The effect of guaranteed prices for green certificates on technology adoption

Solar photovoltaic panels in Belgium

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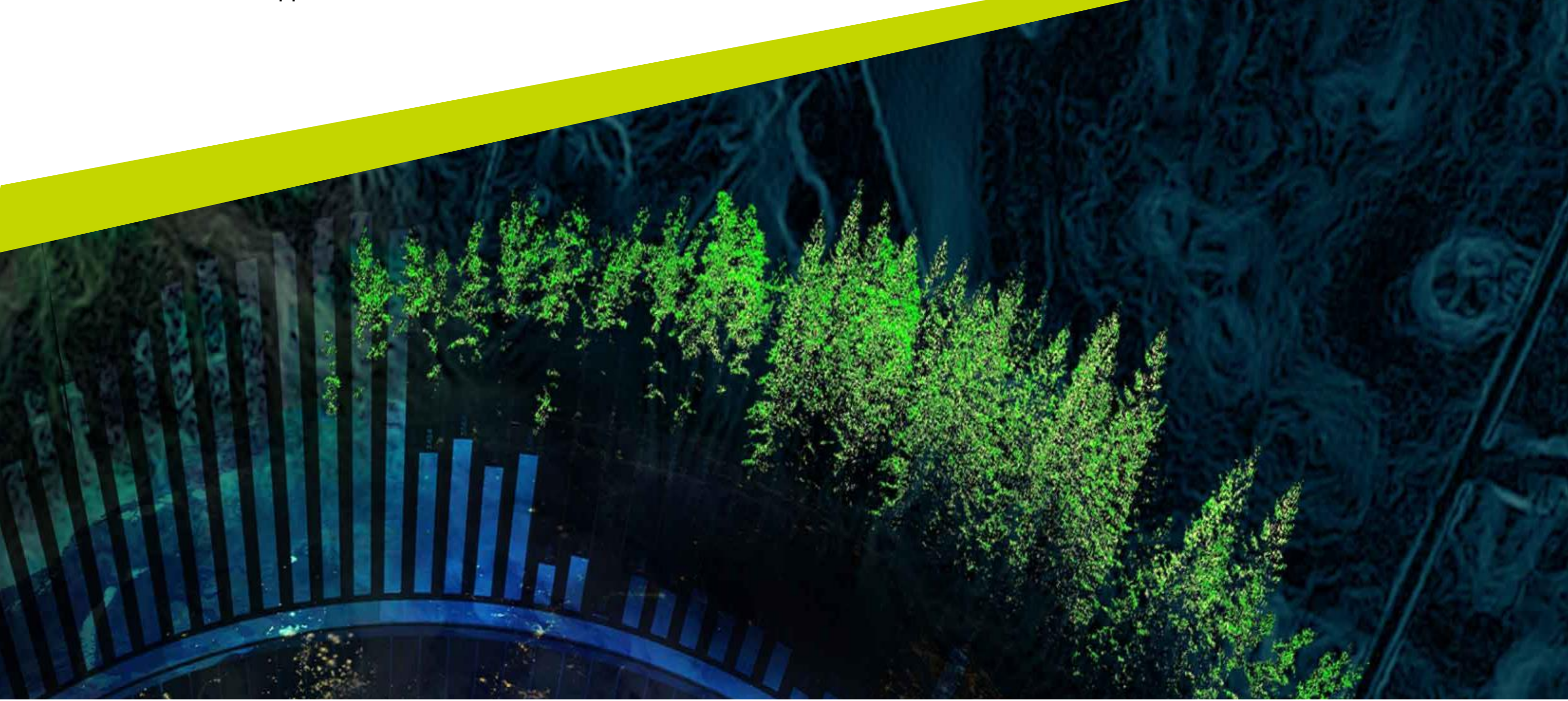

The effect of guaranteed prices for green certificates on technology adoption. Solar photovoltaic panels in Belgium

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Abstract

There is rising concern about the adverse implications of climate change on ecosystems and human livelihoods. This concern has led to a growing emphasis on enhancing the generation of renewable energy as a means to foster sustainability in societies. As part of this endeavor, governments around the world have tried to promote the adoption of renewable energy through different policy instruments. Countries, such as Belgium, have implemented a market for green tradable certificates. Additionally, regional authorities in the country have introduced guaranteed prices for certificates awarded to household solar energy systems. Through a two-way fixed effects model, this thesis investigates the relationship between uncertainty regarding future profits and the adoption of solar energy. Results suggest a positive relationship between the value of the minimum price and the adoption of solar energy systems in households. With a total cost of over €10 billion euros, this result suggests that around 20% of the total solar capacity installed in Belgium between 2008 and 2014 was related to the policy investments in the country.

Keywords: Renewable Energy Sources, Technology Adoption , Solar Energy, Policy Evaluation, Tradable Green Certificates, Household Solar PV panels, Guaranteed Prices.

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Abbreviations

€	Euro
EU	European Union
TGC	Tradable Green Certificates
kW	Kilowatt
kWh	Kilowatt-hour
kWp	Kilowatt-peak
MW	Megawatt
MWh	Megawatt-hour
MWp	Megawatt peak
PV	Photovoltaic
RES	Renewable Energy Sources
US$	US Dollar

1. Introduction

Renewable energy sources (RES) have been heavily promoted by governments over the past decades. Most policies have focused on promoting RES through subsidies, either by reducing direct investment costs or inflating production benefits. One example of how governments can inflate the benefits of production is by introducing a Tradable Green Certificate (TGC) market. A TGC market allows renewable electricity producers to obtain one or more certificates once a certain amount, typically 1MWh, has been generated. These certificates serve as proof that the amount was generated from renewable sources. The main aim of the system is to increase the share of green electricity generated by households. Green certificates can then be sold to the main electricity suppliers. For their part, the suppliers are obliged to achieve a certain percentage of renewable energy production in their supply portfolio. The concept of this policy is based on free competition between the suppliers of green certificates (e.g. private households) and the potential buyers of these certificates (e.g electricity suppliers). Given this free competition, the market should reach a price that is in equilibrium with the current characteristics of the sector. However, some institutions have increased security for households by setting a minimum price at which TGCs can be sold.

This study investigates the impact of decreasing uncertainty about future benefits for solar PV owners on the adoption of solar energy. Specifically, it explores the effect of a minimum price associated with green tradable certificates on the installed solar capacity.

In Belgium, the promotion of onshore renewables is the responsibility of the regional authorities. The federal government has set an overall framework by introducing a system of green certificates in the country, but each region is empowered to decide how to promote this system. Between 2008 and 2014, the two main regions of Belgium (i.e. Flanders and Wallonia) have targeted small installations (i.e. below 250kWp and below 10kWp respectively) to achieve this target. These types of installations could sell their certificates to the regional energy companies at a fixed price if they did not receive a suitable offer from energy suppliers. This guaranteed benefit, focused on the production of green electricity, reduced some of the uncertainty surrounding the selling price of the TGCs. The regional authorities were therefore able to guarantee households a minimum benefit after producing 1MWh from their solar PV systems. The value of this minimum price varied between regions and years. In 2014, both Wallonia and Flanders ended the production-based system and switched to different types of policies. This paper uses the volatility of the minimum price in both regions during this period to investigate the influence of a decrease in the uncertainty associated with production revenues on the adoption of solar panels. A two-way fixed effects model controlling for regional and time differences is used to determine the influence of this guaranteed profit on the adoption of solar energy. Although the minimum price volatility was observed for small installations, the total installed capacity is used due to data availabilities. At the beginning of the century, solar panel technologies were too expensive for households to invest, and only larger installations were profitable. Since then, data shows a dominance of smaller installations in the country (Energie commune, 2022). At the end of 2014, installations below 10kWp represented around 90% of Wallonia's total capacity (SPW, p. 59, 2016). They therefore accounted for a significant proportion of newly installed capacity over the study period.

The promotion of renewable energy sources has emerged as a pivotal responsibility for public authorities, due to the existence of two important distortions in the energy market. Distortions that have straightforwardly diverted the market from achieving social optimality. Namely, the historical energy market has been subject to the generation of a negative environmental externality and has suffered from a lag in technological progress. The negative externality generated by the market was mainly due to the importance of fossil fuels in the overall energy mix and the greenhouse gases released by their combustion. The lag in technological progress, on the other hand, was a consequence of the lack of incentives to invest in these technologies on the supplier side, combined with low uptake on the consumer side. Fossil fuels have always been associated with lower costs compared to any other alternatives. In a market that has evolved freely for a long time, reliance on fossil fuels has historically reached a level that can only be described as socially sub-optimal. However, there is a chance of hitting two birds with one stone. Realistically, this two-sided market failure can be defined as a market with one major failure leading to the second. Once the problem associated with the market failure for RES technologies is solved, reliance on fossil fuels should rationally decrease, and so should the negative externalities they engender. Government interventions to encourage investment in these technologies can therefore have multiple benefits. Solving the lag in RES technologies can be addressed in two ways: through a supply or a demand shock. In the specific case of solar energy, most of the supply of materials, both raw and finished, comes from Asia. China has been leading the race since 2008 and accounted for 75% of global production in

2021 (Earth Policy Institute, 2013; Fernàndez, 2023). European countries have therefore been left to generate this shock mainly on the demand side.

Furthermore, renewable energy sources can provide energy security. The current energy crisis in Europe due to the war in Ukraine and its impact on inflation and purchasing power is a clear example of how important energy security is. Due to its heavy dependence on Russian gas, the Old Continent has been severely affected by the reduction in Russian gas exports. Renewable energy can play a crucial role in providing energy security by diversifying energy sources, reducing dependence on finite resources and mitigating the risk of supply disruptions generated by geopolitical tensions. Renewable energy sources are widely spread and available in most parts of the world. Their global availability can reduce the risk of energy supply disruptions or natural disasters such as storms, earthquakes and forest fires. However, renewable energy systems, such as solar panels, still rely on rare earth elements for their manufacture. As their names suggest, these types of metals can only be found in very specific places of our planet. As a result, RES can still be at the mercy of geopolitical tensions. However, most solar panel manufacturers are located within reasonable proximity to the mines extracting such rare elements, with China leading the way in both areas again. This reduces their vulnerability to geopolitical tensions compared to a market that relies predominantly on fossil fuels. The availability and reliability of energy supplies are essential for economic development and prosperity. However, the majority of the world's energy supply still comes from finite fossil fuel reserves, which are subject to these tensions. By promoting renewable energy, governments can diversify their energy mix and reduce their dependence on fossil fuels from foreign countries. This can improve energy security and reduce vulnerability to energy price volatility and supply disruptions.

Due to the current threats that climate change poses to our planet, there is general agreement that we need to rethink our entire consumption pattern away from fossil fuels. The combustion of fossil fuels releases large amounts of greenhouse gases, which have been identified as the leading factor in global climate change (Ramanathan and Fend, 2009). Governmental institutions such as the European Union or the United Nations have therefore set targets to move away from fossil fuels in the foreseeable future. The UN's 2030 Agenda for Sustainable Development is a clear example of such targets. This agenda sets out 17 Sustainable Development Goals. As a matter of fact, goal number 7 is to ensure access to affordable, reliable, sustainable and modern energy for all (United Nations, 2015). Similarly, the European Commission launched a 2030 Climate Action Plan, which aims to reduce greenhouse gas emissions by 55% by 2030 compared to 1990 levels. By 2050, the continent should be completely carbon neutral. At the heart of this shift in consumption is therefore the energy sector, which has relied heavily on fossil fuels since the industrial revolution. Renewable energy sources have been highlighted as a great tool to initiate this transition. These types of energy have the advantage of not releasing harmful particles into the atmosphere when generating electricity. Additionally, the challenges posed by climate change are closely linked to social challenges around the world. Renewable energy sources can also make a contribution in that aspect. RES offer long-term price stability as the cost of technologies such as solar continues to fall. This can help reduce energy poverty and improve access to energy for low-income communities, as well as reduce the economic vulnerability of countries that are heavily dependent on imported energy resources.

Although the cost of renewable energy technologies is falling, historically there has been insufficient incentives to invest in these types of technologies compared to market needs. This was largely due to the fact that traditional energy sources, such as fossil fuels, were relatively cheap and widely available. As a result, there was little motivation for governments and businesses to invest in RES technologies. In addition, the lack of investment in RES has been perpetuated by policies that have favoured traditional energy sources. This has led to an uneven playing field for renewable energy technologies, with fossil fuels continuing to dominate the energy mix. In recent years, however, the cost of renewable energy technologies has fallen dramatically, making them more competitive with traditional energy sources. Since 2004, the share of renewables in gross final energy consumption has more than doubled (Eurostat, 2023). In 2021, renewables will account for more than a third of gross electricity consumption in the EU. Some countries, such as Iceland and Norway, have even achieved a fully renewable electricity market. Norway has even managed to produce more renewable electricity than it consumed in 2021, taking its share above 100%. Solar energy was the fastest growing source, rising from an individual share of 1% in 2008 to more than 15% of total renewable electricity generation. These values highlight the surge in investment in RES that has taken place in the EU. Recent literature has therefore sought to understand where this surge in investment has come from. Within this research, governmental institutions have mostly tried to find answers to two very important questions. Has the current shift towards renewables been triggered by successful government policies? If so, could the same level of improvement have been achieved at a lower cost? This thesis focuses on the first fragment, but also addresses the second.

2. Literature Review

The adoption of renewable energy systems, particularly solar energy, is a critical step in achieving sustainable development and mitigating climate change. However, the process of technology adoption is complex and influenced by several factors, including individual attitudes, social norms and policy interventions. This section highlights some of the key factors influencing the adoption of solar energy systems and assesses the effectiveness of policy interventions in this area.

Several studies have identified the main factors influencing the adoption of solar energy systems. Schelly (2014) studied early adopters of solar panels and suggested that environmental motivations, economic considerations and demographic characteristics all play a role, but not individually. It seems to be the combination of all these factors that characterises the so-called early adopters in the US. In South Korea, a study introduced an integrated adoption model and concluded that trust, system quality and perceived benefits play a role in public attitudes towards solar energy technologies. Intention to use these technologies, on the other hand, was influenced by public attitudes and satisfaction, as well as perceived costs (Kim et al, 2020). Jacksohn et al. (2019) came to a similar conclusion regarding the cost of the technology. The study included a similar range of factors and concluded that the most important factors influencing the adoption of solar panels were economic. Economic factors appear to outweigh both personality and socio-demographic factors. In addition, the initial cost of the project seemed to have a greater impact on adoption than the income from the project. This observation is consistent with the concept of discounted utility and time preferences (Samuelson, 1975). Costs are incurred at the beginning of the project and usually all at once, whereas revenues are incurred once the project is adopted and continue throughout the life of the structure. In light of these findings, policymakers around the world have focused their efforts on increasing the economic attractiveness of solar PV installations.

Bauner and Crago (2015) used option valuation to examine the power of uncertainty on the adoption of residential solar power in the presence of renewable energy incentives. The authors found that uncertainty about future electricity prices and the cost of solar installations had the power to delay, and even discourage, households from adopting solar systems. Bauner and Crago (2015) also showed that the size of the incentive needed to overcome this uncertainty depended on the degree of uncertainty and the level of risk aversion of households. They concluded their analysis by arguing that policymakers should consider the uncertainty inherent to the adoption of renewable energy technologies, and aim to reduce it as much as possible when designing renewable energy policies. Policies that directly affect the uncertainty surrounding solar PV projects should therefore have the power to stimulate the adoption of this technology.

Several studies have explored the effectiveness of policy interventions that targeted the previously mentioned indicators of solar adoption. Matisoff and Johnson (2017) investigated the comparative effectiveness of different types of residential solar incentives in the United States. They found that, on average, the return on a US$1 investment was an increase of just under 0.5kW of solar capacity per thousand residential electricity customers. The combination of direct financial incentives, financing initiatives and net metering was found to have a significant impact on residential solar adoption. Direct financial incentives being a particularly strong driver of adoption. Interestingly, Matisoff and Johnson (2017) also found that two-thirds of observed solar incentives failed to lead to an increase in residential solar PV installations. The incentives that did not trigger solar PV installations involved a complex administrative process, took a long time to deliver, or were contingent on the payment of taxes before they could be claimed.

In Europe, two main types of policy have emerged as the preferred policy instruments for promoting the uptake of renewable technologies. These two instruments are feed-in tariffs and tradable green certificates. Feed-in tariffs have been preferred in countries such as Spain, Germany and Denmark, while green certificates have been preferred in Sweden, Belgium and the UK. A large body of literature has examined the former policy, with the main findings being that feed-in tariffs have been able to promote technology development and diffusion, but at a relatively high cost (Del Rio and Gual, 2007; Rowlands, 2005). Sweden was an early adopter of the latter policy. Bergek and Jacobsson (2010) analysed the Swedish green certificate market. This system was introduced at the beginning of the twenty-first century as a market-based policy instrument to promote renewable energy. They found that the system has been successful in increasing the share of renewable energy in the electricity mix, but that it has also been subject to some challenges and criticism. Namely, the system led to windfall profits for renewable energy producers, as the price of certificates was higher than the cost of producing renewable energy. Another criticism was that the system was not effective in promoting innovation and technological development, as the certificates were mainly used to support existing technologies rather than new ones. Bergek and Jacobsson (2010) conclude that the Swedish green certificate system has been a cost-effective policy instrument and should be preferred when the main concern is to minimise the short-term social costs of achieving a certain target with a high degree of certainty, but cannot be expected to drive technological change at the same time.

Belgium was also an early adopter of the TGC system, with its northern region (i.e. Flanders) being the first to implement it. As a result, several evaluations have examined the effectiveness of the programme between 2006 and 2013 in this region. Huijben et al. (2016) found that the government policy was effective in stimulating the growth of the PV market in the region. The article presented a comprehensive and chronological analysis of the different types of government support instruments used to promote the rapid growth of the solar energy market in this region of the country. The authors carried out economic calculations to determine the relative contributions of these instruments and found that TGCs had the greatest impact, driving both the growth and eventual stagnation of the market. These certificates cost around €1.5 billion between 2006 and 2013, and the long-term social costs were estimated to be even higher, reaching €6.7 billion between 2014 and 2031. The costs were found to be unevenly distributed, with residents bearing the brunt through higher energy bills. It was also found that companies were adapting their organisations to take advantage of the support instruments available, although counter-intuitively the substantial support shifted the focus towards larger systems, despite the incentives to invest in smaller systems were higher.

The system implemented in Flanders was also used to build a model analysing the effect of subsidies on the timing of new technology adoption by firms (De Groote and Verboven, 2019). The authors found that firms with a lower discount rate were more likely to adopt a new technology earlier, even in the absence of subsidies. However, subsidies accelerated adoption for firms with higher discount rates. This suggests that subsidies may help overcome the initial investment costs of adopting a new technology, which may have been too high for firms with high discount rates. The authors tested their theoretical model using data on the adoption of solar photovoltaic technology in Flanders. They found that subsidies had a positive effect on the adoption of solar PV technology, especially for firms with high discount rates. They also found that the effect of subsidies was larger for smaller firms, which have fewer financial resources to invest in new technologies. Furthermore, De Groote and Verboven (2019) investigated the effect of the subsidy levels on the adoption of solar PV technology. They found that a higher subsidy rate led to a higher probability of adoption, but that the marginal effect decreased as the subsidy rate increased. This suggests that there may be diminishing returns to increasing the subsidy rate. Subsidies could therefore be an effective policy tool to promote the adoption of new technologies, especially for firms with a high discount rate.

However, the authors warn that the level of subsidy should be carefully calibrated to avoid wasteful spending and to ensure that the subsidy is effective in achieving its objectives.

No real research has been conducted for the whole country, where similar policies have been implemented in the southern region (i.e. Wallonia). This thesis extends the current literature for Flanders to the case of Wallonia and how both regions may have been affected by different levels of certainty regarding future benefits for small-scale solar PV installations between 2008 and 2014. Furthermore, it quantifies the total impact of governmental investments in the country on solar adoption during that period. With the combination of marginal certainty effects and total budget costs, this thesis provides a global assessment of the institutions' role in the adoption of solar energy.

3. Policy and Data Description

Even in a market where green certificates are dominant, an investment in solar energy is particularly risky for households. Future selling prices are unknown by people with limited knowledge of the energy market, but also for experts. The global risk aversion regarding such investments may therefore be a blocking factor for the adoption of solar energy. Regional authorities in Belgium have decided to make such investment less risky for households.

Flanders was the first region to take action in that direction. In 2006, the Flemish government introduced a purchase obligation and guaranteed minimum price for Flemish distribution system operators for certificates issued from a solar PV source. Under this obligation, energy suppliers, which are controlled by government agencies, were required to buy certificates at a predetermined price. The allocation of certificates in this region has always followed the system preferred at federal level. A certificate would be issued after the generation of 1MWh of electricity from a renewable energy source. For solar installations below 250kW, the guaranteed price was set at €450 per certificate. (European Commission, 2018). In May 2009, the Flemish government published its own 'Energy Decree', which included a revision of the existing minimum support level for January 2010 (Energiedecreet, 2009). Later, this decree has been revised several times, and Table 1 shows the evolution of the guaranteed price, the period in which this price would apply, and when the revision was implemented.

Table 1: Policy evolution in Flanders[1]

Date of revision	Date of implementation	Updated minimum price	Period impacted
May 8th, 2009	January 1st, 2010	350€ 330€	2010 January-June 2011
June 10th, 2011	June 30th, 2011	300€ 270€ 250€ 230€	July-September 2011 October-December 2011 January-March 2012 April-June 2012
April 12th, 2012	July 1st, 2012	210€	July 2012
July 30th, 2012	August 1st, 2012	90€ 93€ 93€	August-December 2012 2013 2014

It was not easy to define an exact minimum price, given the constant adjustments. However, the solar capacity data in this paper includes annual observations. Using the values from Table 1 and the length of time a price was in place within a year, the following values were generated as an average of the guaranteed price in place within a year.

Year	2008	2009	2010	2011	2012	2013	2014
Minp	450€	450€	350€	307.5€	176€	93€	93€

For the year 2011, the average minimum price that would be available to new installations has been calculated on the basis of the following formula, where MP_{2011} stands for « Average minimum price per TGC in 2011 » :

$$MP_{2011} = 330€/TGC * \left(\frac{6}{12}\right) + 300€/TGC * \left(\frac{3}{12}\right) + 270€/TGC * (\frac{3}{12}) = 307.5€/TGC$$

The guaranteed price was 330€/TGC for the first 6 months of the year, then 300€/TGC for the next 3 months and 270€/TGC for the last 3 months of the year. The same reasoning was used for 2012. The guaranteed price remained unchanged in the other years in the dataset.

[1] The values included in Table 1 are the guaranteed prices for installations with a maximum peak power of 250kW.

A few years after Flanders took the first step, Wallonia joined the race to promote solar energy. On 20 December 2007, a Walloon government decree on various measures to promote electricity from renewable energy sources introduced a minimum price for the local electricity grid operator of €65 per certificate (Gouvernement Wallon, 2007, p.11). This price was selected to not overcrowd the current free market as the average price per certificate in the region was around €90 in the 2005-2007 period (CWAPE, 2008). However, the strategy in Wallonia differed from the one in Flanders. In parallel with this decree, the Walloon government launched a programme called "Solwatt". Until 2014, the guaranteed price per certificate remained the same, but the number of certificates per MWh was inflated for newly installed small-scale PV systems. After 2014, the government changed its strategy and opted for another program, favouring an annual bonus for this type of installation instead. Over the years, several multiplication methods have been introduced. The first method, which lasted until the end of 2011, depended on the size of the installation. After generating 1MWh, the owner of the installation would receive 7 certificates for the first 5kWp installed and 5 certificates for the next 5kWp. Installations between 10 and 250 kWp capacity would receive 1 or 4 certificates depending on several regulations. An installation with a capacity of 7kWp would receive 6.43 certificates per MWh whereas a 4kWp installation would receive 7 certificates. In other words, the smaller the installation, the bigger the minimum price.

From 2012 onwards, the policy changed to a calculation based not on the size of the installation, but on how long it has been installed. The older the installation, the fewer certificates it would receive. Generating an accurate value for the minimum price that each installation could benefit therefore requires a specific dataset with information at an individual level. Unfortunately, such data was not available for this work. Nonetheless, data was available on the total amount of electricity generated by solar PV installations in the region and number of solar certificates issued each year in that region. By combining these two data sets, it was possible to calculate an average number of certificates issued per megawatt-hour. This value was then multiplied by the €65 guaranteed per certificate, resulting in a variable that is the current guaranteed benefits in place in the market in a given year. This variable is expected, in this thesis, to influence the adoption of solar PV in that year. Table 2 shows how the minimum prices were obtained during the Solwatt period.

Table 2: Minimum prices per MWh in Wallonia[2]

Year	Electricity Generated (MWh)	Number of certificates awarded	Number of certificates per MWh	Average minimum price (€/MWh)
2008	1,519	10,138	6.674	433.81
2009	22,233	152,004	6.837	444.405
2010	54,594	370,914	6.794	441.61
2011	140,663	938,066	6.669	433.485
2012	416,174	2,749,567	6.607	429.455
2013	578,019	4,006,364	6.931	450.515
2014	722,849	4,627,428	6.402	416.13

The price per MWh is used here instead of the price per certificate in order to to compare the values in Table 2 with the prices per certificate in Flanders, as they both represent guaranteed benefits after 1MWh. *Figure 1* highlights the policy numbers and shows the minimum prices applied in both regions during the period 2008-2014. This figure shows a continuous decrease in the minimum price per MWh for Flanders, whereas this value seems to have been relatively more constant in Wallonia. Additional variables were also used in this thesis. These are the price per kilowatt of solar PV installations[3], the regional population size[4] and the annual installed capacity[5].

[2] Data in Table 2 were retrieved from the annual report of 2014 from the CWAPE related to the evolution of the green certificate market in Annexe 2 : « Évolution de la production d'électricité sur la période 2005-2014»

[3] Data expressed in constant 2021 US$/W for solar PV installations represent world prices and were retrieved from: https://ourworldindata.org/grapher/solar-pv-prices?time=2006..2014 and transformed in €/kW using 2021 average exchange rate from the European Central Bank retrieved from: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html

[4] Population sizes for both regions represent the numbers of inhabitants in the region on January 1st of the year. Data was retrieved from: https://bestat.statbel.fgov.be/bestat/crosstable.xhtml?view=fc14c1ce-7361-4d42-a892-fce8e81a1b79

[5] Yearly capacity retrieved from: https://energiecommune.be/statistique/observatoire-photovoltaique/ for both regions.

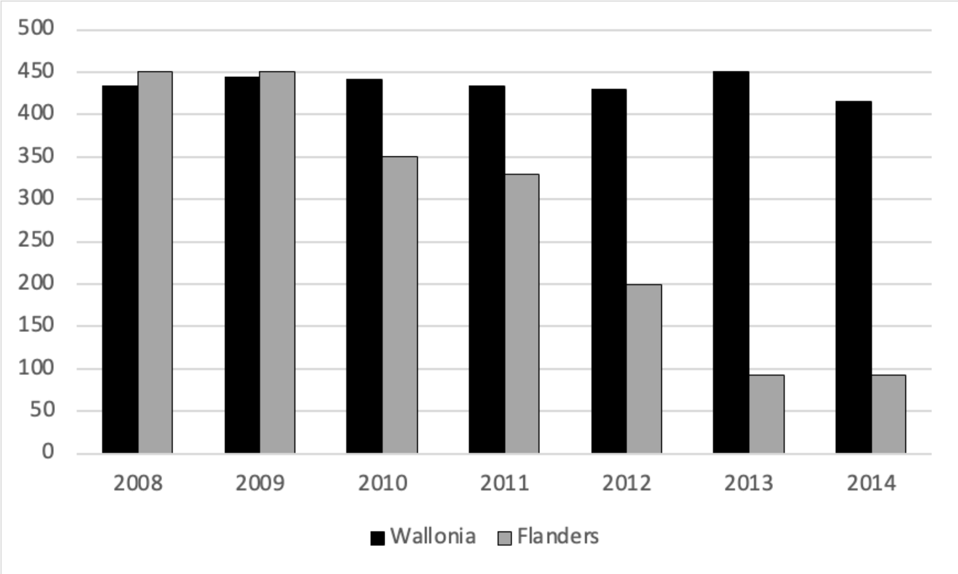

Figure 1: Guaranteed Prices (€/MWh)

Below are some additional relevant descriptive statistics for both regions from the available dataset. On average, the minimum prices for TGCs in Flanders were almost €155 lower than those granteed to Walloon installations. This was mainly due to the calculation of the minimum price. The variation of the minimum price in Wallonia was smooth, with values fluctuating between €416 and €451 per MWh during the Solwatt programme. Conversely, the policy design in Flanders produced values within a much wider range, from €455 at the beginning of the analysis to €93 at the end. On the other hand, the average annual per capita installed capacity in Flanders exceeded that in Wallonia over the same period. The highest value in the former region exceeded the best performance of the latter by more than 75%. *Figure 2* shows the evolution of this variable over time in both regions. After a sharp increase in 2011, installed capacity per capita fell sharply in Flanders, and a similar observation can be made with a one-year delay in Wallonia. Overall, total solar capacity per capita has increased in both regions over the period observed. The increase in Wallonia can be considered as almost continuous, whereas the increase in Flanders started steeply before reaching a kind of plateau after 2011. *Figure 3* shows this observation. The combination of *Figure 2* and *Figure 3* suggests that the Flemish market may have reached some sort of maturity. An analogous plateau does not seem to exist in the Walloon region yet. Furthermore, the population in Flanders is almost double that of Wallonia. Prices per kilowatt for solar PV installations were assumed to be the same in both regions. They have been continuously decreasing, with a first observation of more than 3500€/kW in 2008, down to just under 575€/kW in 2014.

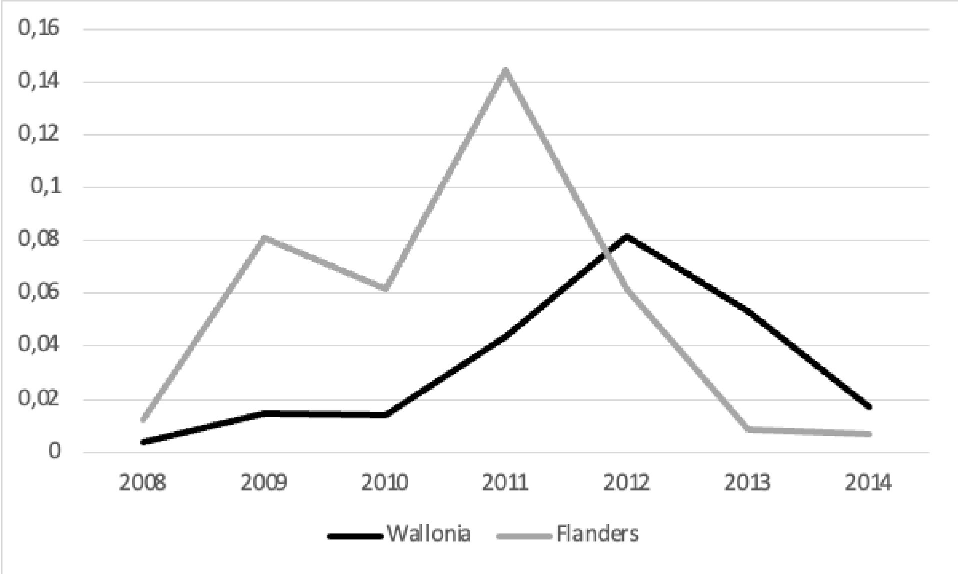

Figure 2: Yearly Installed Solar Capacity per Capita (kW/inhabitant)

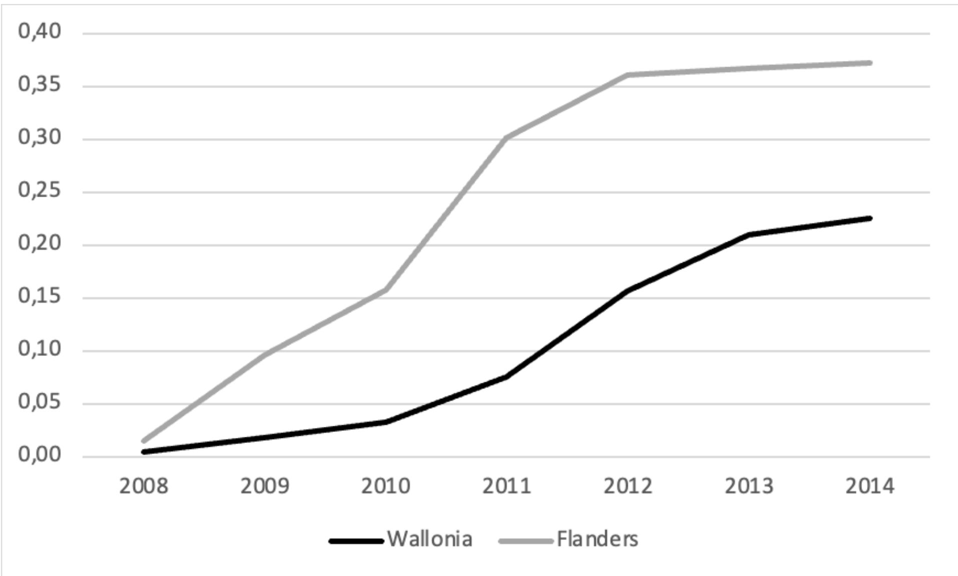

Figure 3: Cumulative Solar Capacity per Capita

A final set of variables was included to assess the overall efficiency of these policies. This set includes total policy cost, average household size, average energy yield and average installation size. The total cost in the country was around €10 billion[6] over 16 years. In both regions, new installations were given minimum prices for a certain period of time and both are still paying. The average household size remained constant in Wallonia at 2.29 persons per household, while in Flanders, this variable fluctuated slightly with an average of 2.35 persons per household[7]. The average energy yield was taken from Leloux et al. (2015) and amounted to 908 kWh/kW, in the country[8]. This figure corresponds to the amount of electricity generated in one year per kW of installed solar PV. Finally, the average installation size was estimated using observations from De Groote and Verboven (2019). Full descriptive statistics for both regions can be found Table *6* and Table *7* in Appendix 1.

[6] Data for total cost: https://doi.org/10.3917/rpve.541.0071 in Wallonia and https://www.serv.be/serv/publicatie/rapport-hernieuwbare-energie in Flanders.

[7] Data retrieved from: https://www.geo.be/catalog/details/a64fd4ae-1fa4-11ec-8223-7478273ff935?l=en for Wallonia and: https://provincies.incijfers.be/databank for Flanders, during the 2008-2014 period.

[8] Data retrieved from: https://www.geo.be/catalog/details/a64fd4ae-1fa4-11ec-8223-7478273ff935?l=en for Wallonia and: https://provincies.incijfers.be/databank for Flanders, during the 2008-2014 period.

4. Econometric Model

Between 2008 and 2014, Wallonia and Flanders both implemented policies that included a guaranteed price for green certificates. However, the determination of this minimum value differed between the regions. Flanders set a fixed euro value per MWh that remained unchanged for a certain period, while Wallonia increased the number of certificates available. This number was mainly influenced by the size or the age of the installation, as explained in the previous section. In Wallonia, although the minimum value of a certificate was fixed for the period analysed, the number of certificates granted varied considerably over the same period. As a result, the guaranteed benefits after the production of 1 MWh by the relevant installations varied considerably in these two regions.

This thesis uses panel data to address the research question, allowing the inclusion of time and regional fixed effects as control variables. Both individual unobserved characteristics and confidence in renewable energies play pivotal roles in their adoption. First, these unobserved characteristics are expected to show significant variation over time. In addition, the increasing body of research on global warming is expected to heighten interest in RES technologies, thereby exerting a notable influence on their adoption (Schelly, 2014). Furthermore, the disparities between the populations of different regions in Belgium are expected to be more pronounced than in many other countries. Historical and linguistic differences have contributed to a clear divide between the populations amongst regions. The proliferation of successful separatist parties in Flanders serves as a clear manifestation of the gradual cultural and social divergence (Billiet et al., 2006). In terms of sustainable behaviors, Flanders has traditionally held a comparative advantage over the other regions.

Moreover, economic characteristics differ both between years and over time. GDP per capita has been increasing continuously since 2008, but is significantly higher in Flanders than in Wallonia. Both time-varying and fixed regional characteristics should therefore play a role in the adoption of solar PV panels and need to be controlled for.

In this two-way fixed effects model, the chosen dependent variable is the annual installed capacity per capita, while the independent variable is the value of the guaranteed benefits received after generating one megawatt-hour of solar electricity. The regression also includes the price of solar panels as a control variable, along with controls for time and regional fixed effects. The cost of the investment being highlighted as one of the major factor influencing adoption in the literature (Jacksohn et al., 2019; Kim et al., 2020). The regression model can be presented as follows:

$$Installed\ capacity\ per\ capita_{rt} = \beta_1 MP_{rt} + \beta_2 PVp_t + \lambda_t + \alpha_r + \varepsilon_{rt}$$

The subscript « r » denotes the regional category, and « t » denotes the time category for each data point. The variable « $Installed\ capacity\ per\ capita_{rt}$ » denotes the annual installed capacity in megawatt-peak (MWp) per inhabitant, calculated by dividing the annual installed capacity in region *r* and year *t* by the population size of that region at the given year. This per capita variable allows for a comparative analysis of the two regions despite their different demographic characteristics. The primary variable of interest, « MP_{rt} », is expressed in euros per megawatt-hour (€/MWh) and represents the guaranteed benefits that new solar PV installations in region *r* could earn after generating 1 MWh of electricity at time *t*. This variable can be thought of as an instrument influencing certainty with regards to future earnings. The most relevant coefficient in this thesis is called « β_1 » and is expected to be greater than zero. It quantifies the effect of an increase in guaranteed benefits for future production on the annual installed solar capacity per inhabitant.

In addition, the variable « PVp_t », which represents the world price for solar PV installations in euros per kilowatt (€/kW), is included in the regression as a control variable. This variable is only subject to time variation and is assumed to be the same in both regions, as the country's solar energy market relies on imports, and overall global prices do not vary significantly between the two regions. The control variables « λ_t » and « α_r » account for time and regional fixed effects, respectively. These control terms play a central role in the analysis, as the use of panel data allows for the examination of unobserved factors that may influence solar PV adoption by controlling for time and regional differences.

Nevertheless, for this regression to yield meaningful interpretations, several additional identifying assumptions must hold. First, the regression should be free of omitted variable bias, i.e. there should be no variable that influences both the minimum price and the adoption of solar PV. The panel data regression provides some confidence that this assumption is met, as it controls for unobserved time-invariant factors that may vary across regions, as well as potential time trends that may influence both variables. Second, the independent variable should be exogenous. In other words, there should be no variables affecting the value of the minimum price that are excluded from the analysis. The main threat to this assumption comes from the possibility of reverse causality, wherebe the decision to set a minimum price and its value could be influenced by investments in previous years. An increase in the value of the minimum price for TGCs could be a consequence of underinvestment in the past. Robustness checks will provide insight into the magnitude of each of these threats and their potential impact on the validity of the model. These include a focus on potential effects of GDP per capita, lagged effects, and checks for reverse causality and endogeneity biases. A number of limitations and possible improvements will complete the analysis.

The statistical software Stata was utilized to run this model, employing the "xtreg" command to analyse the available data as panel data. By specifying the dataset using the "xtset" command, the software considers the year variable as the time factor and the dummy variable identifying the region as the grouping factor.

5. Results

5.1 Model Results

Table 3 presents the main results from the two-way fixed effects analysis. In particular, the coefficient of primary interest (i.e. β_1) shows a statistically significant relationship with the dependent variable. This suggests that the minimum price for tradable green certificates has a significant influence on solar energy adoption in Belgium, at the 10% confidence level. In line with the initial hypothesis, the effect exhibits a positive direction. However, the magnitude of the effect appears to be relatively small. The results indicate that a €1 increase in minimum price would be associated with a 0.22W increase in solar installations per capita. These results are consistent with the findings of Matisoff and Johnson (2017). The authors concluded that the average return on a $1 intervention would be an increase of just under 0.5kW in solar capacity per thousand customers. The study examined several types of incentives for residential solar panels, which would place the results from Table 3 at the lower bound of the efficient policy rankings.

However, in order to fully understand the impact of the policy as a whole, some manipulations need to be made. First, with an average size of 2.32 people per household in the country, the same marginal effect on household adoption increases to about 0.5W per household. Using marginal effects in this particular case may not grasp the full extent of the policy effect. On the other hand, the availability of data on total costs allows for meaningful interpretations regarding the full impact of such policy. With a bill reaching €10 billion over 16 years, this represents an investment of €625 million per year for both regional governments combined. This amount can then be divided by the number of households to give the average annual investment per household. On average, this means that government support amounted to €147.4 per household each year. This cost can now be combined with the approximation of 5kW per installation for households and the average solar PV panel yield in the country of 904kWh/kW. On average, a household with these characterisitcs would therefore produce 4.54MWh of solar electricity per year. The size of the certainty increase provided by the government, measured in € per MWh throughout this thesis, was therefore 32.47€/MWh per household. The final step is to compute the effect of this level of certainty on the installation of solar capacity from Table 3, which amounts to an increase of 16.59W per household. The average installed capacity throughout the country during the period analysed was 78.20W per household. This implies that, according to the results from Table 3, the total amount spent by public authorities appears to have been associated with 21.21% of the solar PV adoption in Belgium, at the 90% confidence level. This shows that a significant share of solar adoption in the country was achieved through successful policy interventions. Surprisingly, however, no significance could be found for the price of solar panels. A reason behind this observation may be the use of world prices instead of installation specific prices.

Table 3: Two-Way Fixed Effects Analysis

	Coefficients	Std. Errors	[95% Conf. Intervals]
Minimum price	0.0002263*	0.0001207	[-0.00001 ; 0.00046]
Solar PV price	-8.92e-06	7.38e-06	[-0.00002 ; 5.54e-06]
Flanders	0.0562098**	0.024932	[0.00734 ; 0.10508]
2009	0.018765	0.0288418	[-0.03776 ; 0.07529]
2010	0.0115287	0.0284124	[-0.04416 ; 0.06722]
2011	0.0698355**	0.0284672	[0.01404 ; 0.12563]
2012	0.0462905	0.0309554	[-0.01438 ; 0.10696]
2013	0.01557	0.030831	[-0.04486 ; 0.07600]
2014	0	(omitted)	
Constant	-0.0657516	.0452605	[-0.15446 ; 0.02296]
Observations	14		
Prob > Chi2	0.0269		
Corr (ε, X) =	0		
Time fixed effects	YES	(assumed)	
Regional fixed effects	YES		

P-values are presented in the following forms:
$p < 0.1$ = *, $p < 0.05$ = **, $p < 0.01$ = ***

The variable labelled as « *Flanders* » in Table *3* is the dummy variable that includes the regional fixed effect factor. If the data point was observed in Flanders, the dummy variable takes the value of 1, otherwise it takes the value 0 for data from Wallonia. This variable captures any unobserved characteristics that may contribute to differences in the variable of interest between the two regions. These characteristics can range from attitudes towards renewable energy sources to deeper cultural disparities that could affect the adoption of solar PV. The analysis suggests that Flanders has a statistically significant advantage of 56.21W per year over Wallonia in terms of the dependent variable, at the 5% level. This result was expected from the descriptive analysis. The mean value for installed capacity per inhabitant was 32.4W in Wallonia and 53.6W in Flanders. These figures are included in the descriptive statistics in Table *6* and Table *7*.

As far as the specification of the model with time fixed effects is concerned, there is no discernible global time trend in the installation of solar PV in Belgium over the whole period under study. *Figure 2* illustrates this observation, as the independent variable shows a decline after 2012. Compared to 2008, only 2011 shows a significantly higher installed capacity per capita, with 95% significance. The analysis shows that the installed capacity in Belgium in 2011 was 69.84W per inhabitant, significantly higher than in 2008. In addition, the Chi-square value gives an indication of the joint significance of the independent variables in the regression model. With a value below 0.05, the null hypothesis that all coefficients of the independent variables in the model are equal to zero can be rejected with confidence. However, several sensitivity analyses still have to be carried out to ensure the validity of these results.

5.2 Sensitivity Analyses

This section includes these sensitivity analyses. As highlighted by most of the relevant literature in this field, economic factors play an important role in the adoption of solar energy systems. Therefore, the first sensitivity analysis to investigated is the role that GDP per capita could play in this context. The same analysis was therefore carried out, this time including GDP per capita. Table *8* shows the final results. With the inclusion of GDP per capita, no significance could be found for any of the variables included. This would imply that neither the policy intervention, nor the price of solar panels, nor the economic situation of households play a role in the adoption of solar energy. There are several explanations why GDP per capita should not be included in this specific analysis. First, *Figure 4* shows that GDP per capita was significantly higher in Flanders than in Wallonia. The results for the *Flanders* variable in Table 3 could therefore include some of the effect of GDP per capita. Given the small number of observations, the integration of additional variables may have introduced unnecessary biases into the model. In addition, pairwise correlations with all explanatory variables from this specification were computed and presented in Table *4*. Pairwise correlations calculate the correlation coefficient between two variables across all observations, without taking into account the panel structure of the data. Regional data must therefore be analysed individually for both GDP per capita and for the minimum price variables.

The price of PV panels is assumed to be the same in both regions and therefore does not need to be specified in a similar way. Table 4 shows that GDP per capita for both regions is significantly correlated with almost all relevant explanatory variables. The only variable with which it does not seem to be significantly correlated to is the minimum price in Wallonia.

Table 4: Pairwise correlations

	Minp Fl	Minp W	PV price	GDPc W	GDPc Fl
Minp Fl	1				
Minp W	0.27	1			
PV price	0.89*	0.19	1		
GDPc W	0.94*	-0.49	-0.83*	1	
GDPc Fl	0.96*	-0.45	-0.83*	0.98*	1

* corresponds to a correlation with a p-value < 0.05

However, such a significant correlation with so many variables raises the question about potential multicollinearity. GDP per capita therefore seems to create more problems for the model than it solves. In the initial specification, the development of the minimum price in Flanders seems to be significantly correlated with that of the price of solar panels. However, the same statement does not seem to be true for the minimum price in Wallonia. Multicollinearity in the initial specification thus seems to be a somewhat smaller problem, but still should be considered, especially given the constant modification of the energy decree in Flanders.

The direct effect of certainty has been used for solar adoption. However, the hypothesis that this effect may indeed be lagged should be investigated. Households may use observations from previous years in order to make their investment decisions. Table *9* reports the results of an analysis that includes the value of the minimum price in the previous year as an additional control variable. Compared to the original analysis, all effects remained similar and no lagged effects could be observed. The sign of the effect and the level of significance also remained unchanged. Table *9* therefore suggests that the relationship between an increase in certainty and solar adoption is relatively direct.

One additional issue that can affect the validity of the model's results is the potential for reverse causation. In other words, there may be reasonable doubt about the determination of the independent variable. The level of government support for solar systems could be a response to low public interest in previous years. In the case of this thesis, problems of reverse causality may overestimate the effect of the policy. If minimum prices had been lowered in response to overinvestment (as in Flanders, for example), then the supposed reduction in installed capacity would not only be due to the lower guaranteed price, but could also be a response to overinvestment in the past, which would crowd out future investment. Leszczensky and Wolbring (2022) provide a guideline for researchers to deal with different types of threats, in particular reverse causality. According to their work, the following equation can help to identify reverse causality:

$$x_{rt} = \beta_1 y_{rt-1} + \beta_2 Z_r + \mu_{rt}$$

Where x_{rt} is the value of the guaranteed price in place in region *r* at time *t*, y_{rt-1} is the amount of installed capacity per capita in the previous year in the same region and Z_r represent time-invariant variables (i.e. the regional fixed effect variable in the main econometric model). Leszczensky and Wolbring (2022) argue that β_1 conceptualises the potential reverse causality between the dependent and independent variable. The results from this equation are presented in Table *5*. In this table, no significant relationship could be found between y_{rt-1} and x_{rt}, suggesting that reverse causality should not be a major threat for the panel data. However, the risk of reverse causality was moslty associated with the Flemish region. The analysis was therefore extended to that region solely and the same conclusions could be drawn. Results for Flanders solely are presented in Table *10*.

Table 5: Reverse causality analysis (panel for both regions)

	Coefficients	Std. Errors	[95% Conf. Intervals]
Reverse causality	-102.6566	824.2317	[-1718.121; 1512.808]
Flanders	-180.119***	65.73556	[-308.9585; -51.2799]
Constant	439.5304***	52.51992	[336.5932 542.4675]
Observations	12		
Time fixed effects	NO		
Regional fixed effects	YES		

P-values are presented in the following form:
p < 0.1 = *, p < 0.05 = **, p < 0.01 = ***

Finally, this analysis could be subject to endogeneity given the structural determination of minimum prices in Wallonia. From 2008 to 2012, the number of certificates received by a Walloon installation was a function of the size of said installation. Endogeneity occurs when there is a correlation between the explanatory variables and the error term in a regression model. Endogeneity becomes a concern when the population being studied can affect its treatment. This is often referred to as self-selection bias. Without more information on individual decisions, it would be tricky to predict the exact effect of such bias. According to the initial Solwatt program, the two thresholds that would impact the number of certificates received after 1MWh are 5kWp and 10kWp. Installations just below 5kWp could beneficiate from two additional certificates per MWh and installations just below 10kWp could beneficiate from 4 additional ones. Self-selection bias could therefore become an issue exclusively for households that are considering a capacity just above these thresholds. The marginal cost of installing an additional kW is constant however. One would then conclude that they would have reduced the size of their installations, had these households been exclusively concentrated on influencing their guaranteed benefits. The coefficient in Table 3 would therefore potentially be subject to an underestimation for these households. The presence of self-selection bias in this analysis would be represented by a constant incease in the minimum price observed in Wallonia. *Figure 5* depicts the growth in minimum price when the size-based allocation of certificates was in place. The intuition behind the ever increase of the independent variable is that household had figured out the best way to optimize their guaranteed benefits. The increase in 2009 (i.e. around 2.5%) could highlight somewhat of a small self-selection bias in the first year of the program. However, the consequential yearly decreases would suggest that the later years would not be subject to a similar conclusion. According to the results presented, self-selection bias does not appear to be a major issue over time. Characteristics such as the house size, solar exposition and current energy bills may therefore be of larger importance for household when they determine the installation size. Nonetheless, no data involving the individual capacity size was available. Had there been any data reporting such information, a density analysis would have been conducted around the two thresholds mentioned previously.

6. Limitations and Discussion

As has been pointed out several times, data availability was the main limitation of this paper. The short policy timeframe combined with the annual aggregated nature of the data resulted in a small pool of observation points. In order to identify the effect of increased certainty on solar deployment, the dataset required a range of different minimum price values. Outside the 2008-2014 period, no minimum prices were available for new installations in Belgium. In addition, no other country implemented a similar policy. Therefore, only data points from this period were useful. Furthermore, datasets with household level observations were either not public or not free of charge. Given these constraints, annual regional datasets were the only alternative that included all relevant fields. Overall, this severely limited the size of the dataset. With this limited dataset, not a lot of econometric freedom was available to answer the research question. The two-way fixed effects model using the variation in minimum price as an instrument to alter the level of certainty therefore appeared as the best suited method. No further analysis was made on the instrumental level as the minimum price was straightofrwardly impacting the level of certainty regarding future benefits. The minimum price was therefore directly used as the level of certainty.

For further research, where household level data may be more accessible, other econometric tools may be better suited to isolate the causal effect of the policy with more confidence. All this thesis was able to do is confirm a relationship between these two variables at the 90% confidence level, even with regional and time controls. Even though the 90% confidence level is widely accepted, most literature in economics agrees on assigning significance for p-values below 0.05. This therefore pint points that the conclusions from this thesis must be interpreted with precaution. With household-level data, more advanced econometrical tools could be appropriate for this policy. The idea that earnings certainty could significantly be related to solar adoption, introduced in this thesis, could therefore be extended to a better dataset and more econometrically robust methods. Data on the exact minimum price for each household individually could have provided less approximative observations. Minimum prices in Wallonia were computed using the overall solar electricity production in the region. This indicates that non-household installations were also included. Additionally, because only aggregate data was available, the interpretation of the results must be considered with precaution. The conclusions drawn from this analysis uses the average household size with an average yield installation. More accurate interpretations could be drawn using household level data. Private data companies such as Solargis could provide some help with this issue but do not release data information for free.

Despite the small dataset, there seems to be one outlier included. Total solar capacity per capita installed in Flanders during 2011, outweights any other observation within the time frame. Besides in 2020, other historical observations in the country are still exceeded by at least 50% (Energie commune, 2022). No clear reasoning could be provided to explain why such a high number was observed. Table *11* shows the result from the two-way fixed effect regression without year 2011. With the exclusion of that, several modifications in results can be observed with the price of solar panels now being a significant negative factor influencing adoption, as what was originally expected. However, the most important observation might be the change in significance for the independent variable. The coefficient on minimum price is now significant at the 99% level instead of 90% initially. This suggests that the relationship between guaranteed benefits and solar adoption could be more significant than originally discovered.

A final factor that could influence the nature of the result is again related to the aggregated nature of data. The policies targeted small-scale installations in both regions. The use of aggregate data also includes capacity observations for larger scale installations. The effect of the guaranteed price, which has been showed to be related to solar adoption, can therefore be underestimated in this analysis. The policies are not expected to have a relationship with adoption of larger plants. Nonetheless, small-scale installations represented the larger share of installation size in the country. Being able to get data for small-scale installations specifically would still have allowed to isolate that effect with more precision.

Even though it is tricky to consider the results from the analysis as purely causal given the size of the dataset, robustness checks on endogeneity, reverse causality and self-selection bias all argues in favor of the model's validity. It can therefore be stated with confidence that there is a relationship between minimum prices for green certificates and solar technology adoption. In 2021, Belgium was the third country inside the EU in terms of solar capacity per inhabitant (Fernàndez, 2023). However, no apparent difference in attitudes or economic characteristics could be observed compared to these other countries. This insinuates that the Belgian authorities have done somewhat of a successful job in promoting that energy source. However, with a total bill of €10 billion, questions remain on the cost optimization of these interventions.

7. Conclusion

This thesis aimed to answer the following research question: “Is certainty about future returns associated with investment in solar energy?”. The research hypothesis in this thesis originated from the premise that reducing uncertainty about future benefits would make solar investments more attractive.

A two-way fixed effects analysis concluded that there was a significant relationship between minimum green certificate prices and solar adoption. By extending the marginal relationship between the two variables to the total cost of the government support, this analysis suggests that 21.21% of the total solar adoption between 2008 and 2014 was associated with the presence of minimum green certificate prices in Belgium. Despite a relatively poor dataset, several sensitivity analyses were conducted and ruled in favor of the results validity. Minor biases still remain small threats to identitfication and should still be kept in mind.

Given the extraordinary high bill, questions remain regarding the cost-efficiency of these policy supports in the country. The answer relies on the initial target of the policy makers. If the goal of the intervention was to stimulate investment at all costs, this paper suggests that the policy should rather be defined as successful. On the other hand, if the goal was to encourage investment in solar energy at the lowest possible cost, the introduction of guaranteed prices might not have been the best alternative. Evidence from literature highlights that tradable green certificate markets usually achieve targets at the lowest social cost, whereas feed-in tariffs are generally more costly. This would therefore suggest that federal authorities would have originally wished to promote solar energy at a low cost, and that resources might have been better allocated with an alternative intervention.

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Appendix 1

The full set of descriptive statistics can be found below:

Table 6: Descriptive Statistics Wallonia 2008-2014

	MinP (€/MWh)	*PV Price (€/KW)*	*Population size*	*Installed capacity (KW/capita)*	*Household size*
Mean	435.63	1595.58	3,529,770.57	0.0324	2.29
Std. Dev.	11.27	1073.65	43,395.95	0.0279	0
Min	416	574.94	3,466,017	0.0038	2.29
Max	451	3508.82	3,583,038	0.0816	2.29
Count	7	7	7	7	7

Table 7: Descriptive Statistics Flanders 2008-2014

	MinP (€/MWh)	*PV Price (€/KW)*	*Population size*	*Installed capacity (KW/capita)*	*Household size*
Mean	280.86	1595.58	6,316,235.14	0.0536	2.35
Std. Dev.	153.59	1073.65	88,825.62	0.050	0.01
Min	93	574.94	6,185,161	0.01	2.34
Max	450	3508.82	6,427,421	0.14	2.37
Count	7	7	7	7	7

Appendix 2

This section presents the results from the sensitivity analysis section. First, information regarding GDP per capita. Below can be found both *Figure 4* with the different GDP per capita values over time and Table *8* for the sensitivity analysis used by including GDP per capita inside the econometric model. Due to the large differences in yearly installed capacity per capita between the two regions and the fact that average GDP per capita in Flanders was always higher than in Wallonia within the studied time period, this variable was added.

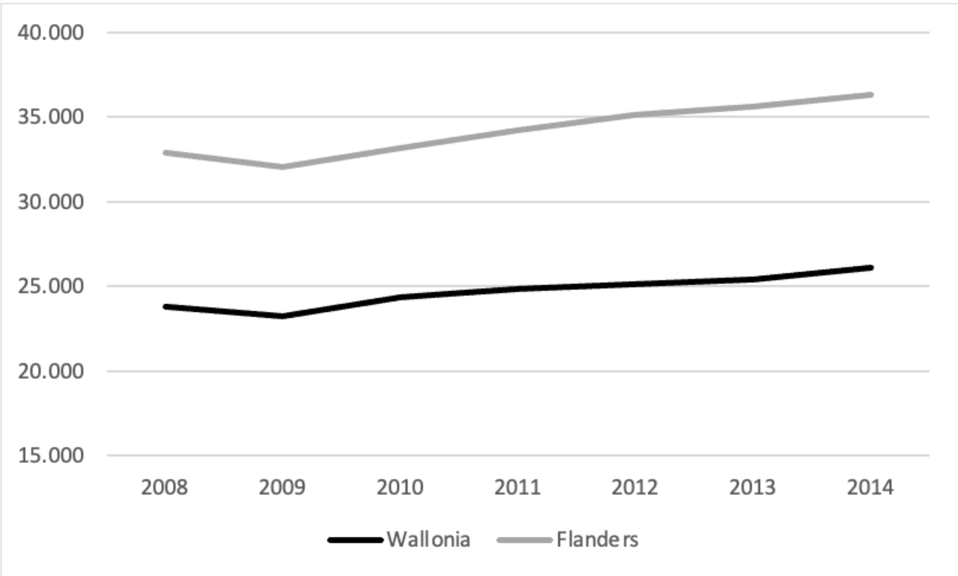

Figure 4: GDP per capita (€/inhabitant)

Second, Table *8* includes the results from the lag ged analysis where a change in certainty would only be perceived in solar adoption with a one year delay.

Table 8: Sensitivity Analysis with GDP per capita

	Coefficients	Std. Errors	[95% Conf. Intervals]
Minimum price	-0.0000466	0.0002946	[-0.00062; 0.00053]
Solar PV price	-0.0000367	0.0000284	[-0.00009; 0.00002]
GDP per capita	-0.0000696	0.0000686	[-0.00020; 0.00006]
Flanders	0.6739308	0.6092838	[-0.05202; 1.86811]
2009	-0.0942573	0.115038	[-0.31973; 0.13121]
2010	-0.0635158	0.0791977	[-0.21874; 0.09171]
2011	0.0307428	0.0478531	[-0.06305; 0.12453]
2012	0.0004452	0.0547171	[-0.10680; 0.10769]
2013	-0.0235552	0.0493125	[-0.12021; 0.07310]
2014	0	(omitted)	
Constant	1.890768	1.928717	[-1.88945 ; 5.67098]
Observations	14		
Prob > Chi2	0.0303		
Corr (ε, X) =	0	(assumed)	
Time fixed effects	YES		
Regional fixed effects	YES		

P-values are presented in the following forms:
p < 0.1 = *, p < 0.05 = **, p < 0.01 = ***

Third, Table *9* highlights the results the lagged effect analysis.

Table 9: Lagged effect analysis

	Coefficients	Std. Errors	[95% Conf. Intervals]
$\boldsymbol{Minimum\ price_t}$	0.0004826*	0.0002757	[-0.00006 ; 0.00102]
$\boldsymbol{Minimum\ price_{t-1}}$	-0.0001698	0.0002747	[-0.00071 ; 0.00037]
$\boldsymbol{Solar\ PV\ price}$	-9.51e-06	0.0000127	[-0.00003 ; 0.00002]
Flanders	0.0902477	0.0301851	[0.03109 ; 0.14941]
2010	0.0062499	0.0285464	[-0.04970 ; 0.06220]
2011	0.0620872**	0.0252421	[0.01261 ; 0.11156]
2012	0.044615	0.0291953	[-0.01261 ; 0.10184]
2013	0.0206141	0.030073	[-0.03833 ; 0.07956]
2014	0	(omitted)	
Constant	-0.1013464**	0.0467519	[-0.19298 ; -0.00971]
Observations	12		
Prob > Chi2	0.0097		
Corr (ε, X) =	0	(assumed)	
Time fixed effects	YES		
Regional fixed effects	YES		

P-values are presented in the following forms:
p < 0.1 = *, p < 0.05 = **, p < 0.01 = ***

Fourth, Table *10* investigates the potential threats of reverse causality in Flanders.

Table 10: Reverse causality analysis for Flanders only

	Coefficients	Std. Errors	[95% Conf. Intervals]
Reverse causality	-134.0631	1432.741	[-4111.989 ; 3843.862]
Constant	261.3471***	109.9501	[-43.92329 ; 566.6175]
Observations	6		
Time fixed effects	NO		
Regional fixed effects	NO		

P-values are presented in the following form:
p < 0.1 = *, p < 0.05 = **, p < 0.01 = ***

Fifth, *Figure 5* presents the growth in minimum price for Wallonia, as part of the investigation surrounding self-selection bias.

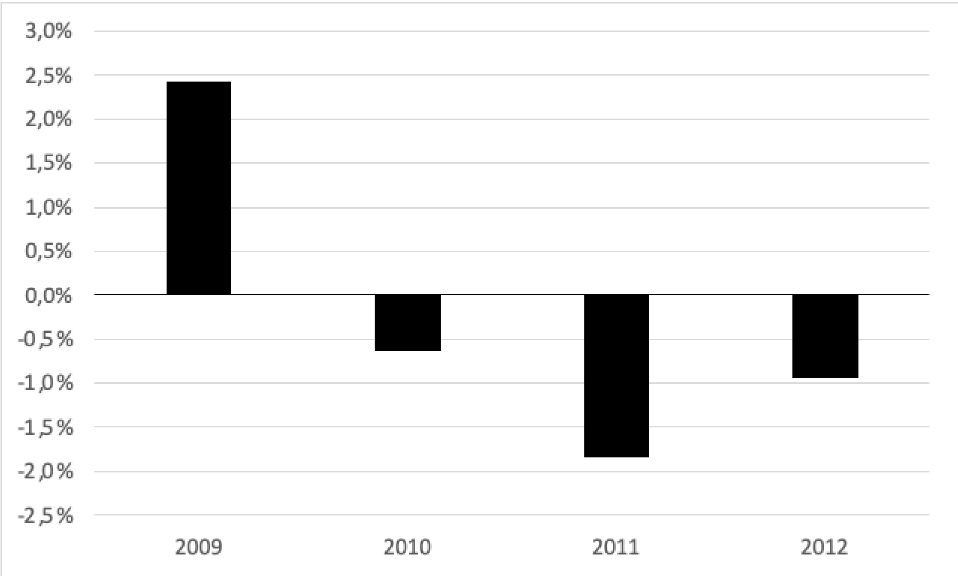

Figure 5: Self-selection bias

Finally, Table *11* includes the results from the two-way fixed effects model excluding the outlier year of 2011.

Table 11: Two-way fixed effects without outlier

	Coefficients	Std. Errors	[95% Conf. Intervals]
Minimum price	0.0002077***	0.0000797	[0.00005 ; 0.00036]
Solar PV price	-8.26e-06*	7.38e-06	[-0.00002 ; 1.27e-06]
Flanders	0.0410815**	0.0172995	[0.00718 ; 0.07499]
2009	0.020358	0.0288418	[-0.01684 ; 0.05756]
2010	0.0128406	0.0186961	[-0.02380 ; 0.04948]
2012	0.0474231**	0.020367	[0.00750; 0.08734]
2013	0.0158446	0.0202813	[-0.02391 ; 0.05560]
2014	0	(omitted)	
Constant	-0.05407*	0.03007	[-0.11302 ; 0.00487]
Observations	12		
Prob > Chi2	0.0041		
Corr (ε, X) =	0	(assumed)	
Time fixed effects	YES		
Regional fixed effects	YES		

P-values are presented in the following forms:
$p < 0.1$ = *, $p < 0.05$ = **, $p < 0.01$ = ***

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