lowering production costs (European Commission, 2007). As a result of outside energy dependency, the volatility in prices is becoming higher and more difficult to hedge (*ibid*). In addition, the EU is supporting the concentration of energy supply in a few actors like Russia and Norway (www, Energy, 2010). The energy prices have a direct impact on the production costs. According to the International Energy Agency (2003) "*if the oil price rose to €100/barrel in 2030, the EU-27 energy total import bill would increase by around € 170 billion, an annual increase of €350 for every EU citizen*" (European Commission, 2007, p. 4).

Renewable energy sources are therefore considered a key factor for competitiveness by the EU since they reduce the energy dependence from outside, lower the volatility and the increase of energy prices and create new employment in the Union's MS (European Commission, 2007).

Environmental issues and climate change

The increase in energy consumption in the EU is accompanied by a rise in environmental concerns among the public (Arnulf, 2007). Energy consumption in the EU is responsible for GHG emissions and climate change (European Commission, 2007). The energy sector is responsible for approximately 80% of the total emissions in the Union (www, Eurostat, 2010). From 2000 to 2007, the GHG emissions within the EU were reduced. However, this reduction was not sufficient since the GHG emissions remained above the defined targets set by the Kyoto protocol[1]. The target set by the EU requires a 20% reduction of GHG emissions by 2020.

The third assessment report of the Intergovernmental Panel on Climate Change (IPCC) confirmed that human activity, especially in terms of fossil energy consumption, is responsible for the Earth's climate change (Sims, 2004). The report states that investments in renewable energies within the next 20 years will have a positive impact on climate change by reducing GHG emissions. Scientists have shown that ongoing use of fossil fuels will result in greater instability in terms of climate change and politicians have accepted this argument. In order to reduce the impact of human activity on climate change the key factor according to Sims (2004) is to change energy behaviour, switching from fossil fuel based consumption to one based largely on renewable energy. This process will need investment in technological change, infrastructure, research, and strong supporting governmental policies. New business opportunities will thrive as the world moves to renewable energy consumption.

1.2 Problem

With respect to the problems concerning the energy sector, the EU is supporting the investments in renewable energies with subsidies, feed-in tariffs and quotas (Munoz *et al.*,

---

[1] "The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change. The major feature of the Kyoto Protocol is that it sets binding targets for 37 industrialized countries and the European community for reducing greenhouse gas (GHG) emissions .These amount to an average of five per cent against 1990 levels over the five-year period 2008-2012" (www, UNFCCC, 2011).

2007; European Environment Agency, 2008). The scope of the European Directive 2001/77 EC is to sustain and encourage the investment in renewable energies by the MS (European Commission, 2001). The state members must develop their own legislation in order to promote the investment in the electric sector by renewable energies.

Due to its geographical position, Italy offers excellent conditions for PV power plants. The country is situated in southern Europe and the solar radiation is considered to be favourable and spread throughout the year (www, PV-Invest, 2011). In addition, the subsidies introduced by “Conto Energia III”, the implementation of EU Directive 2001/77 EC, supports the investments in PV power plants (Ministero dello Sviluppo Economico, 2010).

Ground-based PV installations require the allocation of a certain land area and the agricultural areas are used for this type of installations (www, Aurora, 2011). An agricultural firm willing to quit the agricultural production and rent out the land to a company building a PV power plant will assign a part of land to the PV installations, thereby decreasing the area of land allocated to agricultural production. Using a real option approach the trade-off between these two competing uses is studied.

The real options method is useful for the evaluation of decisions regarding PV installations since it takes into account the uncertainty regarding the agricultural net revenues and the irreversibility of the decision taken by the agricultural firm entering in a 20 to 25 years contract. Once the decision is undertaken, it cannot be undone.

1.3 Aim

The aim of this study is to develop a decision-making model considering the factors affecting agricultural firms willing to quit the agricultural production and rent out the land to a company building a PV power plant. The case study focuses on the province of Bologna in Italy and aims to answer to the following questions:

- Does uncertainty in the agricultural net revenues play a role in the decision to switch and rent out the land?
- Considering the current agricultural net revenues, is it more profitable for an agricultural firm to hold on the production instead of renting out the land to a company building a PV power plant?

- To which extent is this choice sensitive to changes in the discount rate, in the PV contract duration and the initial switching cost?
- At which minimal rent are the agricultural firms willing to rent out the land considering the current agricultural net revenues?

With a real option approach, the profitability of these two choices is studied and the optimal solution is shown. The real option method takes into account the irreversibility of the decision to rent out the land once undertaken and the uncertainty regarding the pay-offs from agricultural production.

1.4 Outline

The thesis is organized as follows: the first chapter presents the introduction, problem and aim of the thesis. Chapter 2 describes the theoretical perspective. This chapter is presented before the method since it provides information regarding the downfalls of the NPV and the advantages of the real option approach chosen for this thesis. Chapter 3 introduces the method used, the choice of the country, technology, and unit of analysis. The empirical background is presented in Chapter 4. Chapter 5 illustrates the empirical study. The data obtained from the annual publications on the average agricultural values are collected, elaborated and presented.

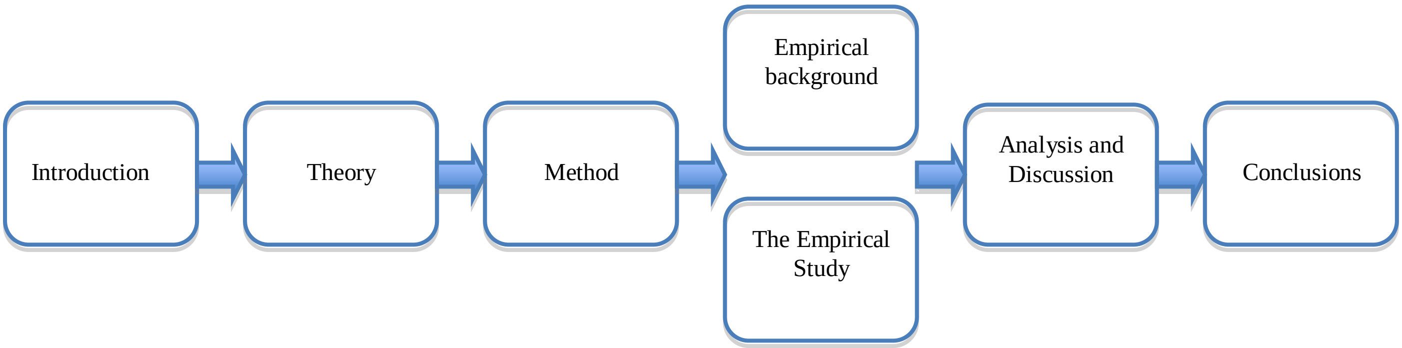

Figure 1. Illustration of the outline of the study

Chapter 6 offers the analysis and discussion as a combination of the theoretical perspective and the empirical findings. The conclusions are presented in the seventh chapter. In this chapter, the author provides also suggestions for future research on the field of study.

2 Theoretical perspective and literature review

This chapter provides the theoretical background of the dissertation. The first section introduces the economic evaluation of investments in general. The second section presents NPV, the traditional method of investment evaluation and its drawbacks. The third section describes the real option approach and the fourth one illustrates some applications to the analysis of energy and agricultural issues. In the fifth section, the model of this theoretical paper is presented. The last three sections of the chapter show the statistical and econometric tests used for the data elaboration.

2.1 Economic Evaluation of Investments

"*Economics defines investment as the act of incurring an immediate cost in expectation of future rewards*" (Dixit and Pindyck, 1994, p. 3). A firm investing in a new power plant is an investor. The costs incurred stem from the construction of the new plant and the operating costs, and the rewards include incoming cash flows from the operation of the power plant. However, investments should not be considered only when a company expands or builds a new production site. A firm shutting down a production plant or part of it because of losses is also "investing". In this particular case, the costs incurred include the value of the production plant and the cost of labour, while the future rewards are represented by the reduction of future losses (*ibid*).

Investments have different features depending on the sector or industry in which the investment is made; however, they also have some important characteristics in common. The first term in common is connected to the fact that an investment is often irreversible (Dixit and Pindyck, 1994). Once a production plant is installed, the value of the capital is connected to the operation of the plant and the resulting production. If the plant is not operating then the initial cost or investment is sunk. The second element investments may have in common is the uncertainty over future pay-offs. The uncertainty expresses the volatility of the future incoming cash flows related to the investment. Future cash flows can be affected by an increase or decrease in prices. Another issue investments have in common is the choice of the time when to invest. An investment can be postponed in the future for the purpose of collecting information, even if the company will not be completely certain.

2.2 Traditional economic evaluation models – NPV

Traditional economic evaluation models like the Net Present Value (NPV) calculate the difference between the discounted cash flows generated by an investment and the initial value of the investment itself (Brealey and Myers, 2003). The NPV expresses the value of a project against the possibility of investing that money somewhere else at an established interest or discount rate (*ibid*). It is used in capital budgeting to assess the profitability of investments and projects.

$$NPV = -I + \sum_{t=1}^{\infty} \frac{CF}{(1+r)^t} \tag{2.2.1}$$

where I is the initial investment cost, CF is the stream of the future cash flows generated by the investment, t expresses the time, and r is the discount rate. NPV shows how much value an investment or project adds to the firm (Brealey and Myers, 2003). By discounting and finding the current value of the net cash flows, it is possible to compare the current value of the investment to other investment projects. According to the NPV method, an investment is profitable when the aggregate sum of the discounted net cash flows is larger than or equal to the initial investment (*ibid*). When the NPV of an investment is equal to zero, the company is indifferent whether to invest or not in the project.

According to Pretorius *et al.* (2008), the calculation of NPV should be made based on incoming cash flows before interest, tax, depreciation and amortization (EBITDA). Using the NPV method to evaluate investments is relatively straightforward, however it carries a certain degree of difficulty and downfalls concerning the determination of the incoming cash flows, the discount factor and its “now or never” approach to the investment decision (Tham and Velez-Pareja, 2004). These downfalls of the NPV method are explained in the following sections.

2.2.1 Cash flows

One of the most difficult tasks for managers dealing with the NPV method is the determination of the future cash flows deriving from the investment (Tham and Velez-Pareja, 2004). The estimation of the future cash flows depends on the future market conditions. Firms use their experience to predict these conditions and draw reasonable estimations. However, despite the experience of managers, analysts and the effort of firms, these future cash flows are only predictions and the real future cash flows can change remarkably.

The standard capital budgeting model does not account for the risk associated with future incoming rewards from the investments. According to Hardaker *et al*. (2004), the future cash flows of a project should be considered as stochastic processes[2] that follow a probabilistic rule. The initial value is known but the future rewards can have a range of possible values associated with different probabilities. In order to account for risk, stochastic models are used. Stochastic simulations give a better indication of risk related to the project and help to estimate the volatility of the future rewards (Hardaker *et al.*, 2004).

The projects' pay-off can take an indefinite number of values depending on the market conditions and future events. Instead of considering fixed cash flow values, managers should model the process with appropriate parameters in order to derive the cash flow at any point in time. The future cash flows CFt should be considered as random variables at any time t. Managers and analysts evaluate usually the most likely scenario instead of all the possible future paths, which is extremely simplistic. By doing so, much valuable information is not considered in the analysis. This information is present in the other possible paths the cash flows can take.

Because of the scarce resources in companies, managers and analysts do not evaluate all the possible scenarios. Usually companies end up considering three possible scenarios regarding the projects they are evaluating. These three scenarios include a base scenario, an optimistic one and a pessimistic.

2.2.2 Discount factor

According to the NPV method, the future incoming cash flows should be discounted using an appropriate discount factor incorporating the systematic risk in the project (Groppelli and Nikbakht, 2006). The determination of this discount rate is a challenging task for managers and analysts. Generally, the discount factor is considered constant even if it is theoretically possible to use different discount factors in different time periods.

---

[2] "A stochastic process is a variable that evolves over time in a way that is at least in part random" (Dixit and Pindyck, 1994 p. 60).

The fact of using a single discount factor for all the lifetime of a project is not plausible since with the acquisition of new information, the risk profile of a project can change sensibly.

The challenges for managers and analysts evaluating a project concerning the discount factor are mainly two. The first considers the fact that it is difficult to decide about a rate of discount upfront and make the decision *a priori*. The second challenge considers the fact of a change in the discount factor. As new information arrives and the risk profile changes, the discount factor should also change but such a change will change the project value.

2.2.3 “Now-or-never” approach

Using the NPV method of evaluation, managers consider the option to invest in the project at the current time without having the possibility to delay the investment for the purpose of acquiring more precious information regarding the market conditions (Brealey and Myers, 2003). For this reason, NPV represents a “now-or-never” decision.

Given that the NPV method is formulated on predictions of future cash flows, a discount factor representing the risk of the project and the value of the initial investment, the result of the NPV today will differ from the result of NPV tomorrow, or another day, as more information is available for the company. Given the dynamic nature of the real world, NPV turns out to be an incomplete method to determine the profitability of a project since it evaluates the value of the project today without taking into consideration the future dynamic variations.

A project with a negative NPV today can turn out to be profitable in the future as the market conditions change. The possibility to adapt to these dynamic conditions along the life of a project is called “managerial flexibility”. The managerial flexibility represents a valuable tool, which should be considered upfront.

2.2.4 Irreversibility

The “now-or-never” approach of the NPV method prescribes to managers the value of the project today (Brealey and Myers, 2003). If this value is positive then the company should invest in the project. If the market condition turns out to be different in the future, then the company should reverse the investment immediately by selling out the project at a liquidation price.

One of the characteristics that investments have in common is irreversibility (Dixit and Pindyck, 1994, p. 3). Once the project is undertaken, the cost of the investment is sunk. If a company invests in a PV plant and it turns out that the industry is not profitable, then it will be difficult to sell the solar panels in the market and find a buyer given that also for the other companies in the same industry will not be profitable.

According to Dixit and Pindyck (1994), since the sunk costs are a characteristic and inherent aspect of most investments, managers should be cautious in addressing precious resources to a project. Having the possibility to wait for a certain period in order to acquire more information about market conditions helps the company to reduce the possibility of losing the investments' costs (*ibid*). Deciding to invest today kills the option to wait, which value is given by the value of acquiring new information.

2.3 The Real Option Approach

As mentioned above, the real world is dynamic and characterized by change and uncertainty. The acquisition of new information regarding the future conditions of the market is of extreme importance for the firm (Dixit and Pindyck, 1994). This is the main reason why managerial flexibility is important in evaluating the investments in new projects. This flexibility allows the firm to collect more information about the market conditions and act in response to them.

$$\text{Expanded NPV} = \text{Conventional NPV} + \text{The Value of the Option to Invest}$$

As shown above, beside the conventional NPV of the project a new component representing the managerial flexibility is included. As a result, a firm can invest in a project with a negative conventional NPV if the value of the managerial flexibility is high enough to justify it, i.e. investments in R&D projects. The purpose of such projects is not to generate a positive NPV but create opportunities for the firm to develop new products, areas of profits or enter new markets. The managerial flexibility gives to the firm the opportunity to make a decision after it observes the business opportunities are developed (Dixit and Pindyck, 1994). If market conditions turn out well on the decision date, the managers will make the decision to invest. If the conditions turn out poorly, they can make another decision and not invest in the project. This flexibility represents the possibility to make future decisions having new information and considering the market conditions.

The real option approach considers the firm as an agent holding the option to invest (Dixit and Pindyck, 2004). This approach is similar to the financial option applicable to stocks tradable on the financial market. The concept of financial options can also be used for the evaluation of real investments (Borison, 2003). Since the underlying asset is a real asset, it is called a real option. The firm willing to invest in a new project is holding a call option. It has the right to exercise the option, although not the obligation to do so. The company, after evaluating the project, will decide whether to exercise the option and the time when to do so.

If the value of the underlying asset rises in value, then the value of the option will increase and it will be more profitable to exercise it. If the value of the underlying asset falls in value, the value of the option will also fall and the firm may choose not to invest in the future.

According to this approach, the firm holding the option has the flexibility to choose the optimal timing to exercise the option. The decision making process is associated with a “wait and see” prospective. The firm can decide to exercise the option immediately if it is profitable or wait and collect information until the uncertainty is reduced. The option to wait has a value because it offers the firm the option to invest in a future period (Dixit and Pindyck, 1994; Hardaker *et al.*, 2004; Trigeorgis, 2005). With the real option approach the firm have the opportunity to choose the perfect timing for the investment, abandon the investment or even stop the investment for a certain period of time and restart it again after the acquisition of more information or if the uncertainty in the market is lower.

2.3.1 The option to delay a project

Companies can evaluate situations where they have the right to make an investment in a determined period of time (Dixit and Pindyck, 1994). A pharmaceutical company for example has a patent to produce a medicine for twenty years. A mining company has an exclusive licence to dig and extract minerals from a particular area for five years. A farmer has the opportunity to rent out his land to a PV company since the government gives subsidies to investments in renewable energies within three years. The NPV method evaluates only the current opportunity to invest. In the examples above, the company should not only consider the value of the option to invest now but also the right time to invest.

If V represents the value of the option to invest and I represent the initial investment, the firm maximizes the investment pay-offs Max $(V - I, 0)$ where $(V_t - I)$ is the NPV of the project at time t. Given that the company has the option to invest for a determined period of time $\tau \in [0,T]$, the problem for the managers is not only to find if NPV is greater than zero today but when the option has the highest value.

$$\mathrm{Max}_{\tau \in [0,T]} E[D_t \times NPV_t] \qquad (2.3.1.1)$$

where $E[D_t \times NPV_t]$ represents the expected value of the future cash flows and D_t is the discount factor at time t. This is similar to the exercise of an American call option where the underlying asset is the project, and the value depends on the stream of its future cash flows.

2.3.2 The option to expand a project

The option to expand an existing project represents a strategic opportunity for the firm. This type of option implies the application of an initial extra cost usually which has to be carried out upfront. The value of an option is not only represented by the future cash flows it generates but also from the opportunity it creates for the firm. According to Damodaran, (2002) p. 796 "*a firm may accept a negative net present value on the initial project because of the possibility of high positive net present values on future projects*". The argument presented by Damodaran is important to justify the investments in R&D from companies.

By paying an extra cost today, a firm can obtain the option to expand its business in the future if the market conditions turn out to be favourable to the industry or type of investment. A car manufacturer constructing an industrial plant for the production of 300 cars per year can carry out an upfront extra cost, which will allow him to expand the production in 500 cars per year if the market conditions turn favourable. If the conditions in the cars' market turn out to be better than initially expected, the firm can expand the scale of production by 200 extra cars by incurring a follow-up cost I_E. The opportunity to expand the initial project is similar to a call option and the opportunity to acquire an additional part paying the extra price. Hence, the project itself and the opportunity to expand can be viewed as the base-scale project plus a call option on the future investment: $V + \mathrm{Max}(V - I_E, 0)$.

2.3.3 The option to abandon a project

In a continuous changing and dynamic world, the future cash flows from a project cannot turn out as expected, even after a good and careful evaluation from managers. In these particular cases, managers have the option to reduce, suspend or even abandon the project (Dixit and Pindyck, 2004). If a production plant is having permanent losses, and the cost of abandoning the plant is lower than the losses the firm is going to face, than managers may abandon the project.

If *K* denotes the salvage value of the project, or the value that the firm gets by selling the project in the secondary market and *V* denotes the value of the project until the end of its life, managers may abandon or continue the project by comparing these two values. If the value of continuing the project until the end of its life *V* is higher than *K*, the firm should continue the operations. If the salvage value of selling the project to the secondary market *K* is higher, than the firm should abandon the project and sell it in order to reduce losses. Managers should continuously, throughout the project's life, make this kind of consideration. The pay-off of holding the option to abandon is equal to Max(0, K – V).

The option to abandon a project represents for the firm an American put option. A put option is "*an option contract giving the owner the right, but not the obligation, to sell a specified amount of an underlying security at a specified price within a specified time*" (www, Investopia, 2011). American put options have usually significant value in high volatile markets. For this reason, the option to abandon can add a remarkable value to the project evaluation today.

As it is shown in the examples presented in this section of the theoretical perspective, real options are common in the everyday life especially when considering the work of managers and their decision-making activities. The next section represents some applications of the real option approach in the energy and agricultural sector.

2.4 Literature review

In this thesis, a real option approach is used to investigate on the factors affecting the decision of agricultural firms to quit the production and rent out the land to a company investing in PV installations. Different authors used in the past the real option approach to evaluate decisions in the energy sector.

Auerswald and Leuthold (2009) use the real option method for the evaluation of investments in the energy sector. In their study, the authors investigate the German energy portfolio until 2030. Different scenarios are drawn considering a change in the subsidies, changes in the policy regarding nuclear energy or CO_2 price. Considering the uncertainty in the market and the irreversibility due to industry – specific investments, the real option approach is appropriate for examining and describing each scenario, determining the optimal timing of investing in every type of energy source the portfolio contains, as well as the time for switching from one to another and the time for abandoning a specific type of production.

Calabrese *et al.* (2005) use the real option approach to evaluate the investment in PV technology. According to their findings, the decision taken by top management to invest in a specific PV power plant must align with the objective of production flexibility. The company's investment in PV technology is a strategic and technological decision that affects its long-term choices. They identify that the key to the success of a firm is to limit its exposure to uncertainty. If there is a high level of uncertainty in the market, the firm can postpone the investment to collect information thereby limiting uncertainty.

The problem this thesis deals with relates to the work of Chakravorty *et al.* (2009). The authors do not use a real option approach, however they state clearly that there is a trade-off concerning land allocation between the production of renewable energies and the use of land for food production. In their study, the authors examine the use of land for the production of biomass energy versus food and the impact on product prices. The connection between biomass energy and food is direct since the US uses corn for the production of biomass and Brazil uses sugar cane. According to The Economist (2007), when the production of ethanol and biodiesel grew rapidly between 2004 and 2007 a high increase in the price of products like corn and wheat was registered in the market (Chakravorty *et al.*, 2009). This rapid increase in prices occurred because of the land allocation decision that resulted in these products being destined for the production of energy instead of agriculture.

A real option model similar to the one used in this thesis is presented by Isik and Yang (2004). In their paper "An analysis of the effects of uncertainty and irreversibility on farmer participation in the Conservation Reserve Program" (CRP) the authors investigate on the possibility of the U.S. farmers to enrol in the CRP program signing a long life term contract with the U.S. Department of Agriculture. The land rental payment in the CRP program and the net revenues from agriculture are both expressed as stochastic in the study. The results stress the fact that uncertainty and irreversibility are determinant factors in the farmers' participation in the CRP program.

By following the work done by Chakravorty *et al*. (2009), and Isik and Yang (2004), the aim of this thesis is to investigate on the opportunity of agricultural firms to enter in a long-time PV rent contract under uncertainty using a real option approach.

2.5 Real option model

The real option model introduced in this section has two important characteristics. First, the agricultural firm's decision is assumed irreversible, in the sense that once it is undertaken, it cannot be undone (Dixit and Pindyck, 1994). Second, the firm can delay the decision in time and have the opportunity for new information regarding the prices, market trends, and costs (*ibid*).

The purpose of this section is the development of a decision making model to investigate the factors affecting the decision of an agricultural firm or landowner between choosing to rent out the land to a company investing in PV installations or continue the agricultural production. The rent offered by the company investing in PV installations is denoted by q and is constant. The net revenues from agricultural production per hectare are denoted by Π and are uncertain due to uncertainty about output prices. These net revenues are assumed to evolve according the following stochastic process represented by the *geometric Brownian motion*:

$$d\Pi = \alpha\Pi dt + \sigma\Pi dz_t \qquad (2.5.1)$$

where α and σ are drift and volatility, and dz is the increment of a Wiener process[3].

The current value of the project is known, while changes in the prices are lognormally distributed. The assumption $\alpha < \rho$ (where ρ is the discount rate) must be made, otherwise the integral in equation (2.5.1) could be made indefinitely larger by choosing a larger T (Dixit and

---

[3] The Weiner process is a stochastic process continuous in time that has three important characteristics. In first place, it satisfies the *Markov property* (Dixit and Pindyck, 1994). The future values of the process depend on the current value of the state variable. Second, the Wiener process is associated with *independent increments*. According to this property, the probability distributions are independent for different time intervals. Third, the changes in the different finite intervals of the process are *normally distributed* and the variance increases linearly with the time interval (*ibid*).

Pindyck, 1994). In addition, if the drift from agricultural net revenues is greater than the discount rate ρ implies that it is more profitable for the firm to continue the agricultural production.

A firm's opportunity to quit the agricultural production and rent the land is similar to an American put option. The firm has the right but not the obligation to exercise the option. The present value of the rental payment received over the contract duration T is equal to:

$$R(q) = \int_0^T q e^{-\rho t} dt = \frac{q(1-e^{-\rho T})}{\rho} \tag{2.5.2}$$

where ρ represents the discount rate.

By renting out the land, the agricultural firm has a missed income represented by the agricultural net revenues. The expected present value of the foregone agricultural net revenues Π evolve stochastically and is expressed by:

$$C(\Pi) = E\int_0^T \Pi e^{-\rho t} dt = \int_0^T E(\Pi) e^{-\rho t} dt \tag{2.5.3}$$

The expected value of the agricultural net revenues which motion is given by equation (2.5.1) is:

$$E[d\Pi] = E[\alpha \Pi dt + \sigma \Pi dz_t] \tag{2.5.4}$$

$$E[d\Pi] = \alpha \Pi dt + \sigma \Pi E[dz_t] \tag{2.5.5}$$

since $dz_t = \varepsilon_t \sqrt{dt}$ and $\varepsilon_t \approx N(0,1)$, the expected value of εt is $E[\varepsilon_t] = 0$

The starting value $\Pi_0 = \Pi$

The expected value of $d\Pi$ is specified as:

$$E[d\Pi] = \alpha \Pi dt \tag{2.5.6}$$

The expected present value of the agricultural net revenues is:

$$E[\Pi_t] = \Pi_t e^{\alpha t} \tag{2.5.7}$$

$$C(\Pi) = \int_0^T \Pi e^{\alpha t} e^{-\rho t} dt = \Pi \int_0^T e^{-(\rho-\alpha)t} dt \tag{2.5.8}$$

$$C(\Pi) = E\left[\int_0^T \Pi_t e^{-\rho T} dt\right] = E\left[\int_0^T e^{-(\rho-\alpha)T} dt\right] \tag{2.5.9}$$

$$C(\Pi) = \frac{\Pi(1-e^{-(\rho-\alpha)T})}{\rho-\alpha} \tag{2.5.10}$$

The pay-off for the agricultural firm quitting the production and renting out the land to a company investing in a PV power plant is equal to:

$$B(\Pi) = q\left(\frac{1-e^{-\rho T}}{\rho}\right) - \Pi\left(\frac{1-e^{-(\rho-\alpha)T}}{\rho-\alpha}\right) - K \tag{2.5.11}$$

where *K* denotes the initial cost the agricultural firm has to pay in order to switch from agricultural production and rent out the land. This switching cost is an agency cost including the transaction costs that may occur in finding the counterpart and the financial consulting services the agricultural firm may need in order to decide the profitability of its decisions. Other costs such as insurance and maintenance are on behalf of the company renting the land. The strike price of the option is then given by the expected present value of the foregone agricultural net revenues and the initial switching cost.

Hence, it is supposed that in order for the agricultural firm to quit the production and rent out the land, equation (2.5.11) should be positive. The present value of the expected rental payments should be greater than the expected present value of the agricultural net revenues plus the initial costs.

$$q\left(\frac{1-e^{-\rho T}}{\rho}\right) - \Pi\left(\frac{1-e^{-(\rho-\alpha)T}}{\rho-\alpha}\right) - K \geq 0 \tag{2.5.12}$$

$$q\left(\frac{1-e^{-\rho T}}{\rho}\right) - K \geq \Pi\left(\frac{1-e^{-(\rho-\alpha)T}}{\rho-\alpha}\right) \tag{2.5.13}$$

The firm holding the option to quit the production and rent out the land to a PV investor maximizes the value of the decision opportunity. The pay-off is given by the difference between the value of the project and the foregone agricultural net revenues. The opportunity to quit the production and rent out the land to a PV investor $F(\Pi)$ yields no cash flows until the switching point. Since the decision opportunity does not yield cash flows, the only return from holding the option must be equal to its capital appreciation. The Bellman equation below shows this expected value:

$$F(\Pi) = \frac{E[F(\Pi + d\Pi)]}{1+\rho dt} \tag{2.5.14}$$

$$F(\Pi)(1+\rho dt) = E\left[F(\Pi + d\Pi)\right] \quad (2.5.15)$$

$$F(\Pi) + \rho F(\Pi)dt = E\left[F(\Pi + d\Pi)\right] \quad (2.5.16)$$

since E[F(V)] = F(V)

$$\rho F(\Pi)dt = E\left[F(\Pi + d\Pi)\right] - E\left[F(\Pi)\right] \quad (2.5.17)$$

$$\rho F(\Pi)dt = E\left[dF(\Pi)\right] \quad (2.5.18)$$

According to equation (2.5.18), the return of the opportunity to quit the production and rent out the land $\rho F(\Pi)dt$ for a time interval dt is equal to the capital gain (Dixit and Pindyck, 1994). In other words, the value $\rho F(\Pi)dt$ represents the value that the firm gets by quitting the production, renting out the land and investing the value of the new venture received at an interest rate equal to ρ. The firm should keep the option until the value it gets by investing the venture at an interest rate equal to ρ is lower than the value of the option to switch.

The function *dF* can be expanded using Ito's Lemma:

$$dF(\Pi) = F'(\Pi)d\Pi + \frac{1}{2}F''(\Pi)(d\Pi)^2 \quad (2.5.19)$$

Using equation (2.5.1) it follows that:

$$(d\Pi)^2 = (\alpha\Pi dt + \sigma\Pi dz_t)^2 = \alpha^2\Pi^2(dt)^2 + \sigma^2\Pi^2(dz_t)^2 + 2\alpha\Pi^2 dt\sigma dz_t \quad (2.5.20)$$

since $dz_t = \varepsilon_t\sqrt{dt}$

$$(d\Pi)^2 = \alpha^2\Pi^2(dt)^2 + \sigma^2\Pi^2{\varepsilon_t}^2 dt + 2\alpha\Pi^2\sigma\varepsilon_t(dt)^{3/2} \quad (2.5.21)$$

for a very small *dt*, this factor at a power greater than one will be almost equal to zero disappearing from the equation above.

$$(d\Pi)^2 = \sigma^2\Pi^2{\varepsilon_t}^2 dt \quad (2.5.22)$$

Substituting the expected value of the *geometric Brownian motion* in the Ito's Lemma, we obtain:

$$E\left[dF(\Pi)\right] = F'(\Pi)\alpha\Pi dt + \frac{1}{2}F''(\Pi)\sigma^2\Pi^2 dt \quad (2.5.23)$$

since $E(d\Pi)^2 = \sigma^2\Pi^2 dt$ and $E(d\Pi) = \alpha\Pi dt$

equalizing equation (2.5.23) with $\rho F(\Pi)dt$ found above (2.5.18):

$$\rho F(\Pi)dt = F'(\Pi)\alpha\Pi dt + \frac{1}{2}F''(\Pi)\sigma^2\Pi^2 dt \tag{2.5.24}$$

Dividing by *dt*, the Bellman equation becomes:

$$\frac{1}{2}\sigma^2\Pi^2 F''(\Pi) + \alpha\Pi F'(\Pi) - \rho F(\Pi) = 0 \tag{2.5.25}$$

Equation (2.5.25) is a second order differential equation, which must satisfy the following boundary conditions:

1. $\lim_{\Pi\to\infty} F(\Pi) = 0$
2. $F(\Pi^*) = R(q) - C(\Pi) - K$
3. $F'(\Pi^*) = -C'(\Pi)$

Condition 1 specifies that when the profit from agricultural production increases, it is less profitable for the agricultural firm to switch. The value of the option to quit the agricultural production and rent out the land, $F(\Pi)$ will be equal to zero since the profits from agricultural products increase significantly.

Condition 2 represents the value-matching condition saying that upon the opportunity to quit the production, the agricultural firm gets as net pay-off the difference between the rental payments received, the foregone agricultural net revenues, and the initial cost it has to pay.

Condition 3 is the "smooth-pasting condition" proving that the function $F(\Pi)$ is continuous and smooth at the critical exercise point Π^*. Otherwise the agricultural firm could do better by exercising at a different point.

In order to satisfy the boundary conditions, the solution must take the form of:

$$F(\Pi) = A\Pi^\beta \tag{2.5.26}$$

where A is a constant and β depends on the parameters α, σ, and ρ. To calculate A and β:

$$F'(\Pi) = A\beta\Pi^{\beta-1} \tag{2.5.27}$$

and

$$F''(\Pi) = A\beta(\beta-1)\Pi^{\beta-2} \tag{2.5.28}$$

Substituting equations (2.5.26), (2.5.27) and (2.5.28) in the Bellman equation above (2.5.25):

$$\frac{1}{2}\sigma^2\Pi^2 A\beta(\beta-1)\Pi^{(\beta-2)} + \alpha\Pi A\beta\Pi^{(\beta-1)} - \rho A\Pi^{\beta} = 0 \qquad (2.5.29)$$

$$\frac{1}{2}\sigma^2\Pi^{\beta} A\beta(\beta-1) + \alpha\Pi^{\beta} A\beta - \rho A\Pi^{\beta} = 0 \qquad (2.5.30)$$

Hence, by simplifying and dividing by $A\Pi^{\beta}$ the following second order equation is obtained:

$$\frac{1}{2}\sigma^2\beta^2 + (\alpha - \frac{1}{2}\sigma^2)\beta - \rho = 0 \qquad (2.5.31)$$

This equation has two roots identified as:

$$\beta_1 = \left(\frac{1}{2} - \frac{\alpha}{\sigma^2}\right) + \sqrt{\left(\frac{1}{2} - \frac{\alpha}{\sigma^2}\right)^2 + \frac{2\rho}{\sigma^2}} \qquad (2.5.32)$$

and

$$\beta_2 = \left(\frac{1}{2} - \frac{\alpha}{\sigma^2}\right) - \sqrt{\left(\frac{1}{2} - \frac{\alpha}{\sigma^2}\right)^2 + \frac{2\rho}{\sigma^2}} \qquad (2.5.33)$$

The general solution of the equation (2.5.25) takes the following form:

$$F(\Pi) = A_1\Pi^{\beta_1} + A_2\Pi^{\beta_2} \qquad (2.5.34)$$

As it is shown in the equation representing the betas, β_1 is positive since the value in the square root is positive and bigger than the value outside, while β_2 is negative for the opposite reason.

If the pay-offs from agricultural products Π grow, then Π^{β_1} increases since β_1 is positive. This means that the value of the option $F(\Pi)$ grows. This parameter does not fulfil the first boundary condition since if the pay-offs from agricultural products grow; the agricultural firm never switches from agricultural production to PV. For this reason, the first term is deleted by setting A_1 equal to zero. A growth in the profits from agricultural production will bring a decrease in Π^{β_2} since β_2 is smaller than zero. The solution of the equation is:

$$F(\Pi) = A_2\Pi^{\beta_2} \qquad (2.5.35)$$

The equation above satisfies the first boundary condition. This means that if Π goes to infinity, the value of the option will be equal to zero since it will be more profitable for the farmer to continue the agricultural production. In addition, the value matching and "smooth-pasting" conditions must be hold according to the second and third condition:

$$\begin{cases} A_2\Pi^{*\beta_2} = q\left(\frac{1-e^{-\rho T}}{\rho}\right) - \Pi^*\left(\frac{1-e^{-(\rho-\alpha)T}}{\rho-\alpha}\right) - K \\ \beta_2 A_2 \Pi^{*(\beta_2-1)} = -\left(\frac{1-e^{-(\rho-\alpha)T}}{\rho-\alpha}\right) \end{cases} \tag{2.5.36}$$

Hence, from the second equation,

$$A_2\Pi^{*\beta_2} = -\left(\frac{1-e^{-(\rho-\alpha)T}}{\rho-\alpha}\right)\frac{\Pi^*}{\beta_2} \tag{2.5.37}$$

By substituting this to the first equation, we obtain:

$$-\left(\frac{1-e^{-(\rho-\alpha)T}}{\rho-\alpha}\right)\frac{\Pi^*}{\beta_2} = q\left(\frac{1-e^{-\rho T}}{\rho}\right) - \Pi^*\left(\frac{1-e^{-(\rho-\alpha)T}}{\rho-\alpha}\right) - K \tag{2.5.38}$$

The critical threshold Π^* is expressed by:

$$\Pi^* = \frac{\beta_2}{\beta_2 - 1}\,\frac{q\left(\frac{1-e^{-\rho T}}{\rho}\right) - K}{\left(\frac{1-e^{-(\rho-\alpha)T}}{\rho-\alpha}\right)} \tag{2.5.39}$$

The constant A_2 is equal to:

$$A_2\Pi^{*\beta_2} = q\left(\frac{1-e^{-\rho T}}{\rho}\right) - \Pi^*\left(\frac{1-e^{-(\rho-\alpha)T}}{\rho-\alpha}\right) - K \tag{2.5.40}$$

$$A_2 = \left[q\left(\frac{1-e^{-\rho T}}{\rho}\right) - \Pi^*\left(\frac{1-e^{-(\rho-\alpha)T}}{\rho-\alpha}\right) - K\right]\left[\frac{1}{\Pi^*}\right]^{\beta_2} \tag{2.5.41}$$

The value $F(\Pi)$ is:

$$F(\Pi) = \begin{cases} \left[q\left(\frac{1-e^{-\rho T}}{\rho}\right) - \Pi^*\left(\frac{1-e^{-(\rho-\alpha)T}}{\rho-\alpha}\right) - K\right]\left[\frac{\Pi}{\Pi^*}\right]^{\beta_2} & for \Pi > \Pi^* \\ q\left(\frac{1-e^{-\rho T}}{\rho}\right) - \Pi\left(\frac{1-e^{-(\rho-\alpha)T}}{\rho-\alpha}\right) - K & for \Pi \le \Pi^* \end{cases} \tag{2.5.42}$$

The critical threshold for the agricultural firm is presented by the value Π^*. If the agricultural net revenues are above this value, it is more profitable for the firm to continue the agricultural production. If the net revenues from agricultural production are below the critical threshold Π^*, it is more profitable for the agricultural firm to quit the production and rent out the land to a company investing in PV installations.

The switching point for the agricultural firm is presented by the point where the net revenues from agricultural production touch the critical threshold. By deciding to quit the production and rent out the land to a company investing in PV installations, the agricultural firm must pay an initial switching cost K. If K is high in value, then the switching point comes later. For lower initial costs K the switching point comes earlier and for lower Π values. Appendix 1 shows that the derivative of Π^* with respect to K is negative.

By renting out the land the agricultural firm receives a fixed annual rent denominated by q. The rent received for renting out the land, represents an income for the agricultural company and influences positively the decision to quit the production. If the company building a PV power plant offers a high amount of rent, then the critical threshold is higher and the switching point comes earlier. The derivative of Π^* with respect to q is positive and it is shown in Appendix 2.

The uncertainty in the market represented by the standard deviation σ influences negatively the decision of the agricultural firm to quit the production and rent out the land. If there is high uncertainty in the market, the firm waits until uncertainty is reduced. The uncertainty influences the income from agricultural production. If there is high uncertainty, the agricultural incomes Π may increase significantly in the future. For this reason, the critical threshold is higher and the switching point comes later for the agricultural firm. Appendix 3 shows that the derivative of Π^* with respect to σ^2 is negative.

The derivative of Π^* with respect to ρ is not monotonic. As shown in Appendix 4, this derivative will influence the option to invest positively for a range of parameters and negatively for the others. A numerical simulation is shown in section 6.3 to illustrate how a change in the discount rate influences the critical threshold.

Appendix 5 shows that the derivative of Π^* with respect to α is not monotonic. The parameter α represents the drift from the agricultural net revenues. The appendix shows that the derivative of the critical threshold with respect to the drift is ambiguous and depends on the other parameters.

The derivative of Π^* with respect to T, representing the duration of the PV contract, is also not monotonic. This is strongly connected to the value of flexibility. Given the fluctuations of the agricultural prices, it may be favourable to quit the agricultural production signing a contract with duration five years but not favourable to sign a contract of twenty years. The agricultural profits can increase dramatically in this period of time due to the drift and volatility while the quantity of rent-received q is constant. The decision to quit is irreversible and the agricultural firm looses the flexibility to switch again to agricultural production.

2.6 Time series

One of the most important types of data used in econometric analysis is time series data (Gujarati, 2004). Examples of time series are observations on the GDP (gross domestic product), observations on profits, dividends, and so on. Time series are stochastic processes of random variables ordered in time. An example of stochastic processes can for example be the GDP of a country in a determined time. The value the GDP takes depends on the economic and political climate of the country in that particular period.

Time series data can be of two types: stationary or non-stationary (Gujarati, 2004). "*A stochastic process is said to be stationary if its mean and variance are constant over time and the value of the covariance between the two time periods depends only on the distance, or gap, or lag between the two time periods and not the actual time at which the covariance is computed*" (*ibid*, p. 797). If a time series does not fulfil the above requirement, it is called a non-stationary time series or random walk model (RWM). A non-stationary time series is characterized by a mean or variance varying in time.

RWMs are important when researchers deal with observations on the stock prices or exchange rates. These observations do not follow a stationary stochastic process. If it were so, it would be predictable to forecast the stock prices and invest having huge profits. There are three types of RWMs: random walk without drift, when there is not the presence of a constant term, random walk with drift, when a constant is present, and random walk with drift and time trend (Gujarati, 2004).

The random walk without drift is represented by the following model:

$$Y_t = Y_{t-1} + u_t \tag{2.6.1}$$

where u_t represents the white noise error term with mean 0 and variance σ^2. According to this equation, the value of Y at time t is equal to the previous observation, time $(t\text{-}1)$ plus a random noise u_t.

The observation at any time t of the phenomenon Y will be equal to the first observation Y_0 plus the sum of the random noise u_t from each observation time.

$$Y_t = Y_0 + \sum_{i=1}^{t} u_t \qquad (2.6.2)$$

Hence, the expected value will be equal to:

$$E(Y_t) = E\left(Y_0 + \sum u_t\right) = Y_0 \qquad (2.6.3)$$

The mean of the phenomenon Y observed is constant, equal to the initial value of Y, while the variance increases indefinitely as the time observed t increases.

$$\operatorname{var}(Y_t) = t\sigma^2 \qquad (2.6.4)$$

As the variance is not constant but increases over time, it violates the conditions of stationary stochastic processes (Gujarati, 2004).

A random walk with drift follows the model above (Gujarati, 2004):

$$Y_t = \delta + Y_{t-1} + u_t \qquad (2.6.5)$$

where δ represents the drift parameter. Rewriting the equation in the following way

$$Y_t - Y_{t-1} = \Delta Y_t = \delta + u_t \qquad (2.6.6)$$

it can be seen that Y_t can have an upward drift if the parameter δ is positive and a downward drift in the presence of a negative δ. As for the random walk without drift, also in this case:

$$E(Y_t) = Y_0 + t\delta \qquad (2.6.7)$$

and the variance increases in time

$$\operatorname{var}(Y_t) = t\sigma^2 \qquad (2.6.8)$$

The increasing variance shows that the random walk with drift is a non-stationary stochastic process (Gujarati, 2004).

The random walk model is differently known in literature as a unit root process (Gujarati, 2004). If the RWM is written in the following way:

$$Y_t = \omega Y_{t-1} + u_t \tag{2.6.9}$$

where ω is within the interval: [-1;1], the model resembles the Markov first-order autoregressive model. In the case when $\omega=1$ the above equation becomes a RWM without drift. When ω is equal to one the time series have a unit root that is a confirmation of non-stationary time series since the RWM is non-stationary.

When the absolute value of ω is less than one, then the time series is said to be stationary.

2.7 The unit root test

The unit root test is a stochastic process with the form of equation (2.6.9). As illustrated above, if the value of $\omega = 1$, there is the presence of a unit root and the equation turns into a RWM without drift. Therefore, the series observed is not stationary since the variance increases over time. For this reason, a unit root test is a test that determines whether a time series is stationary or not (Gujarati, 2004).

Equation (2.6.9) can be written differently:

$$Y_t - Y_{t-1} = \omega Y_{t-1} - Y_{t-1} + u_t = (\omega - 1)Y_{t-1} + u_t \tag{2.7.1}$$

By denominating $\delta = (\omega - 1)$

$$\Delta Y_t = \delta Y_{t-1} + u_t \tag{2.7.2}$$

The null hypothesis that $\delta = 0$ is tested. If $\delta = 0$ than $\omega = 1$ and we are in the presence of a unit root. In this case, the time series is not stationary and has the form of a RWM. The equation (2.7.2) can be rewritten as:

$$\Delta Y_t = (Y_t - Y_{t-1}) = u_t \tag{2.7.3}$$

Equation (2.7.3) shows that the first differences in a random walk is stationary if $\delta = 0$. The unit root test can be made by taking the differences of Y_t and regress them on Y_{t-1}. If the slope coefficient of the regression is equal to zero, then $\rho = 1$, and we are in the presence of a unit root, hence the time series is not stationary. If it is negative, then Y_t is stationary.

In order to test the presence of a unit root in time series, Dickey and Fuller have shown that $\delta = 0$ follows a τ (tau) statistic. Using Monte Carlo simulations, the authors computed the critical values for the τ statistics for three different time series processes:

Random walk without drift:

$$\Delta Y_t = \delta Y_{t-1} + u_t \tag{2.7.4}$$

Random walk with drift:

$$\Delta Y_t = \beta_1 + \delta Y_{t-1} + u_t \tag{2.7.5}$$

Random walk with drift and time trend:

$$\Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + u_t \tag{2.7.6}$$

The error term u_t in the equations presented above is considered to be uncorrelated. In the case of correlated error terms, the *augmented Dickey-Fuller* (ADF) test is used. The test augments the three equations above by adding the lag values of the dependent variables ΔY. The regression of the test is presented by the equation:

$$\Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \sum_{i=1}^{m} \alpha_i \Delta Y_{t-i} + \varepsilon_t \tag{2.7.7}$$

where ε_t represents a white noise error. The idea of the test is to include enough lag terms so that the error term becomes serially uncorrelated. The ADF test as the above presented Dickey Fuller test tests the null hypothesis $\delta = 0$.

2.8 Monte Carlo Simulation

The Monte Carlo (MC) simulation is a stochastic technique that uses random numbers and probability statistics to integrate problems (www, University of Nebraska – Lincoln, 2011). The method was invented in the 1944 working on nuclear weapon projects (Kochanski, 2005). Soon the method was applied in other scientific fields such as mathematics, nuclear physics, chemistry and economics.

In the economic field, the MC simulations are used in finance as an instrument of evaluation for portfolios and investments. A simulation is "*a situation in which a particular set of conditions is created artificially in order to study or experience something that could exist in* *reality*" (www, Oxford Dictionary, 2011). The MC method uses a series of computational algorithms based on repeated random sampling to compute the simulations.

@Risk 5.5 is a computer software, which computes the MC simulations by attributing a fitting distribution to the time series observed and generating a number of extra observations (www, @Risk, 2011). The risk analysis performed by the program shows the possible assumptions telling also the probability of how likely they will occur. @Risk 5.5 is a valuable tool for decisions under uncertainty (*ibid*).

3 Method

The chapter starts with the general views on social research such as positivistic, constructivism and hermeneutics. Then the definition of study cases and different data collection techniques are presented. The following sections explain the reasons for choosing the type of technology, country, region and the real option approach. In the last section, the unit of analysis is explained.

3.1 Views on social research

The *positivistic* view on social research deals with positive facts and observable phenomena (Robson, 2002). According to this approach, the phenomena being observed are unique. They may depend on different factors such as time, location and culture, but they are totally independent and not influenced by the researcher. The researcher should conduct his research with objectivity keeping him and his opinions separate from the study. Important aspects of the positivistic view are the reliability and the validity of the study. This kind of research focuses mainly on quantitative research and measurable methods and data. The results should be complete and explain thoroughly the phenomena observed.

Constructivism "*flags a basic tenet of the approach, namely, that realty is socially constructed*" (Robson, 2002, p. 27). According to this view of research, the researcher has a high degree of interpretation on the study. It is differentially called "*interpretive*" or "*naturalistic*". In this type of research methods such as interviews and observations are used. By these types of data collection researchers acquire multiple observations regarding socially constructed contexts and interpret their results (*ibid*).

In *hermeneutics*, the researcher gives his own interpretation in order to investigate the way people perceive the world. This type of research deals with non-measurable units, which need the interpretation of the researcher in order to be understood (Robson, 2002). Uniqueness is the key factor here too, not in the sense of observed and measurable phenomena like in the *positivistic* view but in the sense of the individualistic point of view each person perceives the world and the various situations or cases. It is not possible in this view of research to be subjective and keep the author's point of view separated from the research. The research is constructed on the researcher’s interpretations of facts and the results should be understandable and thoroughly discussed in the study.

3.2 Case studies

In 1984 Yin defined a case study research method as “*an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used*” (Yin, 1984, p. 23). As it is shown from the definition above, the important points in a case study are:

- the *strategy* followed by the researcher, showing the method or approach;
- the *empirical* data, its validity and reliability;
- the *particularity* of the case and if it can be generalized;
- it must be focused on a *phenomenon in context*;
- and undertake *multiple methods*, points of view or data collection.

According to Bromley (1986), a case study can be conducted in different fields such as administration, anatomy, artificial intelligence, business, history, social work, psychiatry, sociology, etc. Important in a case study is the attention the researcher has to pay to matters of design, data collection, interpretation, and result presentation (Robson, 2002).

Conducting a case study the researcher must focus on a particular case or an isolated area and its empirical observations (Saunders *et al*., 2007). A case study focuses on the study of natural environments analyzing the phenomena into depth and using several research sources such as data collection, interviews, and questionnaires.

Yin (1994) defines a difference between a single case study, which is focused on a single phenomena and a *holistic* case study focused on global phenomena. According to Robson (2002), holistic case studies find a broad application in several fields where the critical case is taken as an example object of study.

3.3 Types of data collection

There are two types of data collection in a research: *quantitative* and *qualitative*.

The *quantitative* data collection involves the use of a large number of numerical observations for a particular phenomenon. The information can then be elaborated using statistical analysis, which is a precious tool for researches to classify and obtain significant information from the data (Saunders *et al.*, 2007).

Information can be numerical by nature, like the age of people, the temperature or the hours worked per day. Other data can be non-numerical by nature but they can be converted into numerical by researchers. For instance, student evaluations of a university course can be converted into a numerical survey by constructing a scale where the lowest value represents the case where the student did not like the course and the highest the opposite. The most used ways to collect the data concerning the *quantitative* data collection are surveys, tracking and experiments. According to Rosbson (2002), the data should have certain characteristics such as *validity, generizability, objectivity,* and *credibility*.

The *qualitative* data collection includes the collection from the researcher of any non-numerical information available that can be captured concerning the study. Different ways for obtaining qualitative data are interviews, direct observations and written documents (Saunders *et al.*, 2007).

Robson (2002) stresses that interviews can be both individual as well as group interviews. The data collected from the interviews can be collected in different ways such as audio recording, video recording or written notes. Interviews differ from direct observations because they assume the presence of a questionnaire prepared before hand and an interaction between the interviewer and the interviewee. The purpose of the interview is to investigate and collect the opinion of the interviewee on regarding the subject matter. In direct observations, the researcher does not interact actively with the respondent. Usually the same characteristics important from the research are viewed with the same way in a large number of respondents. Written documents include the secondary data for a research like published scientific articles, newspapers, magazines, books, annual reports, etc.

In this dissertation a mixed data collection type is used. The *quantitative* data collection is followed for the empirical study case. The data regarding the agricultural net revenues are obtained by the annual publications of average agricultural values “Valori Medi Agricoli”. All the values and parameters used in the study are introduced in the section unit of analysis in this chapter. The *qualitative* data collection is used to obtain the data concerning the rents offered to agricultural firms and the initial costs for the agricultural firms. The interviews were made with S.E.D.I Srl, a consulting company that deals with investments in PV installations. Several e-mail and personal interviews were conducted with Gessica Perini, technical consultant at the company.

3.4 Choice of the country and region

With the adoption of the European Directive 2001/77 EC, the Italian Department for Economic Development jointly with the Department of Environment and the State Regions Joint Conference guaranteed a set of subsidies and feed-in tariffs for PV installations with a power larger than 1 kW.

According to the document “Conto Energia III”, the feed in tariffs are recognized from the Italian government for all the PV installations for a period of 20 years. The tariffs recognized are divided into different categories depending on the type of installation (www, PVTECH, 2011). The different categories are the rooftop and the ground-based category. Rooftop installations are installed on the roof of homes, buildings or industrial sheds while ground-based installations are installed directly on the ground.

The feed in tariffs presented in “Conto Energia III” decrease every four months during 2011 since the costs in PV technology decreases over time and the new solar panels are much more effective because of improvements in technology.

According to PVTECH (2011), for investments in PV installations during the first four months of 2011, the feed-in tariffs for the production of energy with a capacity up to 5 MW will be cut by 9,3%, while for installations with a total capacity of more than 5 MW the tariffs are expected to be cut by 14,2%. The target of the country, introduced in “Conto Energia III”, is to reach the EU target presented in Directive 2001/77 EC, and produce at least a total of 17% of the total energy consumed by RES by 2020 (*ibid*).

The region of Emilia Romagna is one of the regions with the largest number of investments in PV plants (www, Aurora, 2011). The provinces with the greatest number of investments are Bologna, followed by Ravenna and Modena. The installations in Bologna were equal to 1421, generating 29.1 MW. For this reason, this case study focuses in the province of Bologna and mainly in five areas that have a part of the territory classified as plain landscape and a part classified as hill landscape. These five areas are: the hills of Bologna denoted as *Area 1*, the hills of Reno denoted as *Area 2*, Sillaro e Santerno denoted as *Area 3*, the plain on the right side of the Reno river denoted as *Area 4*, and the plain on the left side of the Reno river denoted as *Area 5*.

3.5 Choice of technology

The energy consumption in the EU is larger than the sources it can rely on (www, Eurostat, 2010). In addition, environmental problems such as global warming and acid rain can be attributed to the consumption of fossil fuel (*ibid*). For these reasons, the EU identified as a priority for the MS the investment in renewable energies.

Solar energy is clean and renewable (www, Assosolare, 2011). It brings different benefits like lowering the cost of electricity and the negative impact on the environment. In comparison to windmills and other types of renewable energies, PV cells once installed do not need continuous maintenance. PV installations require only an occasional cleaning in order for the cell to produce more energy.

The investment in PV power plants is considered very profitable and advantageous in Italy according to its geographical position and the yearly exposure to light and sun. The Ren Lab project conducted by the Polytechnic University of Milan identifies the agricultural sector as a leading sector for PV investments in Italy (www, Aurora, 2011).

3.6 Choice of the real option approach

The NPV method presents some limitations and disadvantages. In first place, the NPV approach is not flexible. It has a “now or never” approach considering only the opportunity to invest immediately and does not give the option to choose the timing of the investment. As such, the firm cannot consider the opportunity of delaying the investment, abandoning it, or stopping the project for a certain period. This method implies that the management must forecast precise cash flows of the investment. The forecast of the cash flows becomes more difficult when the cash flows are distant in time. In addition, the NPV method assumes that the discount rate does not change over time. In reality, the discount rate does change over time as the interest rate does (Groppelli and Nikbakht, 2006).

According to Dixit and Pindyck (1994), industry specific investments like those in PV technology may be considered irreversible. The incoming cash flows generated by investments are associated with a degree of uncertainty. The NPV method does not take into account the volatility of cash flows generated by future uncertainty, it rather assumes that the investment generates future rewards, which need to be identified by the managers and simply discounted for the period in which occur.

The real option approach considers the firm as an agent holding the option to invest (Dixit and Pindyck, 2004). It is similar to the financial options but since the underlying asset is a real asset, it is called a real option. The firm willing to invest in a new project is holding a call option. It has the right to exercise the option, although not an obligation to do so. A rise in the value of the underlying asset price corresponds a rise in the value of the option. Consequently, if the underlying asset decreases in value, the option value decreases. This approach is the most adapt to account for the irreversibility of the investment once undertaken and for the uncertainty on agricultural commodities prices.

3.7 The unit of analysis

The thesis focuses on the study of a particular area in the region of Emilia-Romagna in Italy. The factors affecting the decision making process of agricultural firms willing to quit the agricultural production and rent out the land to a company investing in PV installations is studied.

In order to focus on the particular area and have the study not affected by the influences and the connections that a particular firm may have with clients and suppliers, the average agricultural values “Valori Medi Agricoli” are used to evaluate the net revenues from agricultural production.

The average agricultural values are used in case of expropriation of an area outside a building. The allowance is determined on the basis of the agricultural value, taking into account the crop currently grown and the value of the land (www, Agenzia del Territorio, 2011). If the area is currently not cultivated, the compensation is accounted as a result of the average agricultural value for the type of crop prevalently grown and the value of the land. The average agricultural values are regulated by the Presidential Decree art. N. 327. 40 – 42 "Consolidation laws and regulations in mater of eminent domain (Text A)" of June 8th, 2001 and the law N. 865 art. 16 "Programs and coordination of public housing, rules on eminent domain" of October 22nd 1971(*ibid*). The average agricultural values are determined each year by January 31 by the Provincial Commission on Expropriations and the values are expressed in Euro per hectare. Since the average agricultural values expresses the value of the land and the crop cultivated in it, the net revenues from agricultural production are obtained by using a rate of 5% on the average agricultural values. The discount rate is decided following the rates on the Italian multi-year treasury bonds, BTP. The rates on 5 years bonds are equal to 3,83% and rates on 30 years bonds are equal to 5,08% (Ministero dell'Economia e delle Finanze, 2011). Considering the PV contract duration equal to 20 years, a discount rate of 5% is used.

The values are converted in Euro and deflated. Since the observations obtained were for a period of 23 years, a simulation with @Risk 5.5 was run in order to generate 100 observations. The ADF test showed that the time series is non-stationary and then the assumption of a *geometric Brownian motion* is justified.

The agricultural net revenues used for this research are those concerning arable lands since the yearly cultivation of these lands makes it possible to be more flexible to quit the production and rent out the land. In the case of other cultures such as olives, peaches or grapes, the agricultural firm is not as flexible. To rent out the land in this case, the firm has to support the cost of clearing and settling the land and other connected costs.

The rents offered by the firms investing in PV installations are obtained by interviews conducted at S.E.D.I Srl with Gessica Perini. S.E.D.I Srl is a consulting company operating in the region of Emilia-Romagna, which offers consulting and administrative services to agricultural firms regarding PV installations. The medium yearly rents offered were obtained through the interviews conducted. The yearly rents differ in relation to the landscape. The rents per hectare offered in plain landscapes amount to € 4800,00 per year while the rents per hectare offered in hill landscapes amount to € 2400,00 per year. The rent paid to the agricultural firm is constant for all the time of the contract.

In addition, an initial switching cost that the agricultural firm has to pay in the moment it decides to quit the production and rent out the land is assumed. This switching cost includes transaction costs due to the search of the counterpart and financial consulting services the agricultural firm may need in order to decide the profitability of its decision. This initial switching cost is considered as an agency cost and assumed equal to 10% on the yearly rent received. All the other costs such as contract registration, notary public, maintenance or insurance against weather conditions and vandalism acts are in charge of the company renting the land.

4 Background for the empirical study

This chapter illustrates the development of renewable energies and the support from the EU. Particular attention is paid to the PV technology and the development of the industry in Italy.

4.1 Renewable energies

"*We recognize the importance of renewable energy for sustainable development, diversification of energy supply, and preservation of the environment. We will ensure that renewable energy sources are adequately considered in our national plans and encourage others to do so as well. We encourage continuing research and investment in renewable energy technology, throughout the world*". Communication from the G8 Leaders' Summit, Genoa, July 2001 (www, Government of Canada, 2010).

Renewable energy is considered to have a range of benefits such as reducing GHG emissions, reducing air pollution, and increasing security of supply (European Environment Agency, 2008). According to EEA (2008), renewable energy has less environmental impact than fossil fuels. In addition, an increase in the market for renewable energy will bring social and economic benefits including employment, regional and local development opportunities and export opportunities (*ibid*).

The production of energy from renewable sources is growing in the EU. Renewable energy production grew from 4,4% of the total energy market in 1990 to 6,7% in 2005 (European Environment Agency, 2008). The energy share produced by RES continued growing as a result of the supporting policies in the EU and reached 8,4% in 2008 (European Commission, 2010). In percentage, the strongest growth came from wind and solar energy production. In 2006, wind power was the leader in the renewable energy sector representing 75% of the installed capacity excluding hydropower and biomass. The majority of growth occurred in Germany, Spain and Denmark, with a total of 74% of the installed wind turbines. PV technology experienced strong growth in Germany at a rate of approximately 89%. EEA (2008) states that within the EU the consumption of renewable energy varies from one MS to another. Sweden, Latvia and Finland are the leaders in the market with more than 25% while the UK, Luxembourg and Malta account for approximately 2% (*ibid*).

Several directives regarding the promotion of renewable energies have been formulated by the EC such as the Directive on the promotion of electricity from renewable energy sources (EC, 2001b) and the Directive on the promotion of bio-fuels (EC, 2003b). The new directive proposed by the Commission in January 2008, which sets a target of 20% of the energy produced in the EU by 2020 to come from renewable sources, leaves the choice to the MS for how they split the national target between heat and electricity (European Commission, 2001).

Supporting policies regarding renewable energy production have shown positive results so far. The wind energy and biomass markets grew in Denmark, as a result of a combination of tax incentives and subsidies in their favour (European Environment Agency, 2008). The sector grew significantly accounting for 16% of the total energy market in the country. Similarly, feed-in tariffs helped wind energy grow significantly in Germany and Sweden. The high state contributions for energy produced from biomass and waste saw the sectors grow considerably, accounting for 30% of the total energy market (*ibid*).

4.2 Photovoltaic technology

The fundamental part of PV technology is the solar cell (Harmon, 2000). The cells are made from two different layers of semiconducting materials usually called positive-type and negative-type semiconductors. The PV cells are connected together to form a PV module that directly converts the solar energy into direct current electricity. The electricity is then stored in a battery for later use. The PV technology can be grouped into grid-connected and standalone systems.

PV technology was developed in the late 1950s as a solution to provide continuous energy sources for satellites (Harmon, 2000). It is only in the mid 1970s that companies started to promote PV technology as a renewable source of energy for domestic use. The PV industry is concentrated mostly in the United States, Japan and Europe.

The grid-connected PV market in Europe is growing at roughly 40% (Myrzik and Calais, 2003). Subsidy programs and changes to energy laws in the EU and its MS (for example the 1000 Roofs Program in Germany) have supported the growth of this market. Because of this support, new developments in the PV market were seen over the last few years. Developments in the PV technology like the high frequency inductor cores have had an important impact in reducing the price and increasing the efficiency of the solar cells. Over the last years prices for PV grid-connections decreased by 50% while efficiency increased from 94 to 97%. Despite these improvements, decreasing production costs and increasing efficiency remain the current goals for producers of PV technology.

The cost of PV industry is measured in dollars-per-peak-watt ($/W), where the “peak watt” is considered as the power of full sunlight at sea level on a clear day (Harmon, 2000). In the end of the 1950s when PV technology was developed, the cost of production amounted to approximately $ 90/Wp. At the time commercialization began, in the half of the 1970s, the cost of producing solar cells was still very high, around $ 51/Wp, but as a result of a decrease in manufacturing costs and improvement in the module efficiency the cost of production has been lowered to approximately $ 3,50/Wp (*ibid*).

A firm investing in PV power systems must consider the life cycle cost (LCC) of the investment. The LCC costs include the system design and engineering, the installation labour and the operation and maintenance costs (O&M). The useful life of PV solar cells is usually estimated to be 30 years. According to Neij (1997), the O&M costs for PV power systems are between $ 0,02 and $ 0,1 cents/kWh. These costs account for environmental factors such as extreme temperatures but also other external factors such as vandalism. The most important cost in the PV technology is the cost of the battery, which lasts between five and nine years depending on the use (Harmon, 2000).

4.3 The development of PV in Italy

Germany is one of the European MS leaders in the PV industry (European Environment Agency, 2008). The feed in tariffs introduced by the government supported the investments in the sector. It is also interesting to highlight that Spain is the second country in Europe to move toward PV as a source of renewable energies (www, Aurora, 2011). In 2008 the number of PV power plants installed in Spain was higher than the one installed in Germany. The total quantity of energy produced in Spain the same year was equal to 2,6 GW while in Germany the energy produced by PV installations reached 1,3 GW. The European market represents the main market regarding the PV industry with approximately 80% of the worldwide power plants, and a total of 10 GW produced at the end of 2008. Predictions forecast the European market to lead the PV industry in the future since it was the first one to have started promoting the investments in the field and have a strong experience (*ibid*).

Due to the favourable geographical position and the incentives introduced by the Italian authorities, the PV industry is experiencing a rapid growth in Italy (www, Aurora, 2011). The residential area leads the Italian PV market in terms of investments. The industrial installations grew by 31% in 2008 but are still behind the residential installations.

In March 2009, the Milan Polytechnic University undertook the Ren Lab project (www, Aurora, 2011). The purpose of the project was to research the business opportunities in Italy regarding four main areas of renewable energies: photovoltaic, biomass, aeolian and hydroelectric. The project focused also on the particular geographical areas where it was more convenient to undertake these kinds of investments.

The Ren Lab project identified the agricultural areas as possible locations for PV installations and supported the investments in these areas since it would bring a strong increase in the PV market in Italy. Other areas of installation for PV power plants indicated from the project are the middle-size plants installed in shopping malls or industrial sheds. The residential market, which is the market leader in Italy, is forecasted to increase by an additional GW by 2020.

The region producing more power from PV installation is Puglia situated in the south of Italy. The region generates 12.5% of the national power produced from PV installations. The regions of Emilia-Romagna, Lombardy and Veneto have also a high number of installations in PV technology. In these three regions, 34% of all the national power plants are found (www, Aurora, 2011).

According to GSE, the state's renewable energy market operator, in the region of Emilia Romagna there are 7047 PV power plants, which generate a total of 104,4 MW. The amount of energy produced by installations in the agricultural field is considered to be equal to 10% of the total power produced. Bologna is the leading province with a number or PV installations equal to 1421, generating 29,1 MW. The provinces of Modena and Ravenna follow with a number of 1337 installations for a total power produced of 14 MW and 940 installations for a power of 11.3 MW respectively (Regione Emilia-Romagna, 2011).

5 The empirical study

In this chapter, the empirical findings are presented. The first section introduces the factors affecting the decision of the agricultural firm to quit the agricultural production and rent out the land to a company investing in PV installations. The second section presents the agricultural net revenues. In the third section, the results from the data elaboration are illustrated.

5.1 Factors affecting the decision to rent out the land

The empirical application of the theoretical framework focuses on the factors affecting the agricultural firms' decision under uncertainty and irreversibility. There are several factors which influences the decision of quitting the agricultural production:

- The rent contracts for PV installations have usually a duration of twenty to twenty five years (Pers. Com., Perini, 2011). The PV contract time T considered in this study case is equal to 20 years. The decision of the agricultural firm to quit the production and rent out the land is assumed irreversible. Once the decision is made, it cannot be undone and implies that the firm cannot change the use of the land for the entire duration of the contract.
- The agricultural net revenues Π are calculated on the basis of the average agricultural values available on a yearly basis from the Region of Emilia-Romagna. For this dissertation, the data from 1988 to 2010 are used. The case study focuses on five particular areas in the province of Bologna. For the sake of simplicity, only arable lands are considered for the study. The choice of arable lands was made as a result of their yearly productivity and rotation culture. In case of other crops such as apples or grapes, an additional cost of clearing and settling of the land from the trees must be considered.
- The yearly rent q offered to agricultural firms for investments in PV installations was obtained from the interviews conducted at S.E.D.I Srl. From the interviews, the average yearly rent per hectare offered is equal to € 4.800,00 for plain landscapes and € 2.400,00 for hill landscapes (Pers. Com., Perini, 2011).

- The initial switching cost *K* assumed in the case study is an agency cost sustained from the agricultural firm quitting the agricultural production and renting the land for PV solar panels. The cost does not include costs such as notary public, contract registration, insurance against weather conditions and vandalism acts or maintenance. All these costs are on behalf of the company investing in PV installations. The agency costs the agricultural firm must sustain as initial costs include the transaction costs for finding the counterpart and financial consulting regarding the decisions. These costs are expressed as a percentage of the annual rent. An agency cost equal to 10% on the annual rent is used for the study case. In chapter 6, different scenarios with different initial costs and their influence on the decision to invest are shown.
- A discount rate equal to 5% is considered for the study case. In the sixth chapter, a simulation regarding a change in the discount rate is illustrated in order to show in how the discount rate affects the choice of the agricultural firm.
- No tax effects are considered in the study case.

All the values regarding the agricultural net revenues, yearly rents, and initial switching costs are deflated in 1988.

5.2 Agricultural net revenues Π

The agricultural net revenues presented in this section are obtained by the average agricultural values published on a yearly basis by the Region of Emilia-Romagna. The values take into account the value of the land and the crop cultivated on it (www, Agenzia del Territorio, 2011). The average agricultural net revenues per hectare are obtained by applying a rate of 5% on the deflated average agricultural values.

The province of Bologna, which is situated in the region of Emilia-Romagna in the northeast of the Italian peninsula, has been chosen for this case study. The thesis focuses on the province of Bologna since it is the province where it was invested the most in PV installations (Regione Emilia-Romagna, 2011). The case study is conducted in five main areas or territorial divisions within the province.

The peculiarity of these areas is that part of their landscape is classified as plain while part is classified as hill. Conducting the study in these five areas, the purpose is also to emphasize the differences of the decision to quit the production concerning the landscape. These differences come as a result of the disparity of net revenues in plain landscapes and those in hill landscapes. Since the net revenues in plain landscapes are higher than those in hill landscapes (www, Agenzia del Territorio, 2011), it follows that the rents offered for land areas in plain landscapes should be higher than those in hills.

The five areas studied are part of the province of Bologna and are presented in Table 1.

Table 1. Areas

Area 1	**Hills of Bologna**
Area 2	**Hills of Reno river**
Area 3	**Siluro e Santerno**
Area 4	**Plain on the left side of the Reno river**
Area 5	**Plain on the right side of the Reno river**

The agricultural net revenues for arable lands differ depending on the landscape but also in relation to the area the firm is situated. As mentioned before, for reasons of simplicity and practicality connected to additional costs including clearing and settling the land, only arable lands are chosen for the study case.

The time series are made up of 23 observations for the period from 1988 to 2010. Different time series concerning the agricultural net revenues in arable lands are obtained for each and every area object of the study case. In addition, the time series differ considering the landscape.

Five different time series denominated Area 1 to Area 5 are presented in Table 2. The time series have been deflated back in 1988 and show the agricultural net revenues per hectare in plain landscapes. The yearly inflation rates are obtained by the Italian National Institute of Statistics (www, ISTAT, 2011). An interest rate of 5% is used in order to calculate the yearly agricultural pay-offs per hectare. The table illustrates that there is an upward tendency of the agricultural net revenues through the years. The net revenues in Area 1 plain landscapes increase from € 589,67 per hectare in year 1988 to € 844,98 in 2010.

Table 2. Agricultural net revenues in plain landscapes (€/hectare deflated in 1988)

	Area 1	**Area 2**	**Area 3**	**Area 4**	**Area 5**
1988	589.67	442.26	491.40	540.54	565.11
1989	600.95	416.05	508.50	531.61	647.18
1990	716.20	520.87	542.57	607.68	651.09
1991	673.12	489.54	509.94	571.13	611.92
1992	639.24	464.90	484.27	542.38	581.13
1993	611.13	444.46	462.97	518.53	555.57
1994	587.06	426.95	444.74	498.11	533.69
1995	558.04	405.85	422.76	473.49	507.31
1996	553.37	423.16	439.44	488.27	520.82
1997	542.52	414.87	430.82	478.69	510.60
1998	531.88	406.73	422.38	469.31	500.59
1999	522.99	399.93	415.31	461.46	492.22
2000	600.27	450.21	480.23	525.24	570.25
2001	729.91	525.53	569.33	613.12	671.51
2002	741.81	557.04	557.04	598.41	714.23
2003	832.40	644.44	644.44	671.29	805.54
2004	840.75	683.11	683.11	709.38	840.75
2005	927.30	721.23	746.99	746.99	875.78
2006	908.23	706.40	731.63	731.63	857.77
2007	893.04	669.78	719.40	694.59	818.62
2008	864.52	648.39	696.41	672.40	792.47
2009	857.65	643.24	690.89	667.06	786.18
2010	844.98	633.73	680.68	657.21	774.56

The first analysis to make when considering a time series is plotting the data into a chart (Gujarati, 2004). The drift from agricultural net revenues in plain landscapes is shown in Chart 1. The graph illustrates that the time series is growing in value. The net revenues have a general downward trend for 12 years and nearly upward trend for 10 years where the period between 1998-1999 appears to be the critical point.

In addition, Appendix 8 shows the Charts of the time series separately. The charts were generated with the statistical program R. From the charts it can be seen that the data are non-stationary and the agricultural net revenues are increasing in value.

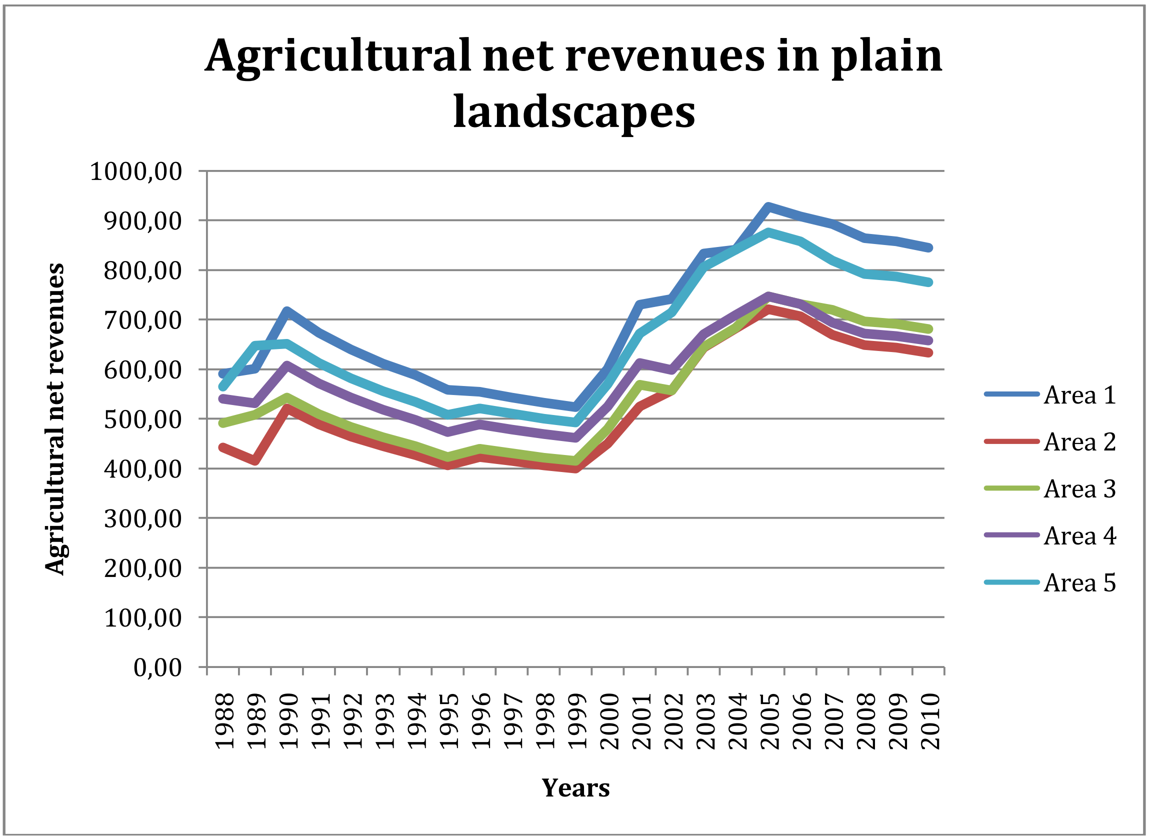

Chart 1. Agricultural net revenues in plain landscapes

During the years 1988 – 1999, the trend is negative and the agricultural net revenues per hectare are decreasing. The reason of this decrease is because the net revenues are deflated in values of year 1988. The net revenues were almost constant during these years and the high inflation rates reduced the values. Appendix 7 shows the inflation rates from year 1988 to 2010. A positive drift is noted from year 2000 to 2005. During these years, the agricultural net revenues were increasing and the inflation rates were low. In the last period observed, the years 2006 – 2010 the agricultural net revenues obtained from the average agricultural values were constant and because of the inflation rates, they have a negative trend.

The agricultural net revenues per hectare in hill landscapes are presented in Table 3. As for the observations in plain landscapes, the time series concerning the five areas object of the study include yearly observations from year 1988 to 2010. The values are deflated back in year 1988. An interest rate of 5% is used in order to obtain the agricultural pay-offs per hectare in hill landscapes.

Table 3. Agricultural net revenues in hill landscapes (€/hectare deflated in 1988)

	Area 1	Area 2	Area 3	Area 4	Area 5
1988	442.26	343.98	343.98	393.12	442.26
1989	439.16	323.59	323.59	416.05	416.05
1990	434.06	347.25	347.25	434.06	434.06
1991	407.95	326.36	326.36	407.95	407.95
1992	387.42	309.93	309.93	387.42	387.42
1993	370.38	296.30	296.30	370.38	370.38
1994	355.79	284.63	284.63	355.79	355.79
1995	338.21	270.56	270.56	338.21	338.21
1996	358.06	292.96	292.96	358.06	358.06
1997	351.04	287.22	287.22	351.04	351.04
1998	344.16	281.58	281.58	344.16	344.16
1999	338.40	276.88	276.88	338.40	338.40
2000	375.16	330.15	330.15	375.16	420.20
2001	452.54	394.15	394.15	437.94	481.74
2002	471.56	386.07	386.07	427.44	471.56
2003	537.03	429.62	429.62	483.33	590.73
2004	525.47	420.38	420.38	472.92	578.02
2005	566.68	463.65	450.77	515.17	618.20
2006	555.03	454.11	441.50	504.57	605.48
2007	545.75	446.52	434.12	496.14	570.56
2008	528.31	432.26	420.25	480.29	552.33
2009	524.12	428.83	416.92	476.47	547.95
2010	516.38	422.49	410.75	469.43	539.85

Table 3 illustrates that the agricultural net revenues in hill landscape increased from year 1988 to 2010. The net revenues for Area 1 hill landscapes increased from € 442,26 in year 1988 to € 516,38 in 2010. This increase is in the agricultural net revenues itself and the inflation rate does not play any role since the time series is deflated in 1988.

Chart 2 represents the agricultural net revenues in hill landscapes for the five areas observed. The general trend of the time series is positive and the net revenues per hectare are increasing in value. However, in some periods the drift is negative.

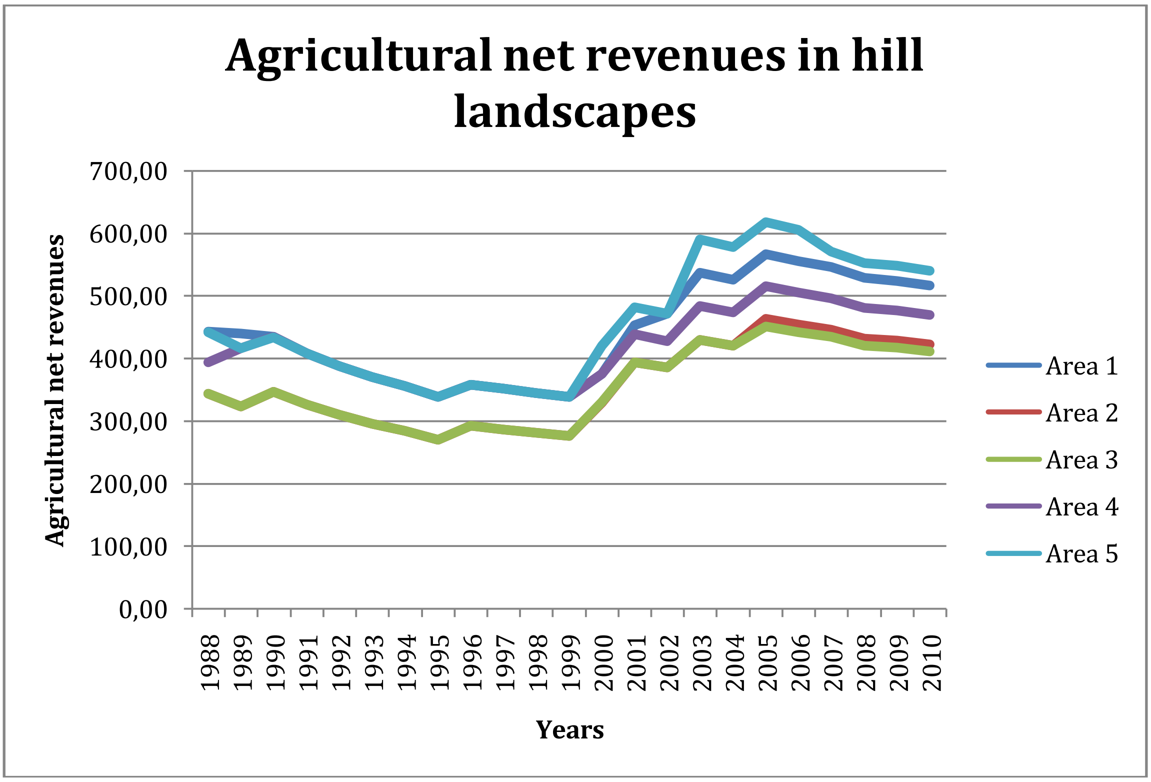

Chart 2. Agricultural net revenues in hills landscapes

The agricultural net revenues in hill landscapes follow the same pattern as the ones in plain landscapes but the net revenues per hectare are lower. The greatest increase is registered from year 2000 to 2006, while for the coming years the agricultural net revenues are constant and the deflation reduces the net revenues per hectare.

5.3 Unit root test, drift and volatility

Since the time series used for this study were composed by only 23 observations, a MC simulation was run in order to generate more observations for the time series. The MC simulation technique generates additional observations to the time series by attributing a distribution, which fit to the input data (www, @Risk, 2011). The program was run and 100 observations were generated for all the time series.

According to the real option model presented in section 2.5, the agricultural net revenues follow the *geometric Brownian motion* in equation (2.5.1). Consequently, the time series presented in the Tables 2 and 3 should be non-stationary and follow a RWM (Dixit and Pindyck, 1994). To test if the time series is stationary or not a unit root test was conducted.

The ADF test introduced in section 2.7 was conducted with EViews, software used by researchers for data elaboration and statistical tests. Appendix 8 shows that the autocorrelation test for all the 10 time series is significant with a lag equal to 4. The ADF tests were conducted with EViews using a fixed lag of four. The results of the tests are presented in Table 4. The different columns represent the different areas studied. The results of the test regarding the time series from agricultural net revenues in plain landscapes are presented in green and bold, while the results of the tests regarding the time series of agricultural net revenues in hill landscapes are presented in red and italic.

Table 4. Dickey Fuller test

	Landscape	Area 1	Area 2	Area 3	Area 4	Area 5
t - Statistic	Plain	**-1.71**	**-2.11**	**-1.61**	**-1.66**	**-1.98**
	Hill	*-1.45*	*-1.32*	*-1.40*	*-1.45*	*-1.68*
p - Value	Plain	**0.41**	**0.24**	**0.46**	**0.43**	**0.29**
	Hill	*0.53*	*0.59*	*0.56*	*0.53*	*0.42*

The ADF test shows if the time series is stationary or not by testing the null hypothesis of the existence of a unit root, equation (2.7.7) (Gujarati, 2004). To test the null hypothesis, the *t*-statistic are calculated and compared against the critical values presented in Table 5.

The *t*-statistic reproduced by the ADF tests for the ten time series takes values from -1,32 to -2,11 under the null hypothesis of non-stationary time series. The critical level of 5% is -1,95, and hence the null hypothesis of non-stationary data is not rejected. The *t*-statistic is above the critical values for the areas 2 and 5 plain landscape, but still below the critical level of 10%.

Table 5. ADF critical values

Critical values for T level of significance			
Sample size	***0,01***	***0,05***	***0,10***
DF distribution			
25	-2,66	-1,95	-1,60
50	-2,62	-1,95	-1,61
100	2,60	1,95	1,61
t-distribution			
∞	-2,33	-1,65	-1,28

The ADF test shows that the p-values are high taking values from 0,24 to 0,59. The results show that the time series are non-stationary.

The drift and the volatility of the five areas observed regarding the landscape are shown in Table 6. As introduced before, the results regarding plain landscapes are presented in green and bold while the results presenting hill landscapes are presented in red and italic.

Table 6. Drift and volatility

	Landscape	Area 1	Area 2	Area 3	Area 4	Area 5
Drift	Plain	**0.006625**	**0.034243**	**0.006301**	**0.004484**	**0.006204**
	Hill	*0.007572*	*0.006352*	*0.004263*	*0.004675*	*0.05646*
Standard Deviation	Plain	**0.115404**	**0.263561**	**0.120460**	**0.101547**	**0.103214**
	Hill	*0.115947*	*0.113426*	*0.098086*	*0.081120*	*0.331962*

The drift is calculated with the following formula:

$$\alpha = \lambda + \frac{\sigma^2}{2} \qquad (5.3.1)$$

where λ is the average on the lognormally distributed agricultural net revenues and σ is the volatility.

The drift shows the general upward or downward tendency of the net revenues per hectare. As illustrated in Table 6, the drifts of the time series after the simulation are positive but very small in value. The only exception is made by Area 5, hill landscape. A drift higher than the discount rate ρ characterizes the area. This means that the net revenues from agricultural production grows at a rate higher than ρ. Since $\alpha > \rho$, it will not be convenient for the agricultural firms operating in this area to quit the agricultural production and rent out the land.

Uncertainty refers to the volatility or the variability of the agricultural net revenues. The variability includes both the upside and downside possibilities of the future incomings. To measure mathematically the volatility the standard deviation is used. "*The standard deviation is defined as the average amount by which scores in a distribution differ from the mean, ignoring the sign of the difference*" (www, Webstat, 2011).

Table 6 shows the standard deviation of the five areas object of the study. In some areas the standard deviation, expressing the volatility in the agricultural net revenues is around 8 to

12%. The volatility is particularly high in Area 2, plain landscapes, equal to 26,36% and Area 5, hill landscape equal to 33,2%.

Since a real option method is used for the study case, the volatility has a great impact on the agricultural firm’s decision to quit the agricultural production and rent out the land to a company investing in PV installations.

6 Analysis and discussion

This chapter tries to answer to the following questions:

- Does uncertainty in the agricultural net revenues play a role in the decision to switch and rent out the land?
- Considering the current agricultural net revenues, is it more profitable for an agricultural firm to hold on the production instead of renting out the land to a company building a PV power plant?
- To which extent is this choice sensitive to changes in the discount rate, in the PV contract duration and the initial switching cost?
- At which minimal rent are the agricultural firms willing to rent out the land considering the current agricultural net revenues?

The first section of this chapter shows the differences between the real option approach and the NPV method. The second section presents the critical thresholds concerning the agricultural net revenues for which the agricultural firms quit the agricultural production and rent out the land to a company investing in PV installation. The sections three, four and five illustrate different scenarios considering a change in the discount rate, in the PV contract duration, and in the initial switching cost. The last section shows the minimal rent a company investing in PV installations can offer to an agricultural firm in order to be more profitable for it to rent out the land considering the current agricultural net revenues obtained by the average agricultural values.

6.1 Real option versus NPV

In this section, the difference between the real option approach and the NPV method is shown. Table 7 illustrates the difference between the critical thresholds Π^{*} calculated using the real option approach and Π^{NPV} calculated by the NPV method.

The results presented in Table 7 demonstrate that the critical thresholds obtained by the NPV method, determining the switching point for the agricultural firm, are higher than the thresholds obtained by the real option approach. As a result, the agricultural firm quits the production and rents out the land earlier with the NPV method.

Table 7. Critical real option and NPV thresholds (€/hectare deflated in 1988)

	Landscape	Area 1	Area 2	Area 3	Area 4	Area 5
Π^*	Plain	**1548.05**	**896.13**	**1524.10**	**1620.98**	**1609.70**
	Hill	*771.73*	*779.14*	*819.55*	*864.41*	*325.05*
Π^{NPV}	Plain	**2113.53**	**1647.41**	**2119.41**	**2152.51**	**2121.15**
	Hill	*1048.20*	*1059.24*	*1078.28*	*1074.51*	*661.88*

Using the NPV method, the agricultural firm quits the production for higher agricultural net revenues because the critical thresholds are higher. On the contrary, the real option approach taking into account the uncertainty represented by the volatility in the net revenues requires from the agricultural firm to wait before quitting the production until the net revenues from agricultural production decreases to a lower value.

By equation (2.5.39), the real option critical threshold is equal to:

$$\Pi^* = \frac{\beta_2}{\beta_2 - 1}\Pi^{NPV} \tag{6.1.1}$$

Since the parameter β_2 is negative, the β_2 relationship is lower than 1. Equation (6.1.1) shows that the critical thresholds obtained using the real option approach will always be lower than the critical thresholds obtained with the NPV method. In addition, if the NPV method suggests that the option to switch is not profitable, it will never be profitable for the real option approach since it tells to the firm to wait and switch for lower critical thresholds.

Table 7 confirms the results above. For Area 1 plain landscape, using the NPV method of evaluation, agricultural firms quit the production and rent out the land when the agricultural net revenues touches or are lower than € 2113,53. For the same area and landscape, using the real option approach, the agricultural firms quit the production if agricultural pay-offs are equal or below € 1548,05. The difference equal to € 565,48 is supposed to cover the value of the flexibility of the option to switch. Once the firm switches the production, the decision is irreversible and it loses the flexibility. If the firm holds the option to switch, the option has a value and this value is presented by the difference between the critical thresholds obtained using the NPV method and the thresholds using the real option approach.

The different thresholds calculated with the two methods regarding the areas object of the study in plain landscapes is presented in Chart 3. The red bars represent the critical thresholds obtained with the NPV method, while the blue bars represent the thresholds obtained using the real option approach.

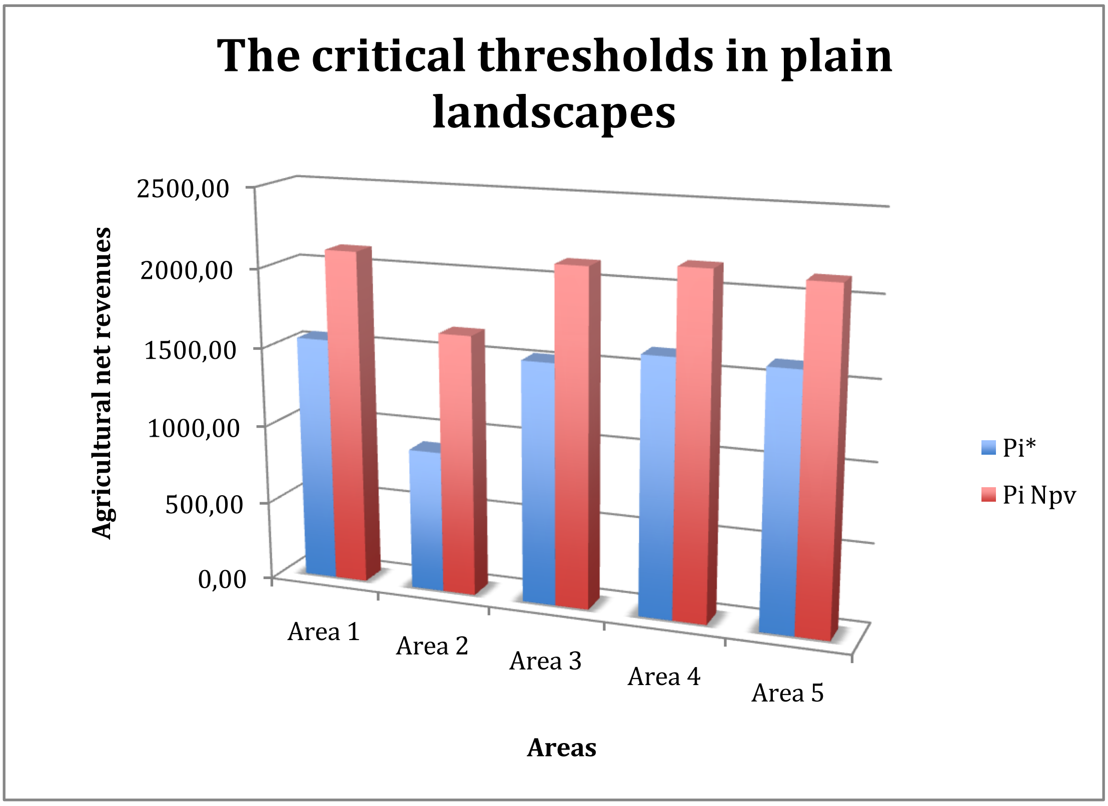

Chart 3. Real options and NPV thresholds in plain landscapes

The chart confirms graphically that the real options approach, taking into account the uncertainty regarding the agricultural net revenues, requires from the firm to wait until the net revenues get lower in value in order to quit the agricultural production. This difference represents the value of flexibility of the option to switch.

The chart demonstrates again the role of volatility. The gap between the thresholds calculated with the two methods is higher in Area 2, plain landscape. This area is characterized by a high volatility in the net revenues, equal to 26,36%. The gap decreases in the other areas as a result of the low volatility, around 10-12%.

Chart 4 shows the difference in the critical thresholds regarding the real option and NPV method in hill landscapes. The red bars represent the critical thresholds obtained by the NPV method, while the blue bars represent the thresholds obtained using the real option approach.

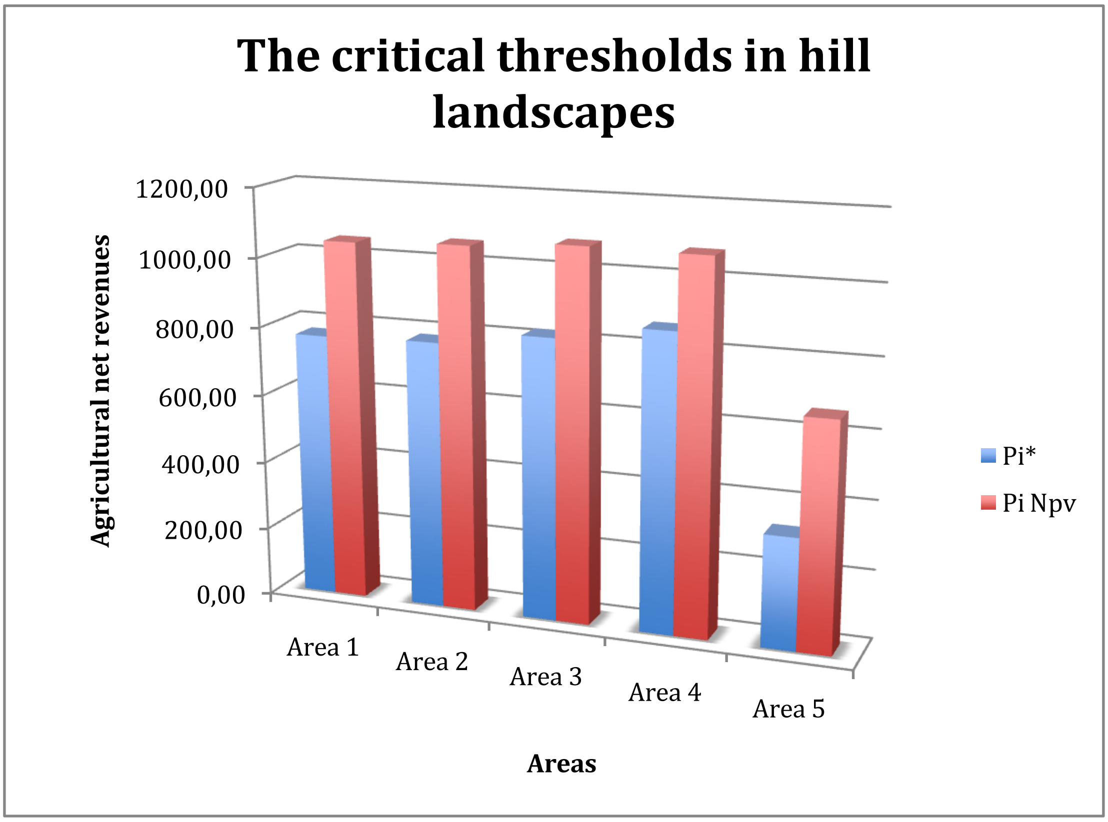

Chart 4. Real options and NPV thresholds in hill landscapes

Similar to the areas observed in plain landscapes, the critical thresholds obtained by the NPV method are higher in value in comparison to the critical threshold values obtained by the real option approach evidencing the value of the flexibility of the option to switch.

6.2 The critical threshold

The critical threshold Π^* represents the optimal value regarding the agricultural net revenues at which the agricultural firm quits the agricultural production and rents out the land to a company investing in PV installations. For agricultural net revenues above Π^* it is more convenient to continue the agricultural production. For agricultural pay-offs below Π^* it is more profitable for the agricultural firm to quit the agricultural production, rent out the land, and receive a fixed amount of rent denominated q.

According to the real option model presented in section 2.5, the critical threshold Π^* for which the agricultural firm is willing to quit the agricultural production and rent out the land is equal to:

$$\Pi^* = \frac{\beta_2}{\beta_2 - 1} \frac{q\left(\frac{1-e^{-\rho T}}{\rho}\right) - K}{\left(\frac{1-e^{-(\rho-\alpha)T}}{\rho-\alpha}\right)} \qquad (2.5.39)$$

Table 8 shows the agricultural net revenues Π per hectare obtained from the average agricultural values as for year 2010 deflated in year 1988 and the critical thresholds Π^* representing the switching point.

Table 8. Critical thresholds (€/hectare deflated in 1988)

	Landscape	Area 1	Area 2	Area 3	Area 4	Area 5
Π	Plain	**844.98**	**633.73**	**680.68**	**657.21**	**774.56**
	Hill	*516.38*	*422.49*	*410.75*	*469.43*	*539.85*
Π^*	Plain	**1548.05**	**896.13**	**1524.10**	**1620.98**	**1609.70**
	Hill	*771.73*	*779.14*	*819.55*	*864.41*	*325.05*

According to the average agricultural values 2010, the current agricultural net revenues per hectare for Area 1 in plain landscape are equal to € 844,98 while the critical threshold representing the switching point for the agricultural firm is equal to € 1548,05. Since the switching point is higher in value than the current agricultural net revenues, it is more profitable for agricultural firms to rent out the land to a company investing in PV installations rather than continue the agricultural production.

According to these values, it is profitable for agricultural firms situated in the five areas to quit the production and rent out the land since the rents offered for PV installations are more profitable then the agricultural production. The same results are obtained for all the areas, except for Area 5, hill landscape, where as a result of the high drift, larger than the discount rate and the high volatility, equal to 33,2%, it is not convenient to switch the agricultural production and rent out the land.

Chart 5 presents the agricultural pay-offs per hectare in plain landscapes from year 2010 deflated in 1988 denoted by the blue bars and the critical thresholds Π^* denoted by the red bars.

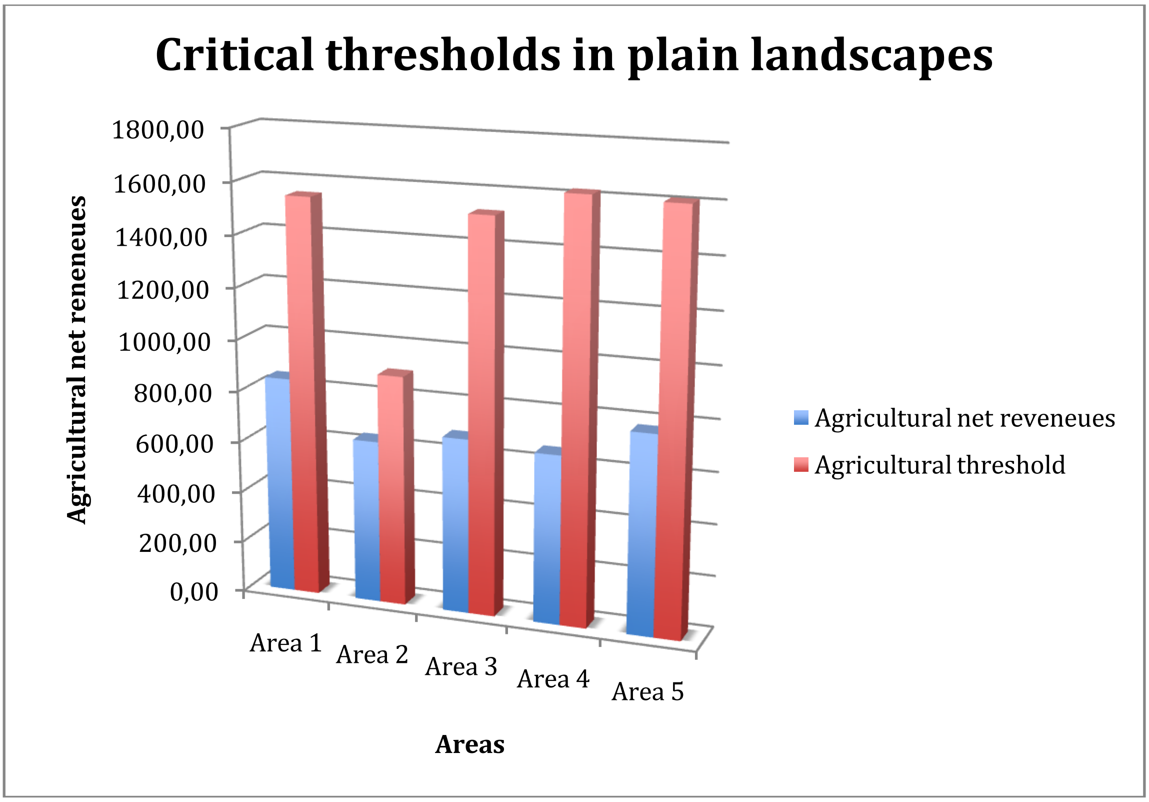

Chart 5 Critical thresholds in plain landscapes

As illustrated in Chart 5, the current agricultural net revenues are lower in value than the critical thresholds Π^* where the switching should occur.

The gap between the current agricultural pay-offs and the critical thresholds is higher in Area 1 and it lowers in Area 2. This difference in the gap can be explained by the volatility in the agricultural net revenues. The volatility for Area 1 is equal to 11.5%, while the volatility for Area 2 is equal to 26,36%. As a result of the high volatility, the agricultural firms are willing to wait instead of quitting the production until the volatility in the agricultural net revenues is at least reduced. The switching point in Area 2 comes for agricultural net revenues per hectare below € 994,49. For the areas 3, 4 and 5 the gap increases again since the volatility in the agricultural net revenues decreases to a value around 10-12%.

Chart 6 illustrates the critical thresholds in hill landscapes for the five areas object of study.

For the areas 1 to 4 it is more profitable to quit the agricultural production and rent out the land. This result is drawn since the critical thresholds Π^* are higher in value than the current agricultural net revenues.

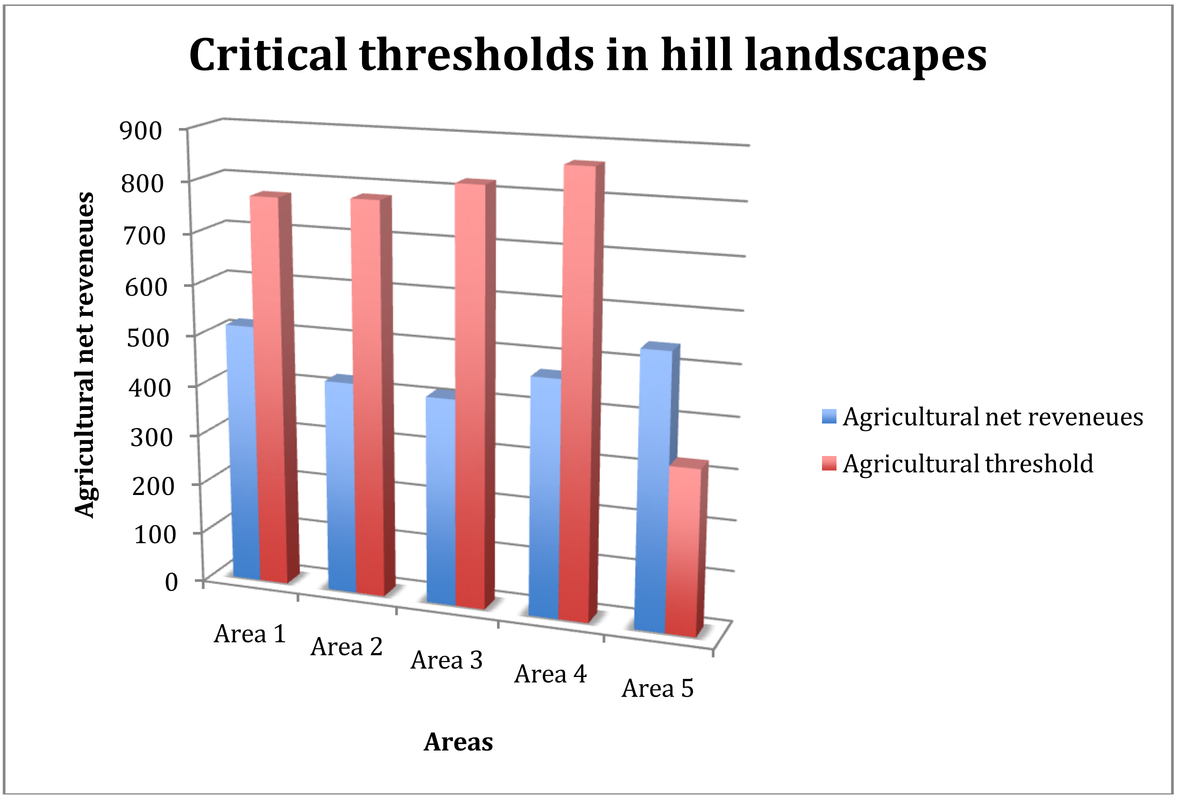

Chart 6 Critical thresholds in hill landscape

The gap between the current net revenues and the critical thresholds is lower for area 1 and it increases for the areas 2, 3 and 4. The increase in the gap comes as a result of the volatility regarding the agricultural pay-offs. The volatility decreases form 11,6% for Area 1 to 8,1% for Area 4. As a result of a lower volatility in the agricultural pay-offs, it is more convenient for the agricultural firms to quit the agricultural production and rent out the land to a company investing in PV installations even for higher agricultural net revenues.

The result for Area 5, hill landscape is quite different from the other areas. As shown in Chart 6, the critical threshold at which it is more profitable for the agricultural firm to quit the agricultural production and rent out the land stands below the current agricultural net revenues. This means that it is more profitable for agricultural firms in this area to continue the agricultural production. The drift in the agricultural net revenues for this area is particularly high, around 5,6%. The drift is higher than the discount rate equal to 5%. For instance, it is more convenient to continue the agricultural production and never switch since the earnings from agricultural pay-offs have a higher rate. This low critical threshold is also explained by the volatility regarding the agricultural net revenues in this area. As shown in Table 6, the volatility regarding the agricultural pay-offs for Area 5 is equal to 33,2%. This is the highest value of volatility regarding the five areas object of this study including both the landscapes. Appendix 3 shows that if the volatility increases, the value of the option decreases. With a high volatility, equal to 33,2%, the value of the option decreases to € 325,05 and it is not profitable for the agricultural firm to quit the agricultural production and rent out the land considering the current agricultural pay-offs.

6.3 A change in the discount rate ρ

In this section, a change in the discount rate ρ is simulated. The discount rate represents also the rate at which the agricultural firm, when quitting the agricultural production would invest the yearly venture received. The different cases elaborated in this section assume an interest rate ρ equal to 1,25%, 2,5%, 5%, 7,5% and 10%. During this simulation, the other parameters are kept constant. The PV contract duration considered is 20 years, and the initial switching costs are assumed equal to 10% on the annual rent received. The results of this simulation are illustrated in Table 9.

Table 9. Change in the discount rate (€/hectare deflated in 1988)

	Landscape	Area 1	Area 2	Area 3	Area 4	Area 5
1,25%	Plain	**1213.68**	**589.05**	**1170.38**	**1285.04**	**1303.50**
	Hill	*612.24*	*612.23*	*654.50*	*733.10*	*203.07*
2,5%	Plain	**1388.11**	**732.96**	**1355.38**	**1463.48**	**1463.48**
	Hill	*694.76*	*699.48*	*742.37*	*802.40*	*257.44*
5%	Plain	**1548.05**	**896.13**	**1524.10**	**1620.98**	**1609.70**
	Hill	*771.73*	*779.14*	*819.55*	*864.41*	*325.05*
7,5%	Plain	**1633.57**	**1003.74**	**1613.77**	**1702.21**	**1687.67**
	Hill	*813.55*	*821.56*	*859.19*	*896.78*	*374.23*
10%	Plain	**1690.34**	**1087.46**	**1673.01**	**1754.69**	**1739.29**
	Hill	*841.65*	*849.63*	*884.72*	*917.83*	*415.50*

Table 9 demonstrates that for low discount rates in value, the switching point comes later in time and the agricultural firm continues the agricultural production. For high discount rates, it is more profitable for the agricultural firms to quit the agricultural production earlier[4]. In relation to the discount rate chosen for our simulation, the critical thresholds are higher for high discount rates since investing the yearly rent received at this rate gains more than the agricultural production.

Chart 7 shows graphically the critical thresholds Π^* with respect to the change in the discount rate ρ for Area 1. The green line represents the critical thresholds in plain landscapes, while the red line represents the critical thresholds in hill landscapes.

Chart 7. Area 1: A change in the discount rate

For low discount rates, the switching point comes later and agricultural firms wait until the net revenues per hectare from agricultural production become low in value. For a discount rate equal to 1,25%, the agricultural firms situated in Area 1, plain landscapes quit the production and rent out the land for agricultural pay-offs per hectare lower than € 1095,89, while for agricultural firms situated in Area 1 but hill landscapes the quitting point comes for

---

[4] Appendix 4 illustrates that the effect of the discount rate ρ on the critical threshold is ambiguous and depends on the value of the other parameters affecting the decision to switch.

Π^* values lower than € 554,24. For a high discount rate equal to 10%, the agricultural firms situated in Area 1, plain landscapes switches the production renting out the land for Π^* values lower than € 1198,01, while agricultural firms situated in Area 1 but hill landscapes cease the activity and rent out the land to a company investing in PV installations for Π^* values lower than € 858,04. Chart 7 illustrates the positive relationship of the critical thresholds per hectare Π^* on the values of the discount rate ρ used in this simulation.

6.4 A change in the PV contract duration *T*

The PV rent contract duration considered in this study is 20 years. In this section, a simulation considering the contract duration is made in order to analyze the effect on the critical thresholds. The contract duration is changed from 5 to 10, 15, 20 and finally 25 years while the other parameters are kept constant. The discount rate ρ is kept constant at 5% and the initial switching cost is assumed to be equal to 10% on the annual rent received. The results from this simulation are presented in Table 10.

Table 10. A change in the PV contract time (€/hectare deflated in 1988)

	Landscape	Area 1	Area 2	Area 3	Area 4	Area 5
5 years	Plain	**1587.63**	**1102.29**	**1559.95**	**1640.75**	**1646.59**
	Hill	*796.10*	*797.72*	*828.43*	*875.98*	*470.80*
10 years	Plain	**1580.40**	**1029.29**	**1553.97**	**1641.07**	**1640.63**
	Hill	*790.80*	*794.57*	*829.00*	*875.78*	*416.14*
15 years	Plain	**1564.50**	**959.03**	**1539.36**	**1631.68**	**1625.53**
	Hill	*781.32*	*787.02*	*824.62*	*870.43*	*367.18*
20 years	Plain	**1548.05**	**896.13**	**1524.10**	**1620.98**	**1609.70**
	Hill	*771.73*	*779.14*	*819.55*	*864.41*	*325.05*
25 years	Plain	**1532.55**	**840.52**	**1509.68**	**1610.58**	**1594.73**
	Hill	*762.76*	*771.70*	*814.59*	*858.59*	*288.96*

Appendix 6 shows the derivative of the critical threshold Π^* with respect to the PV contract duration *T*. This derivative is not monotonic and depends from the value the other parameters take.

The ambiguous effect played by the PV contract duration on the critical thresholds is demonstrated by Table 10. For area 3, plain landscape the critical thresholds decrease with an increase in the PV contract duration T. For the same area but hill landscape, the critical thresholds increase as a result of an increase in the PV contract duration time from 5 to 10 years and then decrease for larger contract durations.

Chart 8 shows graphically the value the Π^* for changes in the PV contract duration T for Area 1. The critical thresholds for which the firm is willing to quit the production and rent out the land in plain landscapes are represented by the green line, while the critical thresholds regarding hill landscapes are represented by the red line.

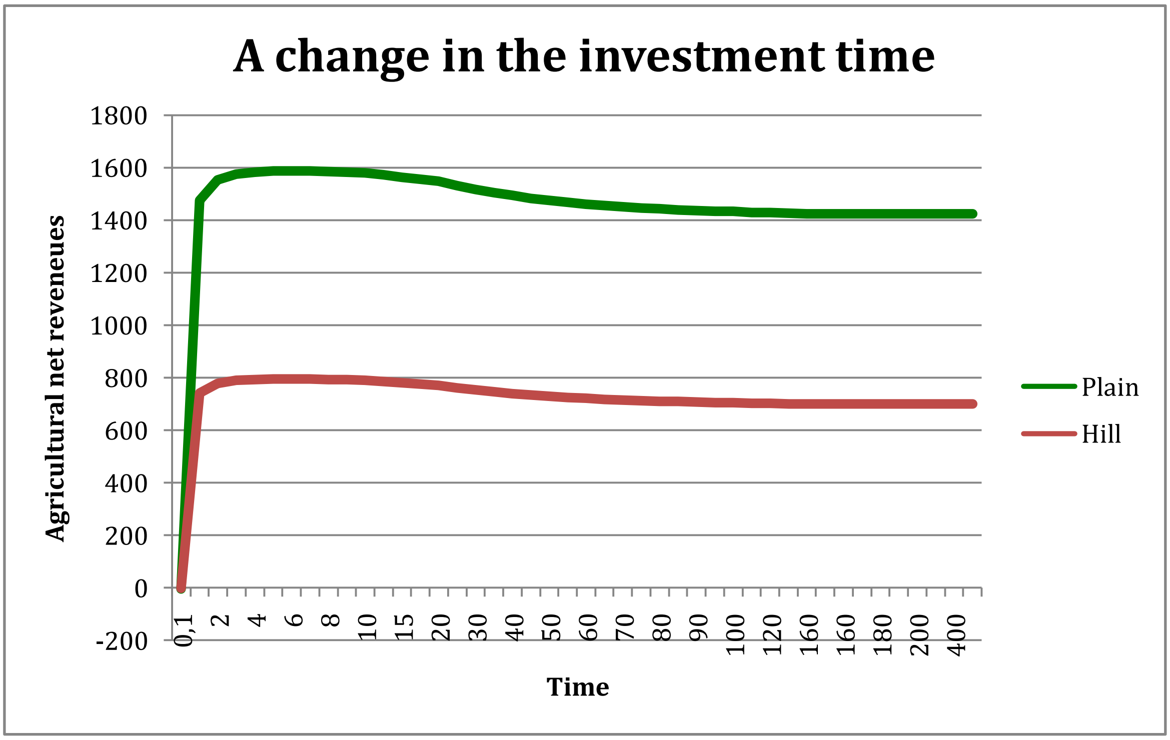

Chart 8: Area 1: A change in the PV contract duration

Since the derivative of Π^* with respect to T is not monotonic, a general conclusion of how it influences the thresholds cannot be drawn. The analysis of how the contract duration influences the option to switch is given by the flexibility. For short contract durations in time, an increase in the contract duration brings an increase in the critical thresholds and the agricultural firm quits earlier the production and rents out the land. Since the agricultural net revenues are characterized by uncertainty and the rents are constant, this represents a short time insurance for the firms in order to have fixed payments non affected by uncertainty in a short period of time. On the contrary, for long PV contract durations, when the contract duration increases, the critical thresholds start decreasing slowly. This decrease comes as a result of the loss of flexibility. Since the decision to switch is irreversible, once undertaken the agricultural firm looses the flexibility of managing the land. The PV rent contracts obtained by the interviews with S.E.D.I Srl have duration of 20 to 25 years. From this simulation it is shown that, as a result of the flexibility, the switching point comes earlier for contracts lasting less. Agricultural firms are willing to enter in a 20 years PV contract even for higher agricultural net revenues then in a 25 years PV contract.

6.5 A change in the initial switching cost *K*

A change in the initial switching cost is simulated in this section of the dissertation. The switching cost *K* considered in this study represents an agency cost expressed in percentage on the annual rent received. This switching cost includes transaction costs due to the search of the counterpart and financial consulting services the agricultural firm may need in order to decide the profitability of its decision. The simulation of this section assumes a change in the switching cost equal to 5%, 10%, 15%, 20% and 25% on the annual rent received. The results of this simulation are shown in Table 11. The other parameters affecting the agricultural firm's decision to quit the agricultural production and rent out the land are kept constant. The discount rate ρ is assumed to be 5%, while the PV contract duration time is considered constant, equal to 20 years.

Table 11. A change in the initial switching cost (€/hectare deflated in 1988)

	Landscape	Area 1	Area 2	Area 3	Area 4	Area 5
5%	Plain	**1554.22**	**899.70**	**1530.18**	**1627.44**	**1616.12**
	Hill	*774.80*	*782.25*	*822.82*	*867.86*	*326.34*
10%	Plain	**1548.05**	**896.13**	**1524.10**	**1620.98**	**1609.70**
	Hill	*771.73*	*779.14*	*819.55*	*864.41*	*325.05*
15%	Plain	**1541.88**	**892.56**	**1518.03**	**1614.52**	**1603.29**
	Hill	*768.65*	*776.04*	*816.28*	*860.97*	*323.75*
20%	Plain	**1535.71**	**888.99**	**1511.95**	**1608.06**	**1596.87**
	Hill	*765.57*	*772.93*	*813.02*	*857.52*	*322.46*
25%	Plain	**1529.54**	**885.41**	**1505.88**	**1601.59**	**1590.45**
	Hill	*762.50*	*769.82*	*809.75*	*854.07*	*321.16*

Appendix 1 shows that an increase in the initial switching cost brings a decrease in the critical thresholds. The result is confirmed from Table 11. For all the five areas object of the study, with no landscape distinction, the value of the option decreases when the switching cost increases.

Considering Area 1 plain landscapes, if the initial cost is equal to 5% on the annual rent received, then it is profitable for the agricultural firm to quit the agricultural production and rent out the land if the agricultural net revenues are below € 1554,22. If the initial switching cost increases to 25% of the annual rent received, then the agricultural firm waits until the agricultural net revenues decrease to € 1529,54 to switch the production.

Chart 9 illustrates graphically the change in the critical thresholds as a result of an increase in the initial switching cost regarding Area 1, plain landscape. Since the results for the other 4 areas object of the study follows the same pattern, they are not included in the chart.

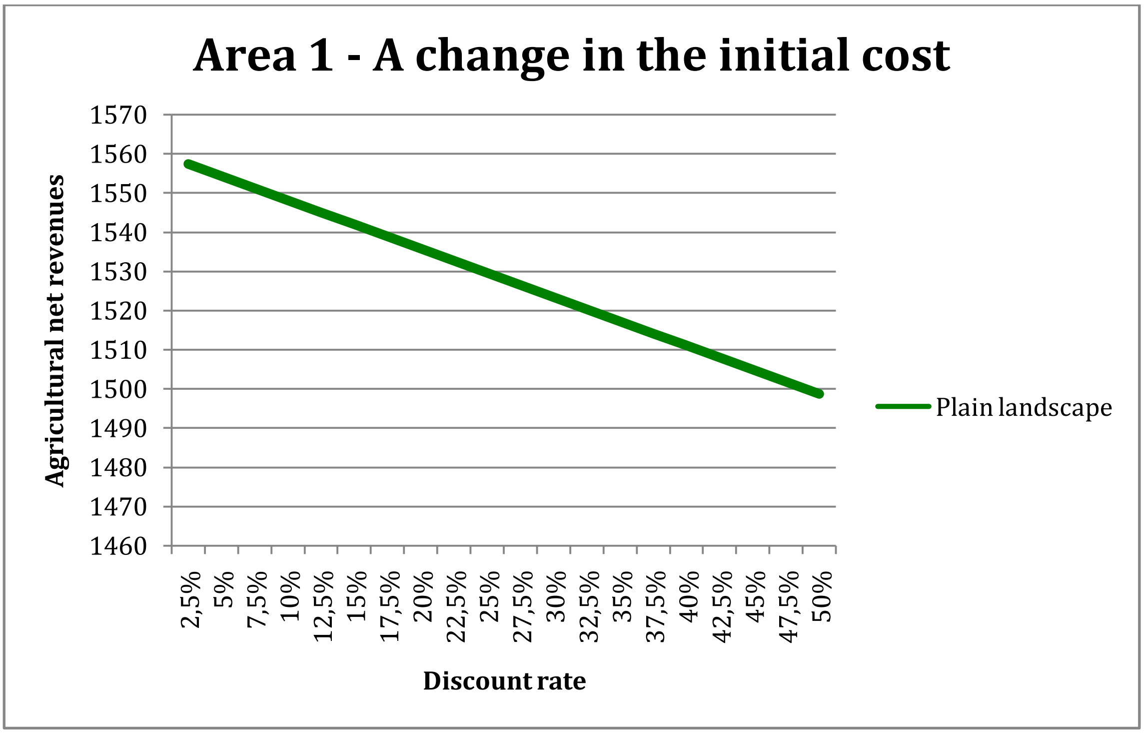

Chart 9. Area 1, plain landscape: A change in the initial switching cost

The chart shows that for an increase of the initial switching cost from 2,5% on the annual rent received to 50% in Area 1 plain landscape, the decrease in the critical threshold is equal to € 58,63. The variation in the critical thresholds considering a change in the initial switching cost *K* regarding Area 1 hill landscapes is presented in Chart 10.

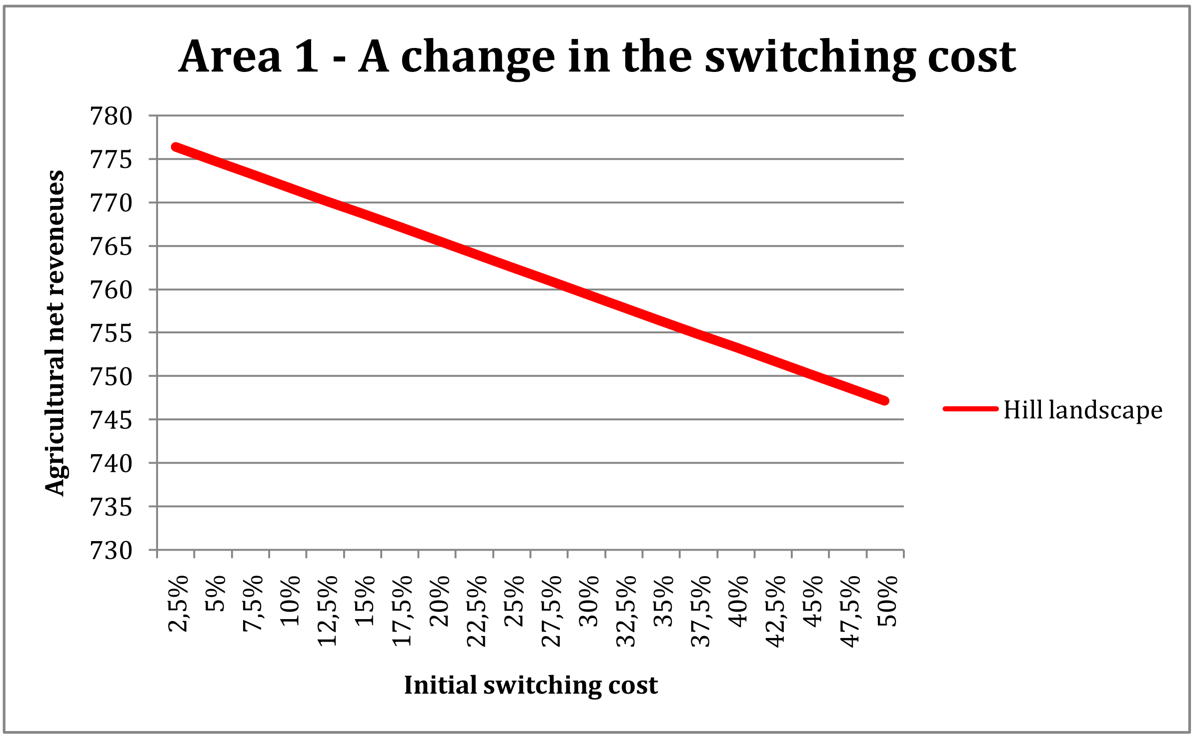

Chart 10. Area 1, hill landscape: A change in the initial switching cost

As in the case of Area 1 filed landscape presented above, the chart shows that as a result of an increase in the initial switching cost the critical thresholds are decreasing. This increase in the switching costs influences negatively the option to switch and the switching point comes for lower critical thresholds.

6.6 The minimal rent requested

The $\tilde{q}$ represents the minimal rent at which, considering the current agricultural net revenues, it is more profitable for the agricultural firms to quit the agricultural production and rent out the land to a company investing in PV installations. From the equation (2.5.39) representing the critical threshold, the minimal rent requested is equal to:

$$q = \frac{\Pi\left[\frac{\beta_2 - 1}{\beta_2}\left(\frac{1 - e^{-(\rho-\alpha)T}}{\rho - \alpha}\right)\right] + K}{\left(\frac{1 - e^{-\rho T}}{\rho}\right)} \tag{6.6.1}$$

Table 12 presents the current rents offered and the minimal rents for which it will be more profitable for the agricultural firms situated in the five areas to quit the production.

Table 12. Minimal and current yearly rents (€/hectare deflated in 1988)

	Landscape	Area 1	Area 2	Area 3	Area 4	Area 5
q	Plain	**2253.28**	**2253.28**	**2253.28**	**2253.28**	**2253.28**
	Hill	*1126.64*	*1126.64*	*1126.64*	*1126.64*	*1126.64*
$\tilde{q}$	Plain	**1309.30**	**1598.70**	**1016.20**	**924.17**	**1093.48**
	Hill	*792.45*	*615.00*	*569.10*	*615.91*	*1878.63*

Table 12 illustrates the gap between the current rents offered from the companies investing in PV installations in the five areas investigated and the minimal rents for which it is more profitable for the agricultural firm to switch. The current rents offered for areas in plain landscapes are equal to € 4800,00 (€ 2253,28 deflated in 1988) per hectare while the minimal rent considering the current agricultural net revenues for Area 1 plain landscape is equal to € 1309,30 per hectare. The gap between the minimal rent and the current is € 943,98. Area 2, plain landscape is affected by a higher volatility equal to 26,34%. The high volatility regarding the agricultural net revenues can bring huge profits from agricultural production if the upward predictions come into being. As a result, the agricultural firm requires a higher minimal rent in order to switch. Since the current rents offered are equal and the minimal rent for Area 2 is equal to € 1598,70, the gap between the two values is equal to € 654,58 per hectare.

Chart 11 presents the current PV rents offered to agricultural firms and the minimal rent for which it is more profitable for the agricultural firms situated in plain landscapes to quit the production and rent out the land. The red bars represent the minimal rents requested while the blue bars represent the current rents.

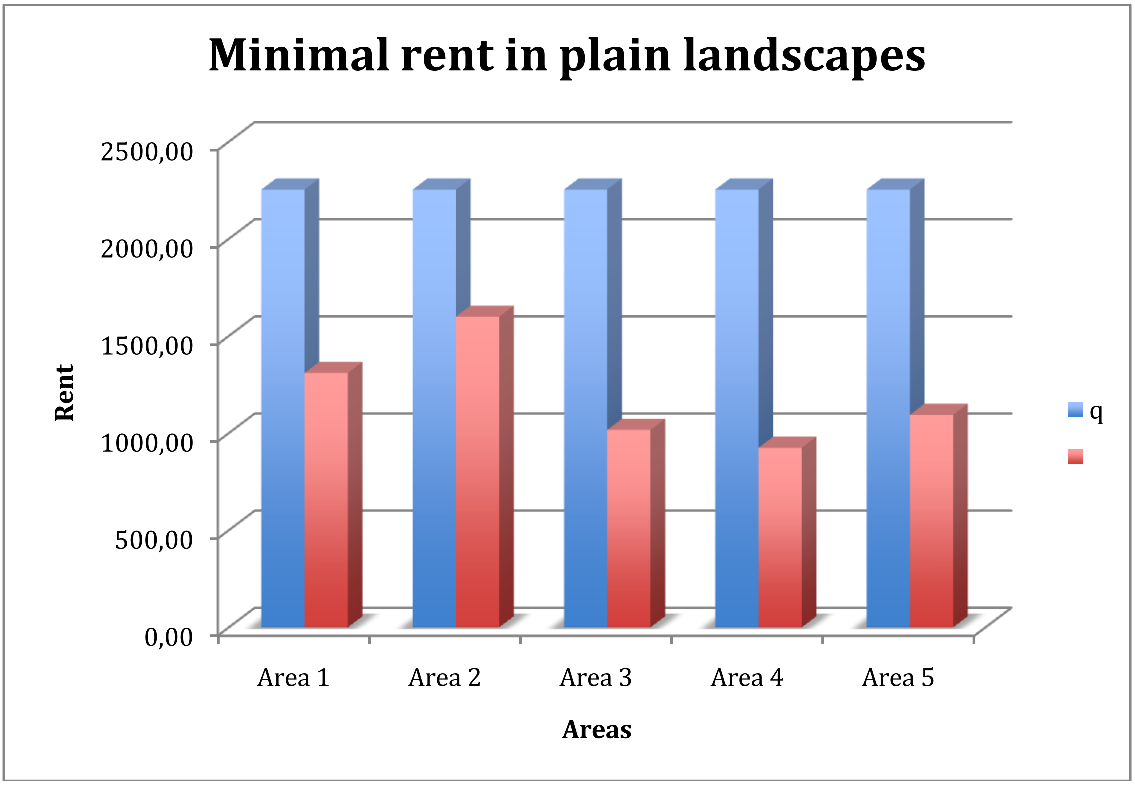

Chart 11. Minimal rent requested in plain landscapes

The change in the gap as a result of the volatility on agricultural pay-offs is well illustrated by the chart. The difference between the two bars is minimal for Area 2, plain landscape where the volatility is equal to 26,34% and it is maximal for Area 4, plain landscape with a volatility regarding the agricultural net revenues equal to 10,15%.

Chart 12 illustrates the current rents offered and the minimal rents for which the switching occurs in hill landscapes. By the interviews conducted at S.E.D.I Srl, the land yearly rent per hectare offered to agricultural firms amounts to € 2400,00 (€ 1126,64 deflated in 1988) for the five areas object of study. Area 1, hill landscape is characterized by a volatility equal to 11,59%. Because of this volatility, the gap between the current rents offered in hill landscapes and the minimal rent is equal to € 334,20 per hectare. As the volatility decreases from Area 1 to Area 4 hill landscapes, the gap increases and becomes equal to € 557,54 for Area 3 where the volatility is the lowest of the five areas, only 8,11%.

The result is different for Area 5 hill landscape. The agricultural net revenues for this area have a drift equal to 5,6%, higher than the discount rate equal to 5%. In addition, the agricultural pay-offs are characterized by a high volatility equal to 33,2%.

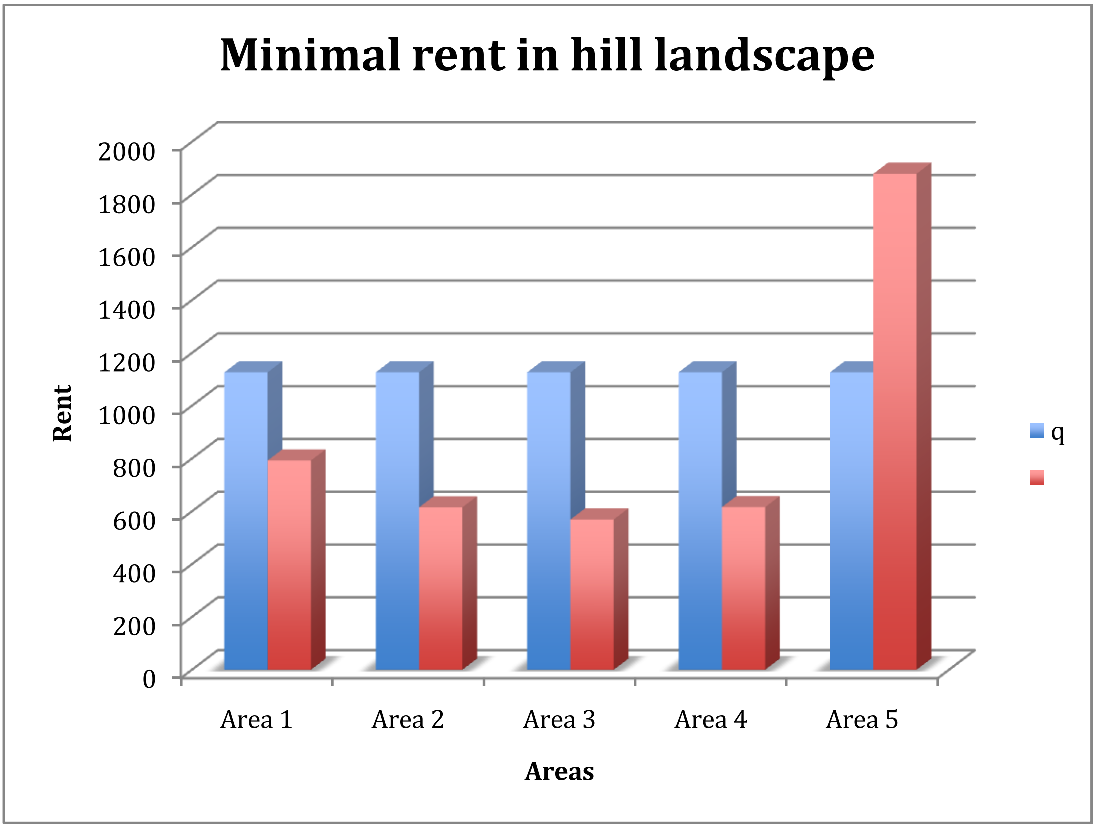

Chart 12. Minimal rent requested in hill landscapes

As a result of the high drift and volatility in the agricultural pay-offs, it is not profitable for the agricultural firms operating in this area to switch considering the current yearly rents offered. The drift higher than the discount rate means that the gains from agricultural net revenues are higher than what the firm gets investing the rent received at ρ. In addition, the high volatility in the agricultural pay-offs equal to 33,2% represents a good opportunity from the agricultural production if the upward predictions become reality.

7 Conclusions

The main aim of the study was to determine the factors affecting the decision of the agricultural firms to quit the production and rent out the land to a PV investor under uncertainty and irreversibility.

The study case, focuses on five particular agricultural areas in the province of Bologna, and illustrates that uncertainty on agricultural net returns and irreversibility of the decision to rent out the land have a great impact on the agricultural firm's choice. In particular, the volatility on net revenues plays a significant role on the agricultural firms' decision influencing negatively the option to switch. On the contrary, an increase in the rent paid for allowing the PV installation and a decrease in the switching costs have a positive impact on the decision to rent out the land. In addition, the results show that a higher discount rate induces an earlier switch. The impact of the contract's duration is instead connected to the value of flexibility. The longer the contract duration, the lower is the flexibility of the agricultural firm when taking future decisions. This is taken into account when setting the switching threshold, which is then negatively related to the contract duration.

In Italy, the current subsidies and feed-in tariffs for investments in renewable energies create the conditions to a market for investments in PV installations in agricultural areas. According to the state's renewable energy market operator GSE, more than one hundred thousand PV power plants have been installed using subsidies and feed-in tariffs from the Italian authorities until September 2010 (GSE, 2011). Some of these installations are rooftop while the rest are ground-based installations, which require a determined amount of land. Chakravorty *et al.* (2009) states that the demand for land produces a conflict for land allocation between food production and energy production. In fact, an increase in the agricultural prices' volatility lowers the critical threshold for which the agricultural companies are willing to quit the agricultural production and rent out the land.

This dissertation has illustrated the importance of governmental subsidies for investments in RES by studying the crucial factors in order to identify the best land allocation. Further research in the area incorporating the theory of investment under uncertainty and irreversibility would be desirable. In the next section, some suggestions for future research are provided.

7.1 Suggestions for future research

A particular and interesting case is the study of the factors affecting the decision of the firm deciding to invest itself in PV installations rather than renting out the land to another company. In this case, the agricultural firm must pay the cost of investment, the costs of insurance for the panels and the costs of maintenance. The pay-offs are represented by the value of the energy produced, and the subsidies and feed-in tariffs offered by GSE. These pay-offs as well as the foregone agricultural pay-offs may be stochastic due to uncertainty in the energy and agricultural commodities' markets.

Another interesting topic to be investigated is the conflict between land destined to set-aside and land for PV installations. In 1988 the EU introduced the set-aside policy in order to address environmental concerns connected to conservation and limit the production of cereals to keep their price high (www, Europa, 2010). According to this policy, the agricultural firms may voluntarily decide the extent of land to put in set-aside. From 1992, the percentage of land to be put in set-aside became obligatory and was specified by the EC in the beginning of every year until 1999. After that time, the area of land that agricultural firms were required to set-aside was fixed at an amount equal to 10% of the firm's total land.

Considering the future forecasts of FAO (2007) regarding increases in demand for agricultural products and the need of more arable land, the land destined to set-aside can be used in the future for the production of agricultural products or other purposes. In July 2007 Mariann Fischer Boel, Commissioner for Agriculture and Rural Development, responded to the increasingly tight situation on the cereals market by proposing to set the obligatory amount of land required to be set-aside by farmers equal to zero. According to this proposal, the extent of land allocated to set-aside should be decided on a voluntary basis by each agricultural firm. By removing the obligation of 10%, agricultural firms may freely decide whether to use the total area of land for agricultural production, or assign a part of it to set-aside or other uses such as the production of energy. Considering the payment the firm receives for putting the land in set-aside, the irreversibility of the decision, the subsidies from the EU for investing in PV power plants and the uncertainty regarding the future prices of energy and agricultural products, it would be interesting to investigate the trade-off between these investments and the optimal amount of land allocated to each of them.

Bibliography

Publications

Arnulf, J. W. (2007) “Photovoltaics and Renewable Energies in Europe”; *Science Direct*, Vol. 11 pp. 1414-1437.

Auerswald, D. Leuthold, F (2009) “Generation Portfolio and Investment Timing until 2030: A Real Option Approach for Germany”, *Electricity Markets Working Papers* WP-EM-33.

Borison, A. (2003) *Real Options Analysis: Where are the Emperor’s Clothes? – Stanford University,* Presented at Real Options Conference, Washington, DC July 2003.

Brealey and Myers, (2003) *Principles of Corporate Finance,* seventh edition, The McGraw-Hill Series in Finance.

Bromley, D. B. (1986) *The Case-study Method in Psychology and Related Disciplines,* Chichester: Wiley.

Calabrese, A. Gastaldi, M. Nathan, L. G. (2005) “Real Option’s model to evaluate infrastructure flexibility: an application to photovoltaic technology”, *Int. J. Technology Management,* Vol. 29 Nos. 1/2, pp. 173 – 191.

Chakravorty, U., Hubert M. H., and Nostbakken L. (2009) “Fuel Versus Food”, *Annual Rev. of Resource Economics,* Vol. 1 pp. 23.1-23.19.

Damodaran, A. (2002) *Investment Valuation – Tools and Techniques for Determining the Value of Any Asset – Second Edition,* John Wiley & Sons, Inc., New York, ISBN 0-471-41488-3, ISBN 0-471-41490-5.

Dixit A. K. and Pindyck, R. S. (1994) *Investment Under Uncertainty,* Princeton University Press, Princeton, NJ.

Energy Research Center for the Netherland ECN (2007) *EU Standards for Energy Security of Supply*

European Commission (1997) *Energy for the Future: Renewable Sources of Energy – White Paper of a Community Strategy and Action Plan,* COM (97) 599 final (26.11.1997).

European Commission (2001) “*Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market”*, Published on the Official Journal of the European Communities L. 233/33 date 27.10.2001.

European Commission (2007), *An Energy Policy for Europe,* COM (2007) 1 Final.

European Commission (2010), *Europe’s Energy Position, 2010* Annual Report.

European Environmental Agency (2008*) Energy and Environment Report 2008*, EEA Report Copenhagen, No. 6/2008.

European Renewable Energy Council (2007), *Renewable Energies Targets for Europe 20% by 2020*.

FAO (2007) *The state of food and agriculture: Paying Farmers for Environmental Sciences*, Rome: Food Agric. Organ.

Groppelli, A. A. and Nikbakht, E. (2006) *Finance*, fifth edition, ISBN-10: 978-0-7641-3420-3, ISBN-13: 978-0-7641-3420-3.

GSE (2011) *Record Fotovoltaico, superati i 100 mila impianti in esercizio*, http://www.gse.it/media/ComunicatiStampa/Comunicati%20Stampa/comstampa_100milafv.pdf

Gujarati, D. (2004) *Basic Econometrics* – Fourth Edition, The McGraw Hill Companies, ISBN 0-07-233542-4.

Hardaker J. B., Huirne, R. B. M., Anderson, J. R., and Lien G. (2004)*Coping with Risk in Agriculture – second edition*, CABI Publishing, EASTBOURNE UK, ISBN-13: 978-0-85199-831-2, ISBN-10: 0-85199-831-3.

Harmon C. (2000) "*Experience Curves of Photovoltaic Technology*", Interim Report IR-00-014 International Institute for Applied Systems Analysis, Schlossplatz 1, A-2361 Laxenburg, Austria.

International Energy Agency (2003) *Energy to 2050 – Scenarios for a Sustainable Future*, ISBN 92-64-01904-9

Isik, M. and Yang, W. (2004) "An Analysis of the Effects of Uncertainty and Irreversibility on Farmer Participation in the Conservation Reserve Program", *Journal of Agricultural and Resource Economics*, vol. 29 (2), pp. 242-259.

Kochanski, G. (2005) "Monte Carlo Simulation", http://kochanski.org/gpk/teaching/0501Oxford/MonteCarlo.pdf

Ministero dell'Economia e delle Finanze (2011) Risultati asta: BTP 30 anni, http://www.bancaditalia.it/banca_centrale/operazioni/titoli/collocamenti/risultati/2010/btp_30_anni/BTP_30anni_.pdf

Ministero dell'Economia e delle Finanze (2011) Auction Resutls: 5 year BTP, http://www.dt.tesoro.it/export/sites/sitodt/modules/documenti_en/debito_pubblico/risultati_aste/risultati_aste_btp_5_anni/5_Year_BTP_Auction_Results_14.04.2011.pdf

Ministero dello Sviluppo Economico, (2010) *"Conto Energia"*, Published in the Official Journal n. 197, 24.08.2010.

Munoz, M. Oschmann, V. Tabara D. J. (2007) "Harmonization of renewable electricity feed-in laws in the European Union", *Energy Policy*, Vol. 35 pp. 3104-3114.

Myrzik, J. M. A. and Calais M. (2003) “String and Module Integrated Inverters for Single-Phase Grid Connected Photovoltaic Systems - A Review”, Paper accepted for presentation at 2003 IEEE Bologna Power Tech Conference, June 23rd -26th, Bologna, Italy.

Neij, L. (1997) “Use of experience curves to analyze the prospects for diffusion and adoption of renewable energy technology”, *Energy Policy*, Vol. 23 pp. 1099-1107.

Pretorius, F., Chung-Hsu, B.-F., Maclnnes, A. (2008) *Project Finance for Constructions and Infrastructure: Principles and Case Studies.* Hoboken, NJ, USA: Wiley-Blackwell.

Regione Emilia-Romagna (2011) *Fotovoltaico* http://www.regione.emilia-romagna.it/notizie/2011/gennaio/energia-pulita-dai-campi/fotovoltaico.pdf

Robson C. (2002) Real World Research – second edition, ISBN:-13: 978-0-631-21304-8.

Saunders, M., Lewis, P. & Thornhill, A. (2007) *Research Methods for Business Students* (4th edition). Pearson Education Limited, Essex, England.

Sims, R.E.H. (2004) “Renewable Energy: A Response to Climate Change”, *Solar Energy*, Vol. 76 pp. 9-17.

Spanjer, A. (2007) “Russian gas price reform and the EU–Russia gas relationship: Incentives, consequences and European security of supply”, *Energy Policy*, Vol. 35, pp. 2889-2898.

Tam, J and Velez-Pareja, I. (2004) *Principles of Cash Flow Valuation*, Elsevier Academic Press, London, UK, ISBN: 0-12-686040-8.

Trigeorgis, L. (2005) “Making use of real options simple: an overview and applications in flexible/modular decision making”, *Engineering Economist*, March 2002.

Yin, R. K. (1984) *Case study research: Design and method*, SAGE Publications, Beverly Hills, California, ISBN 0803920571.

Yin, R. K. (1994) Case study research: Design and method – Second edition, SAGE Publications, Beverly Hills, California, ISBN-10: 0803956630, ISBN-13: 9780803956636.

Internet

@Risk (2011) @Risk 5.5, 20.04.2011 http://www.palisade.com/risk/

Agenzia del territorio (2011) *Average agricultural values*, 19.05.2011 http://www.agenziaterritorio.it/?id=1370

Assosolare (2011) Solar Energy, 19.05.2011 http://www.assosolare.org/associazione/gli-associati/kromotek-srl/

Aurora (2011) *Photovoltaic Market Grows in Italy*, 10.03.2011
http://www.myauroratag.com/eng/component/content/article/7-articoli/88-ecological-strategies

Energy (2010) *Europe's Energy Portal*, 17.10.2010,
http://www.energy.eu/#dependency

Europa (2010) Proposal to set at zero set-aside, 08.11.2010,
http://europa.eu/rapid/pressReleasesAction.do?reference=IP/07/1101&type=HTML&aged=0&language=EN&guiLanguage=en

Eurostat (2010) *Sustainable development – Climate Change and Energy*, 17.10.2010,
http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Sustainable_development_-_Climate_change_and_energy#Energy_dependency

Government of Canada, (2010) G8 Communiqué, 12.11.2010,
http://www.canadainternational.gc.ca/g8/summit-sommet/2001/communique_220701.aspx?lang=eng

Investopia (2011) Put option definition, 19.05.2011
http://www.investopedia.com/terms/p/putoption.asp

ISTAT (2011) Yearly Inflation rates, 19.05.2011
http://www.istat.it/salastampa/comunicati/in_calendario/paniere/20110204_00/

Oxford dictionary (2011) Simulation, 19.05.2011,
http://www.oxfordadvancedlearnersdictionary.com/dictionary/simulation

PV-Invest (2011) *Photovoltaic Invest*, 10.03.2011
http://www.pv-invest.at/lequileIe.php

PVTECH (2011) *PV Technology*, 19.03.2011
http://www.pv-tech.org/tariff_watch/italy

UNFCCC (2011) Kyoto Protocol, 19.05.2011
http://unfccc.int/kyoto_protocol/items/2830.php

University of Nebraska – Lincoln (2011) Monte Carlo Simulation, 19.05.2011
http://www.chem.unl.edu/zeng/joy/mclab/mcintro.html

Webstat (2011) School of Psychology, University of New England, 8.05.2011
http://www.une.edu.au/WebStat/unit_materials/c4_descriptive_statistics/standard_deviation.htm

Eurotreaties (2011) *The Messina Declaration*, 19.05.2011,
http://www.eurotreaties.com/messina.pdf

Personal Comments

Personal Comment Gessica Perini, interviewed on April 4th, 2011.

Appendix 1

The derivation of Π^* with respect to K:

$$\Pi^* = \frac{\beta_2}{\beta_2 - 1} \frac{q\left(\frac{1-e^{-\rho T}}{\rho}\right) - K}{\left(\frac{1-e^{-(\rho-\alpha)T}}{\rho-\alpha}\right)}$$

$$= \left(1 + \frac{1}{\beta_2 - 1}\right) \frac{\rho-\alpha}{\rho} \frac{q\left(1-e^{-\rho T}\right) - K\rho}{1-e^{-(\rho-\alpha)T}}$$

$$\frac{d\Pi^*}{dK} : \left(1 + \frac{1}{\beta_2 - 1}\right) \frac{\rho-\alpha}{\rho} \frac{-\rho}{1-e^{-(\rho-\alpha)T}}$$

$$= \left(1 + \frac{1}{\beta_2 - 1}\right) \frac{-(\rho-\alpha)}{1-e^{-(\rho-\alpha)T}} < 0$$

The derivation of Π^* with respect to K is negative. An increase in the initial switching cost brings a decrease in the critical thresholds. Hence, the agricultural firm quits later the production.

Appendix 2

The derivation of Π^* with respect to q:

$$\Pi^* = \frac{\beta_2}{\beta_2 - 1} \frac{q\left(\frac{1-e^{-\rho T}}{\rho}\right) - K}{\left(\frac{1-e^{-(\rho-\alpha)T}}{\rho-\alpha}\right)}$$

$$= \left(1 + \frac{1}{\beta_2 - 1}\right) \frac{\rho-\alpha}{\rho} \frac{q\left(1-e^{-\rho T}\right) - K\rho}{1-e^{-(\rho-\alpha)T}}$$

$$\frac{d\Pi^*}{dq} : \left(1 + \frac{1}{\beta_2 - 1}\right) \frac{\rho-\alpha}{\rho} \frac{1-e^{-\rho T}}{1-e^{-(\rho-\alpha)T}} > 0$$

The derivation of Π^* with respect to q is positive. An increase in the value of the rent brings an increase in the critical thresholds and the agricultural firm quits earlier the production to rent the land to a PV investor.

Appendix 3

The derivation of Π^* with respect to σ^2:

$$\Pi^* = \frac{\beta_2}{\beta_2 - 1} \frac{q\left(\frac{1-e^{-\rho T}}{\rho}\right) - K}{\left(\frac{1-e^{-(\rho-\alpha)T}}{\rho-\alpha}\right)}$$

$$= \left(1 + \frac{1}{\beta_2 - 1}\right) \frac{\rho-\alpha}{\rho} \frac{q\left(1-e^{-\rho T}\right) - K\rho}{1-e^{-(\rho-\alpha)T}}$$

$$\frac{d\Pi^*}{d\sigma^2} : -\frac{1}{\left(\beta_2 - 1\right)^2} \frac{d\beta}{d\sigma^2} \left(\frac{\rho-\alpha}{\rho}\right) \frac{q(1-e^{-\rho T}) - K\rho}{1-e^{-(\rho-\alpha)T}}$$

β_2 solves:

$$\frac{1}{2}\sigma^2 \beta_2 (\beta_2 - 1) + \alpha\beta_2 - \rho = 0$$

differentiating with respect to σ^2 on both sides:

$$\frac{1}{2}\beta_2(\beta_2 - 1) + \frac{1}{2}\sigma^2\left(2\beta_2 - 1\right)\frac{d\beta_2}{d\sigma^2} + \alpha\frac{d\beta_2}{d\sigma^2} = 0$$

$$\frac{d\beta_2}{d\sigma^2}\left[\sigma^2\beta_2 - \left(\frac{1}{2} - \frac{\alpha}{\sigma^2}\right)\sigma^2\right] = -\frac{1}{2}\beta_2\left(\beta_2 - 1\right)$$

$$\beta_2 = \left(\frac{1}{2} - \frac{\alpha}{\sigma^2}\right) - \sqrt{\left(\frac{1}{2} - \frac{\alpha}{\sigma^2}\right)^2 + \frac{2\rho}{\sigma^2}} < 0$$

This implies that the right hand side of equation is negative.

Note also that it must be:

$$\sigma^2\beta_2 - \left(\frac{1}{2}\sigma^2 - \alpha\right) = -\sigma^2\sqrt{\left(\frac{1}{2} - \frac{\alpha}{\sigma^2}\right)^2 + \frac{2\rho}{\sigma^2}} < 0$$

It follows that for the left hand side to be negative, then:

$$\frac{d\beta_2}{d\sigma^2} > 0$$

and consequently:

$$\frac{d\Pi^*}{d\sigma^2} < 0$$

If the volatility increases, then the critical thresholds decrease and the switching point comes later. If there is great uncertainty in the market then the firm will not exercise the option and wait to acquire more information and for the uncertainty to be reduced in the market.

Appendix 4

The derivation of Π^* with respect to ρ:

$$\Pi^* = \frac{\beta_2}{\beta_2 - 1} \frac{q\left(\frac{1 - e^{-\rho T}}{\rho}\right) - K}{\left(\frac{1 - e^{-(\rho - \alpha)T}}{\rho - \alpha}\right)}$$

$$\frac{d\Pi^*}{d\rho} : -\frac{\frac{d\beta_2}{d\rho}}{(\beta_2 - 1)^2}\left[\frac{q(1 - e^{-\rho T}) - K\rho}{1 - e^{-(\rho - \alpha)T}}\right]\left(\frac{\rho - \alpha}{\rho}\right) + \left(1 + \frac{1}{\beta_2 - 1}\right)\left[\frac{q(1 - e^{-\rho T}) - K\rho}{1 - e^{-(\rho - \alpha)T}}\right]\left(\frac{\rho - \rho + \alpha}{\rho^2}\right)$$
$$+ \left(1 + \frac{1}{\beta_2 - 1}\right)\left(\frac{\rho - \alpha}{\rho}\right)\left[\frac{qTe^{-\rho T} - K}{1 - e^{-(\rho - \alpha)T}} - \frac{(q(1 - e^{-\rho T}) - K\rho)Te^{-(\rho - \alpha)T}}{(1 - e^{-(\rho - \alpha)T})^2}\right]$$

$$= -\frac{\frac{d\beta_2}{d\rho}}{(\beta_2 - 1)^2}\left[\frac{q(1 - e^{-\rho T}) - K\rho}{1 - e^{-(\rho - \alpha)T}}\right]\left(\frac{\rho - \alpha}{\rho}\right) + \frac{\alpha}{\rho}\left(1 + \frac{1}{\beta_2 - 1}\right)\left[\frac{q(1 - e^{-\rho T}) - K\rho}{1 - e^{-(\rho - \alpha)T}}\right]$$
$$+ \left(1 + \frac{1}{\beta_2 - 1}\right)\left(\frac{\rho - \alpha}{\rho}\right)\left[\frac{qTe^{-\rho T} - K}{1 - e^{-(\rho - \alpha)T}} - \frac{(q(1 - e^{-\rho T}) - K\rho)Te^{-(\rho - \alpha)T}}{(1 - e^{-(\rho - \alpha)T})^2}\right]$$

The sign is ambiguous since the first and second term of equation are positive but the sign of the third term might be also negative.

Appendix 5

The derivation of Π^* with respect to α:

$$\frac{d\Pi^*}{d\alpha} : -\frac{\frac{d\beta_2}{d\alpha}}{(\beta_2 - 1)^2}\left(\frac{\rho-\alpha}{\rho}\right)\left[\frac{q\left(1-e^{-\rho T}\right)-K\rho}{1-e^{-(\rho-\alpha)T}}\right] - \frac{1}{\rho}\left(1+\frac{1}{\beta_2-1}\right)\left[\frac{q\left(1-e^{-\rho T}\right)-K\rho}{1-e^{-(\rho-\alpha)T}}\right]$$

$$+\left(1+\frac{1}{\beta_2-1}\right)\left(\frac{\rho-\alpha}{\rho}\right)\left[\frac{q\left(1-e^{-\rho T}\right)-K\rho}{\left(1-e^{-(\rho-\alpha)T}\right)^2}\left(Te^{-(\rho-\alpha)T}\right)\right]$$

$$=\left[\frac{q\left(1-e^{-\rho T}\right)-K\rho}{1-e^{-(\rho-\alpha)T}}\right]\left[-\frac{d\beta_2}{d\alpha}\frac{1}{(\beta_2-1)^2}\left(\frac{\rho-\alpha}{\rho}\right)-\frac{1}{\rho}\frac{\beta_2}{\beta_2-1}+\frac{\beta_2}{\beta_2-1}\left(\frac{\rho-\alpha}{\rho}\right)\frac{Te^{-(\rho-\alpha)T}}{1-e^{-(\rho-\alpha)T}}\right]$$

$$=\left[\frac{q\left(1-e^{-\rho T}\right)-K\rho}{\left(1-e^{-(\rho-\alpha)T}\right)(\beta_2-1)^2}\right]\left[-\frac{d\beta_2}{d\alpha}\left(\frac{\rho-\alpha}{\rho}\right)-\frac{1}{\rho}(\beta_2-1)+\beta_2(\beta_2-1)\left(\frac{\rho-\alpha}{\rho}\right)\frac{Te^{-(\rho-\alpha)T}}{1-e^{-(\rho-\alpha)T}}\right]$$

$$=\left[\frac{q\left(1-e^{-\rho T}\right)-K\rho}{\rho\left(1-e^{-(\rho-\alpha)T}\right)(\beta_2-1)^2}\right]\left[-\frac{d\beta_2}{d\alpha}(\rho-\alpha)-(\beta_2-1)+\frac{\beta_2(\beta_2-1)(\rho-\alpha)Te^{-(\rho-\alpha)T}}{1-e^{-(\rho-\alpha)T}}\right]$$

again, β_2 solves:

$$\frac{1}{2}\sigma^2\beta_2(\beta_2-1)+\alpha\beta_2-\rho=0$$

differentiating with respect to α:

$$\frac{1}{2}\sigma^2\frac{d\beta_2}{d\alpha}(2\beta_2-1)+\beta_2+\alpha\frac{d\beta_2}{d\alpha}=0$$

$$\frac{d\beta_2}{d\alpha}\left[\sigma^2\beta_2-\left(\frac{1}{2}\sigma^2-\alpha\right)\right]=-\beta_2$$

since β_2 is negative, then -β_2 is positive. In addition, since:

$$\sigma^2\beta_2-\left(\frac{1}{2}\sigma^2-\alpha\right)<0$$

then:

$$\frac{d\beta_2}{d\alpha}<0$$

this implies that the first term into square brackets is positive. The sign of the derivative of Π^* with respect to α is however ambiguous due to the presence of the third term.

Appendix 6

The derivation of Π^* with respect to T:

The sign of $\frac{d\Pi^*}{dT}$ depends on the sign of $\frac{d\Phi}{dT}$, where:

$$\Phi = \frac{q\left(1-e^{-\rho T}\right)-K\rho}{1-e^{-(\rho-\alpha)T}}$$

$$\frac{d\Phi}{dT} : \frac{qe^{-\rho T}\rho\left(1-e^{-(\rho-\alpha)T}\right)-\left[q\left(1-e^{-\rho T}\right)-K\rho\right]e^{-(\rho-\alpha)T}(\rho-\alpha)}{\left(1-e^{-(\rho-\alpha)T}\right)^2}$$

Hence, the sign depends on the numerator. Suppose it is less than zero, then:

$$qe^{-\rho T}\rho\left(1-e^{-(\rho-\alpha)T}\right) < \left[q\left(1-e^{-\rho T}\right)-K\rho\right]e^{-(\rho-\alpha)T}(\rho-\alpha)$$

$$\frac{qe^{-\rho T}\rho\left(1-e^{-(\rho-\alpha)T}\right)}{e^{-(\rho-\alpha)T}(\rho-\alpha)} < q\left(1-e^{-\rho T}\right)-K\rho$$

$$q\rho\left[\frac{e^{-\rho T}\left(1-e^{-(\rho-\alpha)T}\right)}{e^{-(\rho-\alpha)T}(\rho-\alpha)}-\frac{\left(1-e^{-\rho T}\right)}{\rho}\right] < -K\rho$$

$$K < q\left[\frac{e^{-\rho T}\left(1-e^{-(\rho-\alpha)T}\right)}{e^{-(\rho-\alpha)T}(\rho-\alpha)}-\frac{\left(1-e^{-\rho T}\right)}{\rho}\right]$$

$$\frac{K}{q} < \frac{e^{-\alpha T}\left(1-e^{-(\rho-\alpha)T}\right)}{\rho-\alpha}-\frac{\left(1-e^{-\rho T}\right)}{\rho}$$

Hence, since the sign of $\frac{d\Phi}{dT}$ is negative, also the sign of $\frac{d\Pi^*}{dT}$ will be negative.

Otherwise, if

$$\frac{K}{q} \geq \frac{e^{-\alpha T}\left(1-e^{-(\rho-\alpha)T}\right)}{\rho-\alpha}-\frac{\left(1-e^{-\rho T}\right)}{\rho}$$

The signs of $\frac{d\Phi}{dT}$ is positive and also the sign of $\frac{d\Pi^*}{dT}$ will be positive.

Appendix 7

Yearly inflation rate 1988 = 5.1%
Yearly inflation rate 1989 = 6.3%
Yearly inflation rate 1990 = 6.5%
Yearly inflation rate 1991 = 6.4%
Yearly inflation rate 1992 = 5.3%
Yearly inflation rate 1993 = 4.6%
Yearly inflation rate 1994 = 4.1%
Yearly inflation rate 1995 = 5.2%
Yearly inflation rate 1996 = 3.9%
Yearly inflation rate 1997 = 2.0%
Yearly inflation rate 1998 = 2.0%
Yearly inflation rate 1999 = 1.7%
Yearly inflation rate 2000 = 2.5%
Yearly inflation rate 2001 = 2.8%
Yearly inflation rate 2002 = 2.5%
Yearly inflation rate 2003 = 2.7%
Yearly inflation rate 2004 = 2.2%
Yearly inflation rate 2005 = 2.0%
Yearly inflation rate 2006 = 2.1%
Yearly inflation rate 2007 = 1.7%
Yearly inflation rate 2008 = 3.3%
Yearly inflation rate 2009 = 0.8%
Yearly inflation rate 2010 = 1.5%

(ISTAT, 2011)
http://www.istat.it/salastampa/comunicati/in_calendario/paniere/20110204_00/

Appendix 8

Autocorrelation test regarding the ten time series object of the study. Figure 1 shows that the ADF tests are significant with lag = 4.

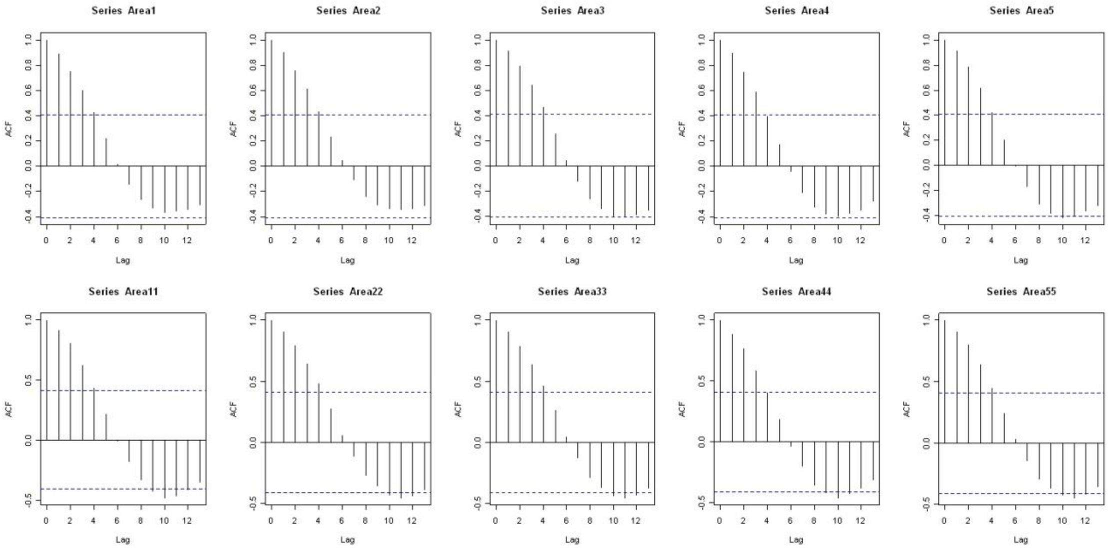

Figure 2. Autocorrelations test

Graphically, the time series for the five areas object of the study in both landscapes:

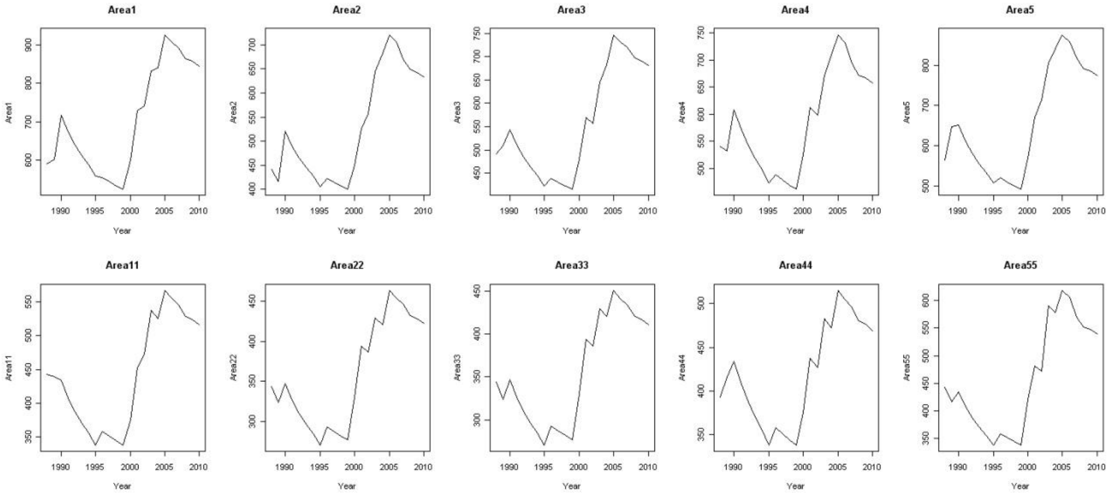

Figure 3. Time series