IMT School for Advanced Studies, Lucca

Lucca, Italy

Worldwide diffusion of solar photovoltaic panels and the role of state incentive: perspectives based on diffusion models

PhD Program in Management Science

XXX Cycle

By

Anita Mariana Bunea

2018

The dissertation of Anita Mariana Bunea is approved.

Program Coordinator: Prof. Massimo Riccaboni, IMT School for Advanced Studies, Lucca

Supervisors: Prof. Pietro Manfredi, University of Pisa

Prof. Pompeo Della Posta, University of Pisa

The dissertation of Anita M. Bunea has been reviewed by:

Prof. Mariangela Guidolin, University of Padova

Prof. Aldo Goia, University of Piemonte Orientale "A. Avogadro"

IMT School for Advanced Studies, Lucca

2018

Contents

List of Figures

List of Tables

List of abbreviations

Country 3166-1 alpha-3 codes:

AUS = Australia

AUT = Austria

BEL = Belgium

CAN = Canada

CHE = Switzerland

CHN = China

DEU = Germany

DNK = Denmark

ESP = Spain

GBR = Great Britain

FIN = Finland

FRA = France

IND = India

ISR = Israel

ITA = Italy

JAP = Japan

KOR = Korea

MEX = Mexico

MYS = Malaysia

NLD = the Netherlands

NOR = Norway

PRT = Portugal

SWE = Sweden

THA = Thailand

TUR = Turkey

USA = Unites States

SPP = Solar Photovoltaic Panels

RES = Renewable Energy Sources

RE = Renewable Energy

GBM = Generalized Bass Model

GIM = Generalized Internal Model

SMPCC = Squared Multiple Partial Correlation Coefficient

FIT = Feed-in tariff

NMS = Net Metering Scheme

RPS = Renewable Portfolio Standards

ROC = Renewable Obligation Certificate

Acknowledgements

Chapter 2 is the reproduction of the paper "*State incentive and the global adoption of solar photovoltaic panels: perspectives based on diffusion models*" co-authored with Professor Manfredi and Professor Della Posta.

Chapter 3 is the reproduction of the paper "*Patterns of sectoral diffusion of solar photovoltaics: a comparative analysis in UK*" co-authored with Professor Manfredi and Professor Della Posta.

I would like to thank my mentors Prof. Manfredi and Prof. Della Posta for their constructive critics, continuous support and encouragements. They are the best professors a student can have!

Also, I would like to thank the referees Prof. Mariangela Guidolin and Prof. Aldo Goia for their insightful comments on the thesis, as their professional opinion was essential to improving the thesis. I took into consideration all their fascinating and quite far-reaching remarks and addressed them in the thesis.

Vita

1988	Born, Oltenița, Romania
2010	Bachelor's Degree in Finance, Insurance, Banking and Stock Exchange
	Bucharest University of Economic Studies, Romania
2012	Master's Degree in Marketing and Market Research
	University of Pisa, Italy

Presentations

1. A. Bunea, *"State incentive and the global adoption of solar energy: perspectives based on diffusion models"* (with P. A. Manfredi and P. Della Posta), presented at 2nd International Conference on Energy Economics and Energy Policy Conference, Barcelona, Spain, April 2018.

2. A. Bunea, "*Patterns of Sectoral Diffusion of Solar Photovoltaics: A Comparative Analysis in UK*" (with P. A. Manfredi and P. Della Posta), visual poster at 35th European Photovoltaic Solar Energy Conference and Exhibition, Brussels, Belgium, September 2018, ISBN: 3-936338-50-7

Abstract

The main goal of this thesis is to use the diffusion models to improve our understanding of SPP markets, with special focus on (a) identifying the main determinants of the diffusion of solar photovoltaic panels worldwide, particularly the role played so far by public incentives, (b) characterising the scale and temporal profiles of the major domestic shocks in SPP markets which mostly occurred after 2007, (c) discussing the resulting perspectives, and the involved role of public policies, for the future development of the market.

Chapter 1 is introductory and preparatory for subsequent ones and pinpoints that (a) the presence of shocks is an intrinsic and often dominating feature of energy markets, thereby motivating the use of tools as the GBM, (b) only a few countries have developed long-term energy plans towards which to manage consistently their short-medium term policies, (c) the concept of energy framework was useful to indicated a number of commonalities among countries.

The main findings of Chapter 2 were the following: i) essentially everywhere the effectiveness of media communication proved negligible, ii) the early phase where the growth of the market was completely sustained by internal communication only, iii) major changes in the market adoption curves have occurred in the form of massive positive shocks which took place between 2006 and 2016 possibly following incentive measures in the various states, iv) inspection of the parameter estimates describing the temporal pattern of the shocks showed a lack of temporal persistence of the effects of incentive as well as a sharp trade-off between intensity and persistence of the actions.

The results of Chapter 3 show that the SPP residential market in UK suffers not only the structural difficulties of this sector, but also the possible perception of relative penalisation suffered by late cohorts of adopters compared to the past cohorts who benefited higher rates of FIT. In the commercial and utility sectors the imitation rate is higher which might be explained by the fact that firms make more rational decisions based on economic factors rather than being led by perceptions.

Introduction

Under the scaring pressure and threats of global warming and global climate change, the current model of the earth economic development, mainly based on fossil fuels, is coming to an end (Archer and Rahmstrof, 2010; Clark and York, 2005; Dessler and Parson, 2006; IPCC, 2014; Paris2015; Bonn2017). Though available estimates and forecasts based on current rates of use of fossil fuels suggest that reserves of oil and gas might last for some decades and coal for another century (Shafiee and Topal, 2009), nonetheless the recent scientific evidence on global warming clearly indicates the need to rapidly switch to renewable energies (RE) even if the availability of reserves of fossil fuels were much more optimistic than currently forecasted (Höök and Tang, 2013; IPCC, 2014; Mohr et al., 2015; Shafiee and Topal, 2009)]. These pressures, ranking at the top of the agendas of international agencies at least in the last twenty-five years i.e, following the 1992 Rio Earth summit on sustainable development, the resulting Kyoto Protocol (1997), and the 2002 Johannesburg summit, are finally spurring numerous countries to invest for mitigation alternatives that better suit their energy needs conditioned on the international agenda and their current energy framework (Johnstone et al., 2010; Meade and Islam, 2015; Popp et al., 2011).

In this regard, the spread of technologies for the exploitation of RE - ranging from solar photovoltaic panels (SPP), to wind energy, biomasses etc. - represents a growing reality whose rate of diffusion was able to outperform that of all other energy technologies ever appeared on earth (ITRPV, 2018). Nonetheless, even this might be plainly insufficient to meet the recent targets of the Paris agreement (ITRPV, 2018). This state of affairs therefore calls for a massive effort, both at the international level as well as at the level of single countries, in order to remove the major barriers – be they economic, political, cultural, or socio-demographic - that are delaying or preventing the generalised adoption of RE (Beck and Martinot, 2004; Karneyeva and Wüstenhagen, 2017; Painuly, 2001; Reddy and Painuly, 2004).

This thesis focuses on SPP as a key RE source (Schleicher-Tappeser, 2012; Strupeit and Palm, 2016). SPP are of interest in many respects, first because they represent the main RE technology currently available to households, second – in relation to barriers - because they represent costly long-term investment for both households and firms. For instance, the SPP literature highlighted the negative impact resulting from (i) the high installation cost of the system and the long payback period (Hammond et al., 2012; Yamaguchi et al., 2013; Zhang et al., 2011); (ii) the lack of environmental awareness (Dharshing, 2017); (iii) the uncertainty of the internal political situation (Stokes, 2013); (iv) logistic arguments e.g., related to the difficulty in developing large SPP installations in urban areas with high population density (Balta-Ozkan et al., 2015).

Given these barriers, public incentives can play a key role to help SPP competing successfully against «dirty» alternatives, which are currently less costly but not environmentally friendly. There is a growing literature on the possible beneficial role of public incentive in supporting the domestic demand of SPP (Avril et al., 2012; Chowdhury et al., 2014; Lund, 2015; Zhang et al., 2011). Consequently, all the world's largest SPP adopters have massively resorted to incentive policies, to the point that incentive possibly represented a necessary driver of SPP adoptions (Faiers and Neame, 2006; Guidolin and Mortarino, 2010; Keirstead, 2007a; Olaniyan and Evans, 2014). Nonetheless, despite these large efforts the SPP diffusion is slow or even stalling in many countries (IEA International Energy Agency, 2018).

The main goal of this thesis is to use the diffusion models of the management literature, namely the Bass model (Bass, 1969) and especially the generalised Bass model (Bass et al., 1994), to improve our understanding of SPP markets, with special focus on (a) identifying the main determinants of the diffusion of solar photovoltaic panels worldwide, particularly the role played so far by public incentives, (b) characterising the scale and temporal profiles of the major domestic shocks in SPP markets which mostly occurred after 2007, possibly reflecting the complex interplay between major epochs of public intervention supporting domestic SPP demand and a number of external stimuli, such as (among many others) e.g., the Kyoto protocol deadlines, (c) discussing the resulting perspectives, and the involved role of public policies, for the future development of the market.

After a few fore-runners, the main momentum to the growth of diffusion models in the management sciences was supplied by the publication of the celebrated Bass model (Bass, 1969). The Bass model describes an irreversible diffusion process where an item (a durable good, a new technology, a new idea, etc) spreads in a population of potential adopters having fixed size, thanks to two main drivers identified in the key communication channels. These communication channels are represented by both the spontaneous communication between individuals as a consequence of their daily social encounters (be they real or virtual), often termed as "word-of-mouth", and an external communication, justified by the individual's intrinsic propensity to adopt a new technology as a result of the publicly available information supplied by the media, the public system, etc, i.e., without being affected by other individuals in the social system. The Bass model is nowadays considered a cornerstone paradigmatic model especially in the field of the marketing sciences (Mahajan and Muller, 1998), that is still providing motivations and stimuli for the development of new research tools and areas (Peres et al., 2010).

The Bass model was later extended (Bass et al., 1994) with the purpose to also include decision variables inner to the firms of the sector considered, such as advertising and prices. This extended model was termed the generalised Bass model (GBM). However, a main conclusion by Bass and co-workers (Bass et al., 1994) was that in many cases the role of inner decision variables was secondary compared to the communication forces. A major innovation in the use of the GBM was provided by Guseo and co-workers, who suggested in a number of papers that the GBM model was rather valuable as a key tool to capture the effects, rather than of inner decision variables, of external shocks capable to perturb the "normal" diffusion trajectory as shaped by the communication forces. They consequently applied the GBM to a number of problems including e.g., the effects of the price shocks in the oil markets (Guseo et al., 2007), modelling seasonality in innovation diffusion (Guidolin and Guseo, 2014), the competition between nuclear power and RE technologies (Guidolin and Guseo, 2016) up to the role of public incentive in stimulating the domestic demand in SPP markets (Guidolin and Mortarino, 2010).

The latter paper by Guidolin and Mortarino (2010), who applied the GBM to describe and forecast SPP adoptions in the eleven countries that represented the major SPP adopters worldwide up to 2006, was a main source of inspiration for the present work. Their study was important in clearly highlighting the positive effect of incentive policies in stimulating the diffusion of the SPP technology. Among their conclusions we found of particular interest the point where they concluded that some SPP markets, amongst the pool of early adopting countries, had already entered their maturity phase. This conclusion, though perfectly correct based on the adopted model, was soon denied by reality, which instead showed since 2007 a dramatic growth in SPP adoption in all countries considered, possibly corresponding to large incentive schemes introduced with a surprising synchrony in most countries. We therefore thought that this, far from representing a forecasting failure of the Bass model, was instead evidence of the complexity prevailing in the SPP market, which deserved an upgrade of their work with the purpose to add further insight and understanding of the main determinants, and barriers, to SPP adoptions.

In relation to our main above stated objectives, it is useful to clarify what is meant by "determinants" of an adoption process according to the language of Bass-type diffusion models, and more in general where the usefulness of diffusion models lies. Unlike e.g., an econometric model, where a response variable is regressed over a number of explanatory variables, perhaps at different hierarchical levels, with the purpose to identify the most important "determinants" of the response, in the standard GBM the determinants of a diffusion process are primarily represented by the mutual dynamic interplay between the communication forces i.e., the media and word of mouth, and those external factors, including public incentive as well as a number of other shock factors, capable to re-shape adoption trajectories by perturbing (either positively or negatively) the strength of communication.

This thesis is divided into three chapters.

Chapter 1 is introductory and preparatory for subsequent ones. Based on data from the International Energy Agency (IEA) and International Renewable Energy Agency (IRENA) the chapter aimed to: (a) identifying the "energy framework" of a large number of countries worldwide representing the major SPP adopters in 2017, (b) reviewing the influence of main shocks occurred in the energy market, including technological innovation, major economic shocks (e.g., oil price shocks), environmental catastrophes, etc on the countries' energy portfolios; (c) reviewing the role of public incentives with special focus on SPP diffusion; (d) reviewing the main aspects of SPP diffusion in the main adopting countries given the underlying energy framework. In particular, this chapter was useful to pinpoint that (a) the presence of shocks is an intrinsic and often dominating feature of energy markets, thereby motivating the use of tools as the GBM, (b) only a few countries have developed long-term energy plans towards which to manage consistently their short-medium term policies, as documented in the proposed analyses by the evidence that a number of public interventions were carried out as mere responses to external stimuli, such as the deadlines of Kyoto protocol; (c) the concept of energy framework was useful to inform the discussion on individual countries SPP adoption trajectories reported in subsequent chapters, which indicated a number of commonalities e.g., countries with oil and gas reserves developed a market for the SPP generally later compared to countries lacking such reserves (while availability of coal reserves seems not to have delayed the SPP diffusion).

Chapter 2, which is the central chapter of this thesis, extends the afore-cited research by Guidolin and Mortarino (2010), by applying the GBM to an extended dataset on installed SPP capacity in the 26 countries that mostly contributed to SPP worldwide adoptions between 1992 and 2016. The analysis paid special focus on the major shocks occurred over the decade 2007-2016, during which the installed capacity worldwide experienced an unprecedented growth (+95%), shared also by those countries, as Germany and Japan, which already experienced an important adoption history. This dramatic acceleration, possibly stemmed from a period of major policy efforts, aimed to sustain the domestic SPP demand.

Our principal findings were the following: i) essentially everywhere the effectiveness of media communication proved negligible, suggesting that the SPP market started its lifecycle without being assisted by continued effective public media support (thus confirming on our extended dataset a previous finding of Guidolin and Mortarino (2010)), ii) this in turn implied a prolonged early phase where the growth of the market was completely sustained by internal communication only, whose magnitude however proved to be plainly insufficient to ensure the achievement of any target of market development within the time frame indicated by international protocols and agreements, iii) major changes in the market adoption curves have occurred in the form of massive positive shocks which took place between 2006 and 2016 possibly following incentive measures in the various states, iv) however, inspection of the parameter estimates describing the temporal pattern of the shocks showed, as a rule, a lack of temporal persistence of the effects of incentive as well as a sharp trade-off between intensity and persistence of the actions (i.e., the more intense actions were also those lasting short).

Crossing out model-based results with the available information about public incentive programs in the countries considered, our findings overall suggest a number of points that might be useful for future policy interventions in both the countries considered in this work as well as in countries where the adoption of this technology is in its infancy. A first one regards the generalised lack of media support in the different countries during the early SPP lifecycle, in turn mirrored by the slow early growth of SPP markets, which is in fact characteristic of diffusion processes mostly driven by word-of-mouth only. Indeed, in Bass-type diffusion models, the importance of sustained media communication is that of rapidly creating an initial cohort of adopters which then "initialise" the word-of-mouth component from much more favourable conditions. Therefore, a target of public policy in countries where the SPP lifecycle is still in its initial phase might be that of relevantly supporting private communication on the media in order to encourage the development of an initial cohort of true "innovators" (Mahajan et al., 1995). A second main point regards the nature of the SPP market and the role of public incentive. The SPP market appears from our results as a frail and complicate one where public incentive were a necessary resource to allow the market full take-off but, at the same time, showed little temporal persistency, thereby failing in going beyond their direct short-term effect and in providing a sustained momentum to the market. Indeed, the characteristic temporal trend of the market, dominated by consecutive incentive-forced waves followed, in many countries, by negligible post-incentive adoptions until the next shock (in relation to this the case of Italy and Spain is exemplar) – besides removing any predictive ability of the model - suggests that the use of incentive was badly designed so to yield undesired counter-productive outcomes. These facts lead, as a further point, to the need to identify the intervening barriers preventing further growth of adoptions. In relation to this, a straightforward but possibly critical consequence of such discontinuous trends, seems to be the emergence of a deleterious role of expectations. Indeed, the dramatic drop in adoptions observed in many countries in the periods in between subsequent incentive actions really seems to mirror the situation where no-one will adopt in an incentive-free period while waiting for (and forcing, thanks to their non-adoption behaviour) the next incentive wave.

This argument suggests that public incentives may play a double and contradicting role: on the one hand they may well encourage the process of SPP adoption in the short-term but, on the other hand, they might eventually create new barriers to the endogenous forces acting in the diffusion process. The latter effect may be due to the role played by expected future incentives that, when implemented, would make a future (rather than current) adoption even more convenient. Though this was not among the main objectives of the thesis, in the Appendix we have developed a game-theoretic scheme aiming to capture this key intuition. In this scheme we argue that the private sector – households and firms – look for a subgame perfect equilibrium in which the threat by the public sector not to provide any more future incentives would not be credible. The optimal strategy for the private sector, then, would be not to adopt SPP in the absence of economic incentives, so as to force the public authorities to provide them in the future. This would explain the stylized fact that in all countries the adoption of SPP has been driven strictly by the shocks represented by public incentives. We believe that this hypothesis might deserve further investigation in future research.

In the final chapter (Chapter 3) we present a case study of the UK as a further and more detailed analysis of a national SPP market with more detailed adoption data. Indeed, a main shortcoming of Chapter 2 lied in the coarse data used, represented by yearly data on total installed capacity and not on installations, therefore not distinguishing between the types of adopters namely households (low-scale installation systems), commercial and enterprises (medium-scale systems), and public utilities (very large scale). To make a trivial example, a single installation by a large public utility in a just started market might represent a large shock in the overall adoption curve, therefore making the aggregate capacity a biased indicator of the true underlying processes. In the UK case, the energy department makes it available from 2010 onward data on both the number of monthly installations disaggregated by type of adopters (household, commercial, public utilities) and the corresponding total installed capacity.

Therefore, in this chapter we again used the GBM to analyse the diffusion of the SPP technology in the UK comparing the trend in the various sectors of the market: residential, commercial and utility, again with special focus on the role of the UK government efforts in sustaining the market.

The results of this chapter are broadly confirmative of some main findings of Chapter 2, for example about the absence of media support in both the household and the commercial SPP branches of the market, as well on the key role of incentives as market drivers. In addition to this the results highlight a number of further interesting issues when disaggregating by type of agents. In particular, the estimated magnitude of the word-of-mouth effect in the residential market appeared to be dramatically low, suggesting a non-vital market, capable to grow only as a consequence of public support. The situation is quite different for the utilities and commercial sectors where the size of the word-of-mouth effect resulted an order of magnitude higher than for residentials. By correlating the temporal trends of the two main types of incentive adopted for the SPP market in the UK in this phase, we argue that the UK incentive policy for households is an example of a badly handled policy that should never be used in the same way in a strategic market as the one for SPP.

Therefore, it seems that the SPP market in UK suffers not only the structural difficulties of this sector, but also the possible perception of relative penalisation suffered by late cohorts of adopters compared to the past cohorts who benefited higher rates of FIT. The value about 0 of the imitation rate (q) suggest that in absence of incentives the market is essentially dead possibly because agents believe in the expectation of further future increasing in the value of FIT and therefore in the return of the investment. In the commercial and utility sectors the imitation rate is higher which might be explained by the fact that firms make more rational decisions based on economic factors rather than being led by perceptions.

A more effective and easy to implement solution for a successful policy might be the creation of individual customized policies which should take into account the real price of the initial investment paid by each individual and the actual material and maintenance costs, instead of an estimated price based on past dynamics. This solution would allow a better government control over the continuously occurring market changes and could avoid excessive SPP demand stimulated by high profitability caused by the gap between a sudden decrease in price and the slow adjustments in FIT tariff as it occurred during the Chinese overproduction.

Chapter 1. The diffusion of solar photovoltaic power within the energy market and the role of public incentives: a review

Abstract

Based on data from the International Energy Agency (IEA) and International Renewable Energy Agency (IRENA) the chapter aimed to: (a) identifying the "energy framework" of a large number of countries worldwide representing the major SPP adopters in 2017, (b) reviewing the influence of main shocks occurred in the energy market, including technological innovation, major economic shocks (e.g., oil price shocks), environmental catastrophes, etc on the countries' energy portfolios; (c) reviewing the role of public incentives with special focus on SPP diffusion; (d) reviewing the main aspects of SPP diffusion in the main adopting countries given the underlying energy framework. In particular, this chapter was useful to pinpoint that (a) the presence of shocks is an intrinsic and often dominating feature of energy markets, thereby motivating the use of tools as the GBM, (b) only a few countries have developed long-term energy plans towards which to manage consistently their short-medium term policies, as documented in the proposed analyses by the evidence that a number of public interventions were carried out as mere responses to external stimuli, such as the deadlines of Kyoto protocol; (c) the concept of energy framework was useful to inform the discussion on individual countries SPP adoption trajectories reported in subsequent chapters, which indicated a number of commonalities e.g., countries with oil and gas reserves developed a market for the SPP generally later compared to countries lacking such reserves (while availability of coal reserves seems not to have delayed the SPP diffusion).

Keywords: energy market, renewable energy sources, global diffusion of solar power, state incentive, classification of public SPP incentives

JEL: N70, O13, O38, Q48, Q58

1.1 Introduction

Earth holds a limited amount of fossil fuels that we use to provide energy. According to (Shafiee and Topal, 2009), the reserves of oil and gas are forecasted to be depleted around 2040 while coal availability is predicted to last until 2112. Additionally, the planet increasing population and consumption brought critical threats regarding global warming and global climate change. These pressures gained the attention of important international organizations in the recent decades which spurred numerous countries to search for mitigation alternatives that better suit their necessities.

At the beginning of the 1970s fossil fuels accounted for 75% of the share in world total electricity output (Figure 1.1), while the rest of the share was mainly sustained by renewables. Also, this was the beginning of the nuclear expansion as the third main source of energy which reached the highest share (almost 18%) in the 1990s. During this decade a sort of market stability was achieved with shares of 60%, 22% and 18% respectively for fossil, renewables and nuclear. Nowadays, fossil fuel is still by far the main energy source with a share in total electricity output of 66% in 2015. Instead, nuclear energy suffered a significant decrease to 10.6% in the past three years while renewables follow an increasing trend.

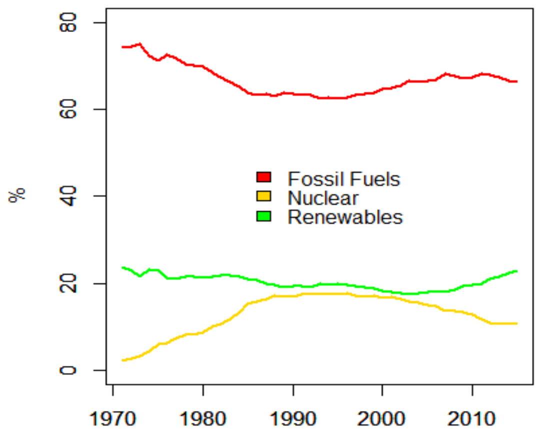


Figure 1.1 Global share of main energy sources in total electricity output (Own calculation using the electricity output from IEA Headline Global Energy Data 2017.

Before 2000 hydropower was the primary renewable energy resource (RES) with over 93% of the share in total renewable energy (RE) installed capacity (Figure 1.2). From then on, the renewable market expanded to mass-production of innovative technologies exploiting alternative sources: geothermal, bioenergy and wind in a first phase and solar in a second phase. This brought the share of hydropower to 58% of total RES in 2015, while wind, solar and bioenergy covered respectively 23.2%, 14.7% and 5.4%. Marine and geothermal technologies are still negligible, with a share under 1%. Thus, the recent growth in the share of RES in total electricity output is fundamentally due to the production of energy from other "clean" sources. This tendency seems to persist since many countries established short or long-term targets in order to reduce the use of fossil fuels.

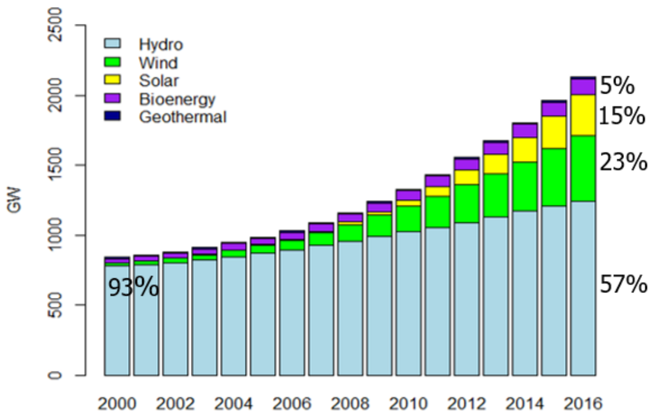


Figure 1.2 Main renewable energy installed capacities in the World (data from IRENA)

Among the RES, solar photovoltaic power (SPP) is considered an attractive solution especially for isolated populations with difficult access to grid-electricity because it transforms sunlight into energy without any further production and transportation costs. The SPP technology market has experienced a great expansion around the World, being present in 178 countries in 2016 (IRENA, 2017). The total installed capacity of SPP grew almost exponentially in the past three decades and reached 303GW in 2016 (Sawin et al., 2017) with nearly 33% increase from 2015. Nevertheless, 85% of the growth was driven by five countries only: China, USA, Japan, India and UK (IEA, 2016). China has 34.5 GW installed capacity and has the largest solar park worldwide, the Tengger Desert Solar Park with 1540MW installed capacity in June 2017 [2]. Also, India, in search of solutions to the air pollution problem [1][1], decided to invest in SPP, particularly in solar farms or parks with huge capacities: Kurnool Ultra Mega Solar Park is the third largest solar park in the World with 900MW installed capacity.

Being a vanguard solution against global warming, the solar power technology has been of vast multi-disciplinary interest. We will focus on the evolution of the solar photovoltaic power (SPP) market with particular attention to public policy schemes as determinants of the SPP adoption (Meade and Islam, 2015; Radomes and Arango, 2015; Yamaguchi et al., 2013; Zhang et al., 2011). Our aim is to compare them using data on electricity generation, research demonstration and development (RD&D) investments from the International Energy Agency (IEA) and data regarding renewable energy installed capacity from International Renewable Energy Agency (IRENA).

In the next section we present the general energy frameworks of different countries analysing the division of the electricity output by main energy source (fossil fuels, nuclear and RES) together with the availability of distinct categories of fossil fuels (coal, oil and natural gas). In the third section, we discuss the motivations which underlie the adoption choice of the energy sources. Our focus is on the dynamics of SPP adoptions by looking at the major events in the energy market and its several sectors. In the fourth section we classify SPP public policies while highlighting their importance based on recent literature. In the fifth section, we will focus on the SPP diffusion within the RES sector highlighting the influence of policies in each country. Finally, in the sixth section, we discuss the SPP evolution and its relationship with other energy sectors.

1.2 Energy framework

In order to understand the motivations driving the adoption of RES, and particularly of SPP, in this section we provide an overview of the energy framework dynamics between 1971 and 2016 in 24 IEA countries[2] which

---

[1] The numbers in brackets refer to the sitography of Chapter 1 that can be found at the end of the document

[2] Excluding Thailand and Malaysia for shortage of data

cover more than 90% of the SPP global market. We classify countries into six major groups according to their main source of energy (domestic fossil fuels, imported fossil fuels with little or no domestic production, nuclear power, RES and mixed portfolio) as a share of total electricity output (Figure 1.3). The origin and the composition of fossil fuel reserves (coal, oil and natural gas) as well as the degree of availability of each traditional energy sources (coal, oil and gas) may render the use of RES more or less compelling (Figure A1. 1).

1.2.1 Domestic production of fossil fuels

The first set comprises five countries with domestic fossil fuel resources as their main energy source for the electricity generation. Australia and India with a rather stable trend at over 80% share of fossil fuels (mostly coal and gas), China and USA, with a soft reduction down from around 80% to respectively 74% and 67%, and Mexico with a generally increasing trend of fossil fuel consumption (mostly oil) from 50% in the 1970s up to 80% in 2016. Mexico is the only country having a systematic increase in the use of "dirty" energy. This is most probably related with the fact that, despite the decreasing gas production, Mexico can fully satisfy the domestic demand for oil. On the contrary, Australia, China, India and USA have more coal, a particularly polluting resource compared to the other two, and present a decreasing trend of domestic oil production. The insufficiency of domestic oil and the dependency on imports might be influential factors of SPP adoption in these four countries. Also, we notice the lack of significant nuclear power in all countries (except 20% in USA). The lack of both nuclear energy (or the refusal to use it given the risks it implies) and oil reserves might have also contributed to boost the SPP market in countries presenting such a feature.

1.2.2 Domestic and imported fossil fuels

The second group consists of five countries mostly relying on imported fossil fuels and some domestic resources. Germany and the UK are quite similar regarding the general energy framework experiencing a general decrease in the share of fossil fuels (mainly coal), respectively from 93% to 56% and from 88% to 53%, implementing nuclear power during the years and having significantly growing RES shares in the past two decades. By comparison, Israel, the Netherlands and Turkey have high shares of fossil fuels and no significant nuclear power. Germany and Turkey use the main categories of fossil fuel for electricity production in rather equal portions. Nevertheless, most of it is imported and only respectively 18% and 15% derive from domestic production, mostly from coal. Compared to the other countries, the UK and the Netherlands have more domestic production (47% and 27%) and they are also fossil fuel exporters mostly of oil in the case of UK and gas in the case of the Netherlands.

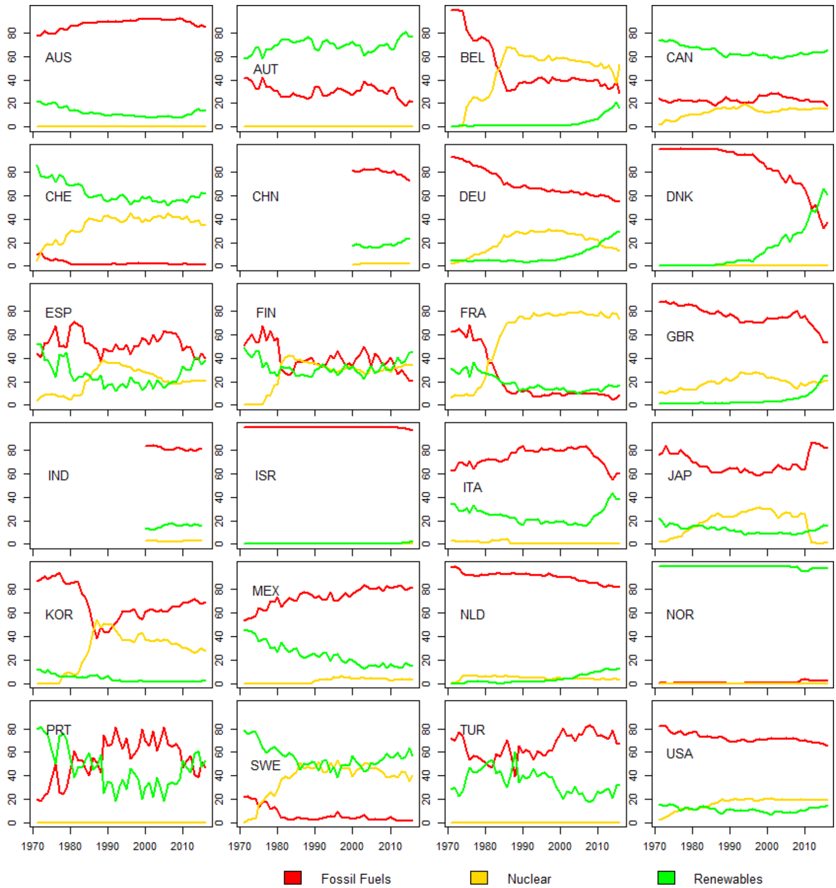


Figure 1.3 Share in electricity output by source of energy 1971 – 2016 (provisional). Own calculations based on IEA Headline Global Energy Data 2017 data on Electricity Output

For a long time, Israel's energy portfolio was entirely composed by fossil fuels. Despite Israel being a producer of natural gas, only 28% of the electricity output is provided internally in 2016 and no significant exports are detected. Over the last decade, country's investments in renewables brought the share to 3% of total electricity output.

The presence of oil and gas might have postponed the SPP deployment until the last decade in countries such as the UK, the Netherlands and Israel, whereas Germany registered an earlier deployment. Interestingly, Turkey has also a delayed SPP deployment despite the high dependency on foreign gas. An explanation might be that the current political situation and the war in Syria prevents the SPP development in the country.

1.2.3 *Imported fossil fuels only*

Next, we group the countries dependent on foreign fossil fuels. In this category we include Italy, Japan and South Korea, all with an average 70% share in total electricity output. The three countries used domestic fossil fuels before 1990: gas for Italy, coal for Korea and both coal and gas for Japan. Nevertheless, the production was only used for the domestic market and it almost faded out in the recent years which made the countries highly reliant on imports. In order to reduce the dependency on other countries, Japan and Korea focused on nuclear power reaching the peaks around the 1980s and the 1990s with shares on total output of 20% and 50%, respectively. Instead, Italy gave up nuclear power (following the outcomes of two referenda on this issue) and focused on renewable energies which reached a share of 43% of overall electricity production in 2014. Nowadays, Japan also shifted its attention to RES almost removing the nuclear power from its energy portfolio, while Korea followed a decreasing trend in nuclear power at the advantage of fossil fuels leaving the RES with only 2% share.

1.2.4 *Nuclear power*

Belgium and France have nuclear power as their main energy source, contributing to respectively 50% and 70% average share of total electricity output. Regarding RES, since 2000 Belgium experienced a sustained growth in RES share while in France the growth was milder and slowed down in recent years. In terms of fossil reserves, domestic production of coal in both countries and natural gas only in the case of France faded out over the past two decades.

1.2.5 *Renewable energy*

Four countries have renewables as their main source of energy. First, Norway has a unique framework, relying almost entirely on RES. In Austria the lack of nuclear power entailed a competition between RES and fossil fuels. Generally, the share of RES increased to approximately 80% at the disadvantage of fossil fuels. Conversely, in Switzerland the fossil fuels are almost absent, and the energy sector is steadily split in 60% RES and 40% nuclear on average after 1990. However, an increasing trend of RES is observed starting with 2010 which is also a response to the ambitious target of Switzerland to eventually phase out the nuclear power [3]. A more diversified energy portfolio is observed in Canada with no radical changes over time: 60% RES, 25% fossil and 15% nuclear on average.

Analysing the fossil fuel domestic production, it is easy to notice that Switzerland lacks reserves and Austria decreased its energy production based on coal, oil and gas to levels close to the phase out. In contrast, both Norway and Canada are large producers and also exporters of all three types of fossil fuels. Indeed, Norway is exporting most of its production while Canada exports around 40% of the energy produced both from domestic and foreign sources.

1.2.6 *Mixed portfolios*

In the last group, we include countries with mixed energy portfolios

Starting from 1980s, Finland had a very balanced energy market divided among the three main sources. Nevertheless, in 2016 the share of energy generated by fossil fuels registered a historical minimum of 21% to the benefit of RES (45%) while the nuclear power shows a stable trend at 34% on average. Also, Spain uses all three energy sources, but with more unstable trends especially due to the introduction of nuclear. The time series display a portfolio mainly composed by energy from fossil fuels and interchangeable trends of nuclear and RES with on average respectively

53%, 21% and 26%. Yet, recently the shares are quite different compared to the past and put RES and fossil fuels on the same level at 39% with nuclear remaining at 22%.

In Portugal we come across a market without nuclear but composed by oscillating trends with the supremacy of fossil fuels between 1990 and 2010, followed by the recovery of RES in recent years to an almost fifty-fifty market division. Similarly, we observe oscillating trends in Sweden between nuclear and RES even though with a more stable tendency, while the fossil fuels decreased considerably over time and reached very low levels. In 2016 the energy market is split in 57% RES, 41% nuclear and only 2% fossil fuels.

Denmark registered the most intense growth of energy from RES after a lengthy period of using only "dirty" energy. Since it was using significant imported resources of fossil fuels and avoiding the adoption of nuclear power, Denmark focused on RES which recently became the main source of electricity with a share of 62% in 2016. Also, the domestic production of oil and natural gas is mainly addressed to exports.

Except for a limited coal production in Spain and Finland, which is nevertheless low compared to the imported quantity, and the modest oil and natural gas production in Denmark, countries with a mixed energy portfolio do not have significant fossil fuel resources.

1.3 Important shocks in the energy market

In this section we investigate the major events that particularly influenced the energy market from 1970 onwards searching for evidence in the trends of shares in total electricity output (Figure 1.3) and analysing the evolution of research, demonstration and development investments (RD&D) by type of main energy source (Figure A1. 2) and by type of RES (Figure A1. 3).

1.3.1 Negative shocks on fossil fuel sector

The first important event that affected the fossil fuel sector was the oil crisis which started in October 1973 by embargoing Canada, Japan, the Netherlands, UK, USA and later Portugal from the Middle East exports. This caused a sharp increase of the oil price which motivated many countries to reconsider their energy portfolio. In the aftermath of the first oil crisis, research on the production of solar energy, for example, started in Japan with the Sunshine Programme in 1974 developed by the Ministry of International Trade and Industry (MITI). Although this ambitious project was considered successful (Chowdhury et al., 2014), the evidence shows that the SPP R&D has always been far below the huge levels directed to nuclear energy (Figure A1. 2)

A second shock wave occurred in 1979 with another oil crisis induced by the Iranian revolution which reduced significantly the oil supply which consequently increased even more the price of oil (Salameh, 2004). This drove the search for alternative resources to fossil fuels. The immediate solution seemed to be the adoption of nuclear power (Toth and Rogner, 2006) as it was the case of Belgium, Finland, France, Germany, Japan, Korea, Spain, Sweden, UK and USA which registered their deployment during this particular period (Figure 1.3). On top of this, even countries without significant nuclear installations throughout history, such as Austria, Denmark, Italy, Portugal and the Netherlands, invested considerable public RD&D in the nuclear technology (Figure A1. 2). Instead, Australia, Canada and Norway concentrated their efforts also into fossil fuels (mainly oil), probably to increase the capacity of extraction of their rich territories and take advantage of the situation to export their products at high prices. The countries that directed RD&D investments into RES are: Australia, Portugal, Switzerland and the Netherlands mainly in solar; Spain and USA in both solar and geothermal; Denmark in wind and solar; and with more balanced proportions Sweden in solar, wind and bioenergy (Figure A1. 3). While the previous shocks were provoked by supply disruption, the third important oil shock which started in October 2007 and lasted until the middle of 2008, was induced by an unsatisfied demand due to stagnation of global production (Hamilton, 2011, 2009). During this period the price peaked at 147.3$/barrel [5]. Though the economy became more flexible to an oil price shock due to the reduction of the share of fossil fuels in total energy production (Blanchard, Olivier J, Gali, 2007; Salameh, 2004), this long-lasting problem was handled rather poorly, because the 2008 financial collapse brought down the oil price but produced other serious long-term problems (Hamilton, 2009). Hence, the consequences of the two opposite shocks are difficult to interpret on yearly data since in that particular short period we cannot clearly distinguish one cause from another. Nevertheless, we could observe a general decrease in the share of fossil fuels over the total electricity output in 2008 compared to 2007, except for Australia, Portugal and Turkey, (Figure 1.3) and a clearer increase on investments in RES technologies for Austria, Denmark, Germany, Italy and Spain, while a decrease in nuclear investments is detected in Korea and France.

1.3.2 Negative shocks on the nuclear sector

In March 1979 an accident occurred at the Three Mile Island Nuclear Generating Station in the USA. On one hand, this could be a possible explanation why Austria, Denmark, Italy, Portugal and the Netherlands that initially invested in nuclear as a response to the 1973 oil crisis did not proceed with the national implementation of nuclear plants. On the other hand, in Sweden even if the public opinion was influenced by the accident, the effect was short-lasting (Nohrstedt, 2005) and the result of the 1980 nuclear referendum on the future of nuclear power was not implemented (Gallager and Uleri, 1996, p. 23). A reduction in RD&D public investment in 1980 can be observed for Belgium, Denmark, Italy, Japan and Spain. (Figure A1. 2)

The Chernobyl disaster in April 1986 is considered the most catastrophic in terms of casualties and costs. For this reason, also Italy had a referendum in 1987 through which the adoption of nuclear power was abolished. Consequently, the nuclear share in RD&D dropped significantly (Figure A1. 2). Even Japan registered a reduction in RD&D directed to nuclear technologies in 1987, but there was no long-lasting effect. Over all, we observe that in the second half of the 1980s many countries that chose the nuclear energy reached the maximum share of nuclear in total electricity output (Figure 1.3) and maintained a rather stable position over the time. Perhaps a phase out of the nuclear power for the countries that invested in this specific technology in order to be less dependent on foreign fossil fuels did not seem a feasible solution despite the catastrophic Chernobyl accident.

The second largest and more recent nuclear tragedy was the Fukushima event on 11 March 2011. Nevertheless, the contemporary global warming debate and the availability of information helped spreading communication regarding the risks of nuclear plants and sensitized significantly the public opinion around the world, probably more than the Chernobyl accident (Glaser, 2011; Kim et al., 2013).

On one hand, the Fukushima event led to the drop in the share of nuclear power in total electricity output in Japan and corresponded with a smooth and continuous reduction in other countries such as Belgium, Germany and Switzerland. On the other hand, UK and Finland continued to increase their share. In the case of UK, policymakers remained on the track of their initial long-term decision to increase electricity generation from nuclear sources. In Germany the government agreed to re-evaluate the security of all national nuclear power facilities (Wittneben, 2012) and later planned to phase out the nuclear plants by 2022 [6].

In the case of Italy, we notice that the nuclear RD&D share remained quite high over the years in view of reviving the nuclear energy in the country. However, the Fukushima disaster put an end to this plan and forced the country to focus on alternative solutions. Another referendum took place in Switzerland after a longer period of debate. However, RD&D directed to RES exceeded the ones directed to nuclear and continue to grow. As a consequence, to the Fukushima disaster the risk perception regarding nuclear energy augmented (Siegrist et al., 2014) and led to the positive result of the 2017 referendum on the gradual phase out of national nuclear plants while the focus will be on RES [7].

1.3.3 Environmental warning shocks

As mentioned above, the RES sector got some attention in the 1970s during the oil crises but its evolution was rather restrained in the following period (Ackermann and Söder, 2002; Leung and Yang, 2012). Exceptions are Austria, Denmark and Sweden which have been making significant investments in RES technologies since the 1980s (Figure A1. 2). Additionally, to the oil crisis shock, a non-profit organisation called the Club of Rome, was the first most important to arise the problem of environmental deterioration. Founded in 1968, it gained public attention in 1972 thanks to its clear message of the famous report “The limits to growth” (Meadows et al., 1972) suggesting that continuous and uncontrolled exploitation would bring our planet to collapse during the 21th century. Despite the warning, most politicians, managers and economists criticised the report. Only later, after the two oil crisis environmental awareness started to grow (Colombo, 2001).

Over time climate change awareness brought countries together to discuss and find solutions for the global threat. The first significant international treaty regarding global warming is the 1994 United Nations Framework Convention on Climate Change (UNFCCC), extended with the Kyoto Protocol signed in 1997 and including 192 countries. The main goal of the treaty is to reduce the greenhouse gas concentrations under a scientifically proven level that would prevent hazardous interferences in the climate system [8]. In order to do so, countries are committed to reach certain targets with pre-established deadlines (2008, 2012 and 2020). This is in line with the fact that only recently we observe that RD&D trends addressed to RES technologies took the lead in terms of share in total RD&D in countries like Finland, Germany, Korea, the Netherlands, Portugal and Spain (Figure A1. 3). The share of RES in total electricity output increased noticeably in Germany, Spain, UK, Italy and Portugal (Figure 1.3). Among the analysed countries Japan, Canada and USA did not participate at the second round of targets.

Additionally, the European Union established climate actions for its members - 20% cut in greenhouse gas emissions compared to 1999, 20% energy from RES sources and 20% improvement in energy efficiency - to be achieved by 2020 [9].

Next it followed the Paris Agreement in 2015 within UNFCCC which motivates countries to self-establish gradual targets for short and long periods. This drove many nations to improve RES policies and set up ambitious thresholds. For example, France announced the implementation of the “Five-Year Plan” which targets the extinction of petrol and diesel vehicles by 2040 [10]. Moreover, the International Solar Alliance (ISA) of 120 countries was founded to join forces to lower the costs of the SPP technology and to promote and develop solar products below the tropics and beyond [11].

As a response to environmental awareness and driven by the technology price reduction various countries fixed targets for the SPP installed capacity or RES in general (Kumar Sahu, 2015). Among the most ambitious countries we find India, China, France, Germany, Korea (RES in general) and Japan. The last four mentioned countries have also made significant investments in SPP RD&D which highlights the success of their initiative.

(Figure A1. 3). On the contrary, among the nations without a target we find Austria, Finland, Norway, Spain, Sweden, Switzerland and USA, while Canada is far from reaching it. This is not surprising since Canada and USA do not participate in the Kyoto Protocol, Austria, Finland, Norway and Sweden have great hydropower and Spain focused more on wind energy (Figure 1.6). Including China and India, 16 out of 24 analysed countries established long or short targets, considering also Denmark which exceeded in advance its scheduled target even though it did not fix another.

Despite the continuous scientific evidences that global warming is a serious threat, over the year some political parties strongly expressed their opinion against the environmental degradation caused by excessive human exploitation of the planet and consumption (McCright and Dunlap, 2011). Especially in the US, the conservative party seems to have impacted the country's climate change policy (McCright and Dunlap, 2003) and thus delayed the deployment of SPP. During his campaign, the president Trump strongly expressed his disbelieve in the global warming. More recently The US government withdrew from the Paris Agreement and announced the promotion of fossil fuel and nuclear power during the Bonn Climate Talks [12].

1.4 SPP public incentives

Before 1990 the SPP technology was mainly used in niche projects beginning with space satellites and followed by off-grid terrestrial applications for isolated rural populations (Breyer et al., 2010). Fossil fuels and nuclear energy enjoyed a competitive advantage in terms of immediate costs and efficiency. However, scientists discovered that long-term costs had not been correctly took into consideration because they should include externalities. "The consequence for costs such as global warming or nuclear power can be very significant"(Rabl, 1999, p. 111) on future generations in terms of environmental damage and health problems.

This is one of the many reasons for which governments around the world offered various incentives to make RES technologies, and SPP in particular, economically attractive to compete with the existing energy technologies. These were the foundations for a more efficient mass-production technology that it is nowadays used mostly as on-grid rooftop PV system and available at a price approximately 30 times cheaper than in the early 1990s [13].

Next, we will present a summary classification of the main SPP policies based on a thorough analysis of the national survey reports in IEA countries [14] and their importance in the SPP adoption, as studied in the literature.

1.4.1 Policy classification

Public intervention supporting the SPP market has been implemented in the form of a wide range of incentives. These can be crudely classified into two broad classes that we call respectively direct and indirect policies.

Direct policies are those offering an economic support directly targeting the SPP adopters (be they households, companies, institutions, etc). These can be further subdivided into (i) installation related actions, including e.g., discounts or refund of a proportion of the initial installation price, credit facilities such as interest-free loans, extended loan periods, etc; (ii) production related, such as feed-in-tariff schemes (FIT) and net-metering schemes (NMS), both aimed at rewarding the electricity produced in excess with at least the same price per kWh as charged by the local utility for a fixed period established at the beginning which could vary from 10 to 25 years. Moreover, for systems connected to the grid there is no need for storage facilities because the electricity can be used at any time from the utility company to whom the consumer is providing the clean energy. The difference between the two lies in the use of two meters in the case of FIT whereas the NMS needs only one bi-directional meter to measure the electricity flow [31]. Also, net-metering allows RES producers to compensate for the energy generated over a long period of time, ranging from one month to several years. With net-metering, customers can compensate for their electricity consumption, over an entire billing period, using it at a time other than when it is produced. This kind of incentives are continuously revised, recently even monthly, in order to fall in line with the SPP market conditions, such as the price decrease of the SPP systems. One of the first and the most successful implementation of FIT happened in Germany starting from 1990 (Kumar Sahu, 2015). In fact, in Germany FIT is adapted very month depending on the degree of achievement of the PV government target. Compensations differentiated sometimes also base on differences in solar radiation in different regions. Nowadays around the world, more than 75 jurisdictions adopted the production related policies which makes FIT the most popular policy (Dusonchet and Telaretti, 2015; Timilsina et al., 2012). NMS was implemented in several countries such as Denmark, the Netherlands, Italy and Belgium (Dusonchet and Telaretti, 2015).

Indirect policies include the efforts provided by the government or companies to promote more favourable market conditions allowing to reduce over time the high initial cost of installation or to discourage the adoption of other technologies, especially "dirty" technologies. These include public investments and taxes. On the one hand, public investment in R&D reduce the direct costs of buying the technology, while the public effort in promoting its awareness e.g., by demonstration projects or promoting associations (Yamaguchi et al., 2013), decrease the side costs of investments (EcoFys B.V., 2012). On the other hand, taxes consist of e.g., (i) the carbon tax for fossil fuel energy users (Farrag and Gmbh, 2013), which increases the relative benefit of investing in SPP, (ii) penalties for utilities that do not buy energy from "clean" energy producers, (iii) green Certificates (IEA, 2013a).

Few policies are directly addressed to SPP producers. Among those we mention the Chinese government intentions to encourage domestic companies by offering tax-free grid connected systems (Kumar Sahu, 2015). As a matter of fact, it would not make any sense to have production facilities if there is not a market for them. So, most incentives are in favour of consumers.

Here we also mention the Renewable Portfolio Standard (RPS), which is a governmental measure that constrains the electricity supply companies to produce a certain share of electricity from RES. Thus, we cannot call it an incentive, but rather an obligation imposed to often monopolist utility companies.

Several studies emphasize the impact on the SPP diffusion of heterogenous policies. In the next section, we discuss the main SPP policies.

1.4.2 *The role of public incentives*

The key role of public policies relative to renewable energies (RE) is to increase their profitability either by expand the scale of production so as to reduce the unitary cost, or by improving the quality of the technology, given the cost. This would make «clean» technologies competitive with «dirty» alternatives, which are less costly but not environmentally «friendly» (Avril et al., 2012; Chowdhury et al., 2014; Ratinen and Lund, 2015; Zhang et al., 2011).

Other two important roles of the policies that have not been stressed sufficiently in the literature could be to provide a viable source of energy for countries missing fossil fuels (in particular oil and gas) and to acquire a technology leadership, as currently evident for China, which has become the major producer of solar modules worldwide since 2007 (IEA, 2016, p. 53) . Other cases such as Germany, Japan, Italy and India (among others) also point in this direction.

Earlier studies used the learning curve approach (Breyer et al., 2010; Foxon, 2010; Masini and Frankl, 2003) to underline the importance of public and private investment (R&D) in reducing the unit cost of the SPP technology. Breyer et al (2010) studies OECD countries and indicates that 6 to 12% of SPP industry sales is invested in R&D dedicated to improvements of the manufacturing process or the creation of new products, such as storage batteries. Moreover, Foxon (2010) highlights that, globally, an annual cost of 1 to 2 % of the GDP would be sufficient to reach the targets against global warming, which in contrast would bring to a loss of 5 to 20% of total GDP. Masini and Frankl (2002) suggest that suitable policy actions are essential for the maximum penetration of the PV system.

Also Avril et al. (2012) highlights the importance of continuous R&D investments. In fact, after analysing the policy schemes in Japan, Germany, USA, France and Italy, they recommend a policy scheme based on R&D in a first phase to be followed by a second phase of FIT or any other demand-pull policy and the prolongation of R&D support even if at a lower level.

The investment in R&D leads to a reduction of the substantial initial plant cost of the SPP technology, which represents a significant disadvantage (Zhang et al., 2011) and requires a more complex decision process. Therefore, not only domestic factors but also globalization factors should be taken into consideration when designing the right policy scheme in a certain country. A prediction of 67% decrease in the module price by 2020 is given in de La Tour et al. (2013) using experience curve models. They indicate consequently that the price of SPP generated electricity should align with the price of conventional electricity especially in countries with high irradiation levels.

Several comparative studies analyse the impact of various types of measures on the SPP diffusion in different locations. Solangi et al. (2011) highlights that, based on past literature, FIT and RPS appear to be the most common and to bring most of the advantages among different incentives. Additionally, in the case of South Korea the RPS reveals to be more significant in explaining the RE diffusion compared with the FIT (Lee and Huh, 2017). Even Ismail et al. (2015), after reviewing the SPP progress in Association of South East Asian Nations (ASEAN) countries shows that 5 out of the 10 analysed countries applied FIT as central policy to drive SPP adoptions and finds it one of the most effective. Also, Radomes and Arango, (2015) study the SPP diffusion in Medellin, Colombia and reveal that the investment subsidy and the FIT rate offer the highest marginal increase in diffusion rate. In line with their findings, Zhao et al., (2013) relying on a large panel dataset, discover that FIT and direct investment incentives are the only efficient promoters for all types of RES.

Furthermore, Kumar Sahu (2015) describes the evolution of SPP installations in the top 10 SPP countries in terms of electricity production and emphasises that the success of the market is highly dependent on each country’s policy schemes, but also on the involvement of manufacturing companies. The study also indicates that the latest reduction in SPP module price pushed various countries to establish short- or long-term targets for the adoption of SPP.

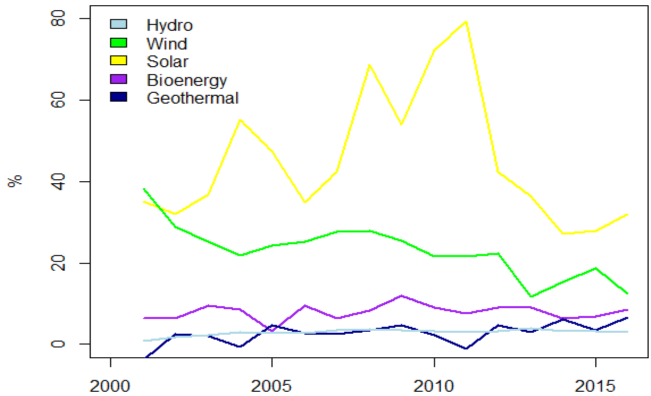


Figure 1.4 Growth rate by type of RES at global level. Own calculation based on data from IRENA Renewable Electricity Capacity and Generation Statistics (RECGS), March 2017

In the next section we examine SPP diffusion within the RES sector in countries with various energy portfolios as presented in the first section.

1.5 SPP diffusion

SPP diffusion is very different from other RES. As we can see from Figure 1.4, in the past two decades, on average, the growth rate of hydropower, geothermal and bioenergy remained rather constant, while wind presents a general declining trend. On the contrary, the solar power registered various significant fluctuations with three peaks in 2004, 2008 and 2011 which match with the implementation of FIT in Germany and the first two deadlines of the Kyoto Protocol. Thus, it is interesting to investigate more deeply the SPP market and the applied policies in various states.

Since every country is unique from the socioeconomic, financial and cultural point of view, the choice of incentives can be thought as tailored to the different objectives that one wants to pursue. It might be useful how much energy is consumed by families as opposed to companies. Moreover, subsidies may favour the installation of PV solar panels with families, or industrial or public institutions.

In general, the countries based their RES mostly on hydropower and only recently they developed a market also for other types of RES, starting with wind technology or, in few cases, with bioenergy. In what follows, we examine the detailed RES framework in each country and highlight the use of RD&D (Figure A1. 3) and the main incentives (as the growth rate peaks suggests in Figure 1.4) addressed to the SPP technology.

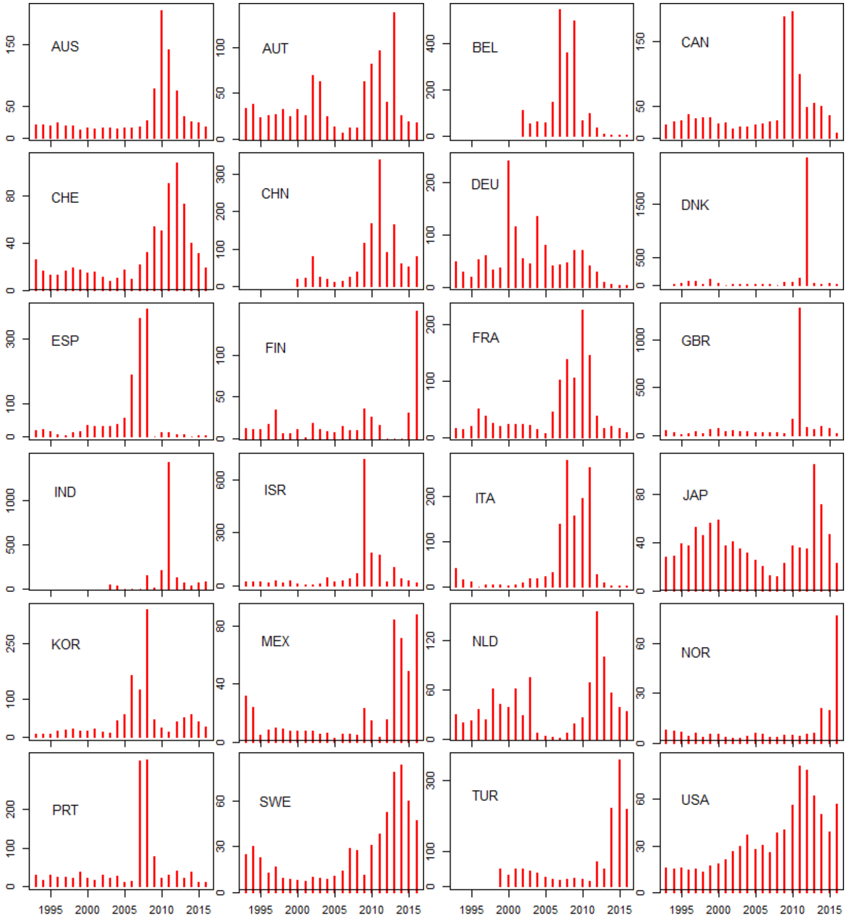


Figure 1.5 Growth rate of cumulative SPP installed capacity 1993 - 2016. Own calculation from IEA-PVPS Trends.

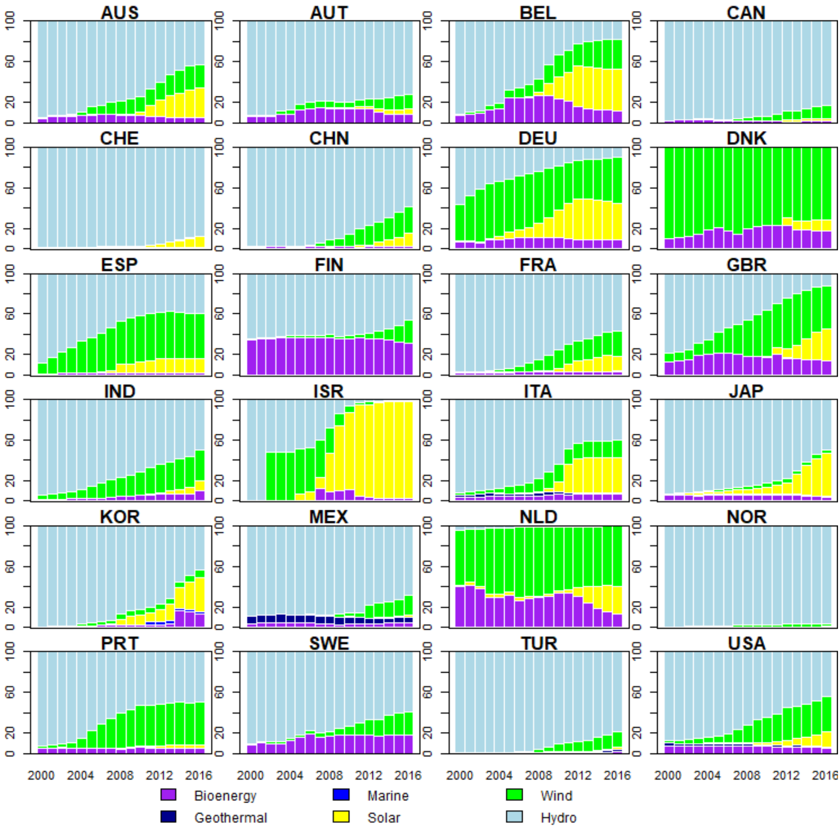


Figure 1.6 Share in total RES by type of source. Own calculations based on IRENA RECGS, March 2017

1.5.1 Countries with energy mainly produced by domestic fossil fuels

From our analysis of countries with large reserves of fossil fuels (Australia, China, India, Mexico, USA) we observe that their main RES is hydropower followed by wind energy (Figure 1.6). Only Australia has installed a significant amount of SPP in the last decade which made it the second source of RES. The Australian effort in adopting SPP can be seen from the important amount of RD&D investments in the technology over the years, ever since 1980 (Figure A1. 3). Also, USA invested in SPP in early years, but most likely her effort was directed to niche projects as explained at the beginning of the section rather than to mass-production. Over the years the RD&D for RES switched mostly to bioenergy. Moreover, in all countries the incentives with higher impact on the SPP diffusion occurred after 2008 which might be as a consequence to the third oil crisis but probably delayed by the sudden reduction in oil price given the following financial crisis.

1.5.1.1 Australia

Since every country is unique from the socioeconomic, financial and cultural point of view, the choice of incentives can be thought as tailored to the different objectives that one wants to pursue. It might be useful how much energy is consumed by families as opposed to companies. Moreover, subsidies may favour the installation of PV solar panels with families, or industrial or public institutions.

In general, the countries based their RES mostly on hydropower and only recently they developed a market also for other types of RES, starting with wind technology or, in few cases, with bioenergy. In what follows, we examine the detailed RES framework in each country and highlight the use of RD&D (Figure A1. 3) and the main incentives (as the growth rate peaks suggests in Figure 1.4) addressed to the SPP technology.

1.5.1.2 China

On the contrary, China became in a brief period the first producer of SPP in the World. Kumar Sahu (2015) highlights the importance of manufacturing companies for the success of the SPP diffusion in China. Thus, the Chinese government is one of the few who created policies directed to SPP producers which include permits and tax-free installations for national grid connected structures. This led to overproduction and as a consequence the survival of the Chinese downstream SPP manufacturing companies is strictly dependent of the export, accounting for 95% of the national production in 2009 (de la Tour et al., 2011; Iizuka, 2015; Yu et al., 2016). The overproduction led to low SPP module prices and conflicts with the importer countries (e.g. “antidumping investigation”) despite the effort of the Chinese government to guide companies to a higher-value-added rather than a low-value-added technology (Iizuka, 2015).

In order to overcome the barriers encountered in exporting SPP technology, the Chinese policy started to shift from production supply prioritization to demand-side policy domination (Zhi et al., 2014) aiming the domestic SPP diffusion also through FITs with deployment in 2009.

This is also the year from which we see a significant increase in growth rate (Figure 1.5).

Despite the increase in the number of patents over time (Fu and Zhang, 2011), criticism concerning low investments in R&D are pointed out in the literature (Zhi et al., 2014) as the production competences of the SPP technology are based mainly on imitative behaviour, low-barrier technological components and building scientific linkages with Germany (de la Tour et al., 2011; Iizuka, 2015).

1.5.1.3 India

A similar case of exceptional development and export (70% of SPP production) of the SPP industry has been registered in India thanks to mixed mechanisms of domestic innovation and international technology transfer (Fu and Zhang, 2011). The country also aims at installing 175GW of RES by 2022 and to eventually reach 100GW from solar energy[3] of which 40GW from rooftop SPP (Goel, 2016; Kar et al., 2016). In order to achieve the established target, India focused also on the construction of 25 huge solar parks with total installed capacity of 20GW for shared use of electricity (Kar et al., 2016).

Furthermore, there have been early RD&D investments in RES in general, but recently the focus is mostly on SPP manufacturing capacities (Goel, 2016; Rao and Shrivastava, 2015). In addition of numerous energy programs and huge solar parks, starting from 2011 some gross or net metering schemes were introduced at regional level[4]. Also, for off-grid systems an initial cost subsidy is provided (Rao and Shrivastava, 2015).

1.5.1.4 Mexico

Even though Mexico has a high radiation index, the country has low SPP installed capacity compared to other RES (Figure 1.6). Because the country is one of the oil exporters and because of the bad economic situation and scarcity of private investments (Ramirez et al., 2000), the interest of Mexico in alternative technology remained low. Only until recently, due to the decrease in oil production and increase in energy consumption, Mexico

---

[3] The target is intended also for other solar technology, not only for photovoltaics.
[4] See (Goel, 2016) and (Kar et al., 2016) for a regional summary of policies.

showed interest in investing in RES to avoid an energy crisis that might be caused by the demand-supply gap (Mundo-Hernández et al., 2014). Initially, the Federal Electricity Boar was aiming to installing wind hydraulic and geothermal (Cancino-Solórzano et al., 2010), excluding solar from the first choices probably because of the absence of domestic manufacturing companies and the high price of imported SPP. It was only in 2014 that the "Mexican Center for Innovation in Solar Energy" was created for consulting services, research and development, etc. (IEA, 2016, p. 83) Moreover, there are no incentives for the mass adoption of SPP except for the Mexican Energy Reform which contemplates a share of 35% of RES in electricity generation. The main part of the installed capacity derive from private investors and developers on large public or private projects (Mundo-Hernández et al., 2014).

1.5.1.5 USA

As pointed out in the case of Australia, the peer effect seems to exert a positive and significant influence on the probability to adopt SPP through the power of example in term of SPP visibility and word-of-mouth, as suggested by a study in California (Bollinger and Gillingham, 2012).

However, the high price of SPP technology in the USA due to associated learning, hardware and soft costs and additional sales taxes (Seel et al., 2014) caused a slower SPP deployment compared to other competitive countries. In order to face the high cost, the Federal Investment Tax Credit was implemented in 2006 (Sherwood, 2010) and successfully continued to stimulate the SPP adoption by offering a 30% tax credit on residential and commercial SPP [15]. Likewise, thanks to the trade dispute resolution the Chinese were allowed to export their SPP technology in the USA at lower prices (Kumar Sahu, 2015) which boosted the SPP diffusion after 2010 (Figure 1.5).

In terms of RD&D the USA shows a declining share of solar in total RES ever since 1970's which got substituted by investments in bioenergy (Figure A1. 3). Nevertheless, since 2011 the SunShot Initiative was launched with the aim of reducing the price of a kWh to 0.06$ by 2020 and to 0.03$ by 2030 (Ardani et al., 2013) and to consolidate the SPP manufacturing industry (Kumar Sahu, 2015).

Despite the absence of a national framework for the support of RES, at state and local levels the incentives have been successful in many areas, especially the RPS (IEA, 2016, p. 110). However, with the Trump administration the attention has been redirected to traditional sources of energy which creates an unpredictable scenario for the future of RES.

1.5.2 Countries with energy mainly produced by domestic and imported fossil fuels

Countries that have some production of fossil fuels but not enough to satisfy the domestic demand of energy are still dependent on imported resources. For this reason, they searched for solutions in the adoption of RES, especially of wind and solar technologies. Exception is the case of Turkey in which case the hydropower is still by far the RES with higher installed capacity.

1.5.2.1 Germany

In Germany the RES market is mainly composed by wind and solar energy with 80% share of total RES. Ever since 1970s Germany focused the RD&D investments mostly on solar power. Recently, the SPP market reached a satisfactory level of development and the RD&D investments are more and more directed also to wind and bioenergy (Figure A1. 3).

The three peaks in the SPP growth rate (Figure 1.5) coincide with: the implementation of the FIT scheme in 2000, which pays 0.52EUR/kWh and gradually decreases by 5% per year; the revision of the FIT rates in 2004 with the increase to 0.57EUR/kWh and decreasing to 0.43EUR/kWh in 2009 and so on until lower rates were achieved such as 0.0671EUR/kWh in 2018; the EU approval of the 18% RES of total electricity consumption target for 2020 [16]. Also, at residential level the SPP adoption rate has been shown to be influenced by distinct financial policies (Dharshing, 2017).

On one hand, the decrease in the SPP module price along with the FIT scheme made SPP more economically appealing (Chowdhury et al., 2014) which made Germany the leader of the SPP market in terms of SPP adoptions. Among the cost components with major impact on the total SPP price which permit to have a lower price in Germany are especially acquisition, installation labour and profit (Seel et al., 2014). On the other hand, Germany was hardly hit by the sharp decrease of the SPP price due to the Chinese overproduction. The phenomenon caused the bankruptcy of domestic manufacturing companies and the disruption of the policy equilibrium also because Germany could not sustain the SPP demand with the domestic production (Yu et al., 2016).

1.5.2.2 Israel

As mentioned in the first section, Israel is highly dependent on fossil fuels, with only 3% share of RES in electricity generation. Hence, the country found in SPP a vigorous solution to start substituting the “dirty” energy especially since it has been scientifically proved that only from rooftop a 32% share of the national electricity consumption could be reached (Vardimon, 2011). Consistent RD&D investments were directed to both academic institutions and start-up companies (Mason and Mor, 2009). The peak in the SPP growth was reached in 2009 thanks to the implementation of FIT in 2008. The value of FIT was of 0.197NIS/kWh and decreased considerably over time but the growth continued to be sustained by the introduction of NMS for all RES up to 5MW in 2013 (IEA, 2016, p. 67). In the past few years the adoption rate returned to the pre-incentives levels probably because politicians continue to support fossil fuel, especially after the discovery of large natural gas reserves in 2009 from which followed the defunding of the national climate change engagement plan (Michaels and Tal, 2015).

1.5.2.3 The Netherlands

RD&D investments in RES are addressed over the years to solar, wind and bioenergy (Figure A1. 3). In fact, we observe that wind and bioenergy always had a great share in RES while solar became significant in the RES portfolio only after 2008 (Figure 1.6) when a FIT scheme was introduced with tariffs around 0.33EUR/kWh for small systems (Vasseur and Kemp, 2011). Before this period the SPP support was given mainly by municipalities and local authorities although with poor success due to inconsistence in policy (Vasseur and Kemp, 2011) and support of other types of RES which nevertheless helped the achievement of the short-term Kyoto and European targets (Guidolin and Mortarino, 2010). However, the efforts of regional support were later rewarded because together with the FIT scheme and other small complementary attractive incentives they increased the technology awareness and facilitated the adoption (IEA, 2013b). Moreover, although the Dutch SPP manufacturing industry is considered rather small at international levels (Vasseur et al., 2013), it remains active and growing and created over 10,000 jobs (IEA, 2016).

1.5.2.4 Turkey

Turkey faces a rapid increase in energy consumption in concomitance with a decrease in production which pushes the government to take actions in improving energy efficiency. Thanks to high irradiation solar might just be the solution if proper incentives are offered (Celik, 2006). In fact, in December 2010 a FIT scheme was introduced with a tariff of 0.133$/kWh for household for 10 years and 0.08-0.12EUR/kWh for industry (Dinçer, 2011) which triggered the SPP deployment in recent years (Figure 1.5). In the past few years we observe an increase of solar RD&D share (Figure A1. 3). This seems to facilitate the achievement of the 2023 target of 5GW solar energy which most likely will be reached given the 3.4GW cumulative installed capacity in December 2017 [17]. However, the target is far from ambitious compared with the domestic consumption and more investments and government support should be provided in order to secure a stable market for this technology with great potential in this particularly highly irradiated country and with significant environmental improvement capacities (Adam and Apaydin, 2016).

1.5.2.5 UK

Over the years there have been RD&D investments in all four types of RES: solar, wind, marine and geothermal, in somewhat balanced proportions (Figure A1. 3), although geothermal and marine have insignificant shares of RES installed capacity, while wind and solar are at the first and the second place with approximately 42%, respectively, 31% (Figure 1.6).

The public incentive that mostly impacted the SPP diffusion is the FIT scheme implemented in April 2010 which consequently led to the sharp growth rate increase in 2011 up to 120 times higher than the previous year (Figure 1.5). The reduction in tariff the following year discouraged especially project developers of large solar installations who still encounter a financial barrier due to the high cost of the system (Balcombe et al., 2014, 2013; Dusonchet and Telaretti, 2015). In fact, in terms of number of installations the SPP market in UK is mainly composed by rooftop rather than large installations. While in the past it was also true in terms of cumulative installed capacity, recently the SPP market has been supported mainly by large systems whereas small installations are following a rather steady trend [18]. Moreover, instead of complementary markets, the SPP and wind technologies seem to be in conflict and immerged in an uncertain environment due to lack of policy stability (Duan et al., 2014).

1.5.3 Countries with energy mainly produced by imported fossil fuels

Countries that are highly dependent on foreign fossil fuels have a RES portfolio composed by mainly hydro and solar power whereas wind and bioenergy register lower shares (Figure 1.6). This reflects the RD&D investments directed primarily to solar technology in all three countries (Figure A1. 3).

1.5.3.1 Italy

The SPP growth rate revels that the technology had its true deployment in the years after 2005 (Figure 1.5) when the "Conto Energia" FIT scheme was introduced. The fluctuations are even more consistent with the five phases of the scheme at monthly level and highlight that almost all of the installations benefitted from public support (Nencioni and Manfredi, 2015). Additionally, between 2009 and 2012 numerous large SPP plants were installed, the largest having approximately 85MW. As the FIT ended in 2013 the diffusion went back to extremely low levels of growth rate sustained only by small programs such as net billing systems, electricity sales and later by the income tax deduction with low effects on the SPP diffusion (IEA, 2016, p. 70). The phenomenon has been analysed by (Palmer et al., 2015) at residential level from 2006 to 2011 through an agent based model of the policy design in Italy based on the payback period of investment, environmental benefits, household income and communication with other agents. Also, their study predicted the stagnation of the SPP market caused by a sudden decrease in the public support while they emphasise that a smoother decrease would have allowed a wider diffusion.

Yet, (Orioli and Di Gangi, 2017) analyse the urban areas of Palermo, Rome and Milan from the economic point of view and compute the discounted payback period (DPB) of the SPP technology from June 2010 to May 2016. Their findings suggest that the value of DPB for the FIT (until July 2013) is longer than DPB of the successive tax credit program, oscillating from 7.44 to 12.78 years at the end of 2015 based on the site's latitude which strongly influences the efficiency of the SPP system.

Although they possess the quality and the efficiency of other international producers, the decrease in SPP adoptions affected the manufacturing industry in Italy which is struggling because of the significant gap between actual output and production capacity (IEA, 2016, p. 71).

1.5.3.2 Japan

In terms of investments, an important RD&D funding for the solar power was applied in 1993 through the "New Sunshine Project". Later, Japan was also among the top inventors of SPP technology in the period 2000-2008 in terms of number of patents (Breyer et al., 2010). In fact, the Japanese market seemed less affected by the Chinese's SPP overproduction because not only it manages to satisfy the domestic demand, but it is also an SPP technology exporter and has more restrictions regarding international trade (Yu et al., 2016).

Japan had predominantly two periods of incentives, before and after 2008. In the first period the increase is more gradual and it was based first on a 50% reduction of the initial cost of residential installations and a NMS (1994-1996) and later, the reduction was extended to industrial and public institutions (1998-2003). (Chowdhury et al., 2014) highlight that factors such as inadequate energy policy, attention towards nuclear power rather than RES, the end of incentives and absence of targets were responsible for the diminishing adoptions in the years before 2009.

In the second period, a substantial FIT scheme implemented in 2008 and improved in 2012, boosted the market to further develop both the residential and the industrial sector (Yamada and Ikki, 2017). From there on the tariff was generally reduced gradually on a yearly basis. Just recently, Japan announced another cut in the FIT for solar plants in 2018 of 14% for non-residential installations [19] All in all, the Japanese SPP market is one of the most developed and counts numerous and various public incentives that helped the mass-adoption.

In view of the forecasted reduction of domestic adoptions, the Japanese manufacturing market is working on further reductions of the module price and prepares itself for a further development on the international market (IEA, 2016, p. 75).

1.5.3.3 Korea

Compared to the other two countries, Korea had a low electricity production from clean sources. Thus, the government is creating basic plans for RES by establishing a target of 13.4% share of total electric energy by 2035 (Lee and Huh, 2017).

In 2001 a FIT scheme was introduced, but it was limited to only 20MW on the first come first served basis [20]. It was only after 2005 that the scheme was enlarged and along with the complementary 60% reduction in the residential installation cost and 100% for public buildings (IEA, 2007) boosted the market (Figure 1.5). The FIT program ended in 2011 because of financial difficulties and it was replaced by the RPS (Chen et al., 2014) which requires that utilities should produce 10% electricity from RES by 2035. Although the FIT scheme had a higher impact from the growth rate point of view, its effect was only temporary, whereas the RPS seems to have influenced more significantly the diffusion of RES in Korea along with the international increase in oil prices (Lee and Huh, 2017).

Over the years the SPP Korean industry developed considerably and nowadays it contains a supply chain of crystalline silicon SPP from feedstock to installation, although it needs substantial political support to become more competitive at international level (Yoon and Sim, 2015).

1.5.4 Countries with energy provided by nuclear power

Even if both France and Belgium have nuclear power as the main energy source for electricity production, the two countries are very different from the RES portfolio point of view, although in both countries the RD&D incentives are primarily addressed to solar and bioenergy.

1.5.4.1 Belgium

SPP in Belgium holds a constant share since 2012 just above 40% of total RES installed capacity, followed by wind which almost reached 30% in 2016 (Figure 1.6). The SPP regulation is different by region. Thus, apart from the national target for 2020 that has been already reached in 2011, all other targets and support are decided at regional level (Dusonchet and Telaretti, 2010). The Flemish region was the first to impact the SPP adoption with the green certificates, a combination between a FIT scheme and RPS (Jäger-Waldau, 2007), which produced the growth rate peaks of 2007-2009 (Figure 1.5). Many other incentives are given even at local level such as premium amounts for investment costs and tax deduction (Huijben et al., 2016). From 2011 onwards there has been a reduction of support in all three regions induced by the decline in SPP price and the financial constraints of public services (IEA, 2013a).

The SPP industry is dynamic, composed by primarily two producers of classical modules for building-integrated SPP and other three companies working on the application of SPP (IEA, 2016, p. 48).

1.5.4.2 France

In the case of France, solar power occupies the third place among the RES, with a share of 14.5%, whereas at the first place we find hydropower with 56.5% followed by wind with 25% (Figure 1.6). The SPP market started growing significantly from 2006 when a new FIT and income tax credit were implemented, along with various support from local authorities (Guidolin and Mortarino, 2010; Solangi et al., 2011). Because of the fear of abusive practices, the French government announced the revision of FIT for 2010 which created a rushed demand observed in the 2010 peak in SPP growth rate. After the reduction of incentives from September 2010 a limited annual growth was imposed at 500MW (Jacobs, 2012) and led to low levels of market growth (Figure 1.5). Recent targets were established to reach 18.2 GW by the end of 2023 established by the Decree of 24th April 2016 [21], pointing especially to the ground based SPP as France has a market dominated by centralized grid-connected systems (Duan et al., 2014).

1.5.5 Countries with energy mainly provided by RES

All four countries which have RES as a main energy source are very rich in hydropower. In fact, the share of hydropower exceeds 70% in all cases (Figure 1.6). However, there are some differences in the implementation of other RES.

1.5.5.1 Austria

With only 5.8% share in RES installed capacity, the solar energy is surpassed by both wind and bioenergy. Actually, the RD&D pattern shows an investment in solar technologies over the year, but an even greater interest in bioenergy which covers approximately 2/3 of total investments, except in the last decade during which solar has received more attention Figure A1. 3). Besides, Austria has an ambitious plan to eliminate fossil fuel by 2030 (IEA, 2016, p. 44) and will shortly exceed the established target of 1.2GW by 2020 with the Green Electricity Act 2012 [22].

The SPP growth rate trend (Figure 1.5) shows three main periods of interest. First, in 2001 the liberalization of the electricity market and the implementation of FIT at regional level brought a significant but short-lasting increase (Mayr et al., 2014). Second, new and substantial FIT were applied in February 2006 (Guidolin and Mortarino, 2010) and revised in 2009 for all RES, but the value of the tariff was higher for the SPP [23] The tariffs assigned through Ökostromverordnung [24] diminished over time and promoted installations above 5kW capacity. Third, in 2013 an investment subsidy was offered for small installations [25]. Furthermore, the Austrian SPP industry has developed and in 2015 it exported 50.5% of the module production and 36.4% in 2016 (IEA, 2017, p. 19).

1.5.5.2 Canada

In Canada the share of SPP is only 2.8% of total RES whereas wind energy goes over 12%, last being bioenergy with only 1.4% (Figure 1.6). Although the bioenergy has a lower share than the solar, in terms of RD&D the country has invested much more in bioenergy over the years (Figure A1. 3). Nonetheless, some significant investments have been made in the past five years which brought an expansion of the industry with 13% manufacturing revenues from export market in 2014 (IEA, 2016, p. 50).

In Canada the situation is very particular because approximately 98% of the SPP installed capacity is concentrated in Ontario [26] which indicates that at the country level the government does not directly invest in solar power but supports the interested provinces in doing so (Moosavian et al., 2013). Here the FIT scheme offered a very high payment for the electricity production, of 0.802 CAD/kWh in 2009 [6] which explains the registered peak (Figure 1.5). On one hand, the scheme attracted many local consumers but, on the other hand, encountered strong opposite political reactions. Thus, many changes have followed which brought criticism from both supportive and opponent coalitions. (Stokes, 2013) The FIT rates were revised periodically and decreased up to 4 times in 2016 [27].

1.5.5.3 Norway

Among the analysed countries Norway has the lowest share of solar power in total RES which is understandable given the great amount of hydropower possessed by the country (Figure 1.6). In fact, based on the RD&D investments we notice Norway's unique interest in improving efficiency of hydropower, but also an interest in all other types of RES (Figure A1. 3), especially in SPP which enforced the Norway's position as a SPP supplier industry of raw material and some companies involved with expansion projects of the SPP technology (Klitkou and Jørgensen, 2011). For example, the Household Subsidy Programme was applied to renewable heating technologies (Bjørnstad, 2012), but there are no targets for the SPP implementation. In 2016 a significant growth rate has been observed (Figure 1.5) although no policies are in act, except the Green Certificates implemented in 2012 with the Act of 24 June 2011 No. 39 [28]. To further increase the market a 35% subsidy of the installation cost for grid-connected plants has been recently implemented (IEA, 2016, p. 88).

1.5.5.4 Switzerland

Switzerland distinguished from the other three countries thanks to its interest in the solar power, with a share of 10.5% or RES in 2016, followed by bioenergy and wind with shares under 2% (Figure 1.6). The market expansion has been a result of vast continuous RD&D investments in solar technology at least since 1974 (Figure A1. 3), strengthening the SPP market to fully cover the value chain (IEA, 2016, p. 103).

A series of important incentives help the deployment of SPP, especially after 2008 when a visible increase in growth rate is detected. First, in 2007 a 20% reduction of fossil fuel consumption was established for 2020. Second, in 2008 a CO_2 tax on stationary fuels was introduced with further increments in 2010 and 2016. Third, a FIT scheme similar to the German one, divided by installation capacity and with payments over 25 years was adopted (Weibel, 2011). The tariffs decreased over time and eventually phased out in 2014 while a direct subsidy for small installations up to 30kW was launched. Also, allowing self-consumption draws numerous commercial installations (Karneyeva and Wüstenhagen, 2017).

1.5.6 Countries with mixed energetic portfolios

Finally, we will talk about countries with mixed energetic portfolios having in common the low interest in solar compared with other RES.

1.5.6.1 Denmark

The RES portfolio of Denmark is rather similar to the Netherlands because of the dominance of wind energy, in this case over 70% of RES. However, the RES portfolio is rather diversified as pointed out also by (Ratinen and Lund, 2012) including bioenergy with 17.7% and solar with 10.7% (Figure 1.6). The pattern shadows the trend of RD&D investments over the years (Figure A1. 3). Despite this, the Danish SPP industry is not very developed, but it contains rather small manufacturing companies (IEA, 2016, p. 56).

A NMS scheme was implemented (Dusonchet and Telaretti, 2010) which was meant to support Denmark's ambitious goal announced in 2011 a commitment to produce energy only from renewable sources by 2050 (Ratinen and Lund, 2015) and because of the global decrease in SPP price, the diffusion largely increased the following year, in 2012 (Pyrgou et al., 2016). The incredible growth was fed by the NMS for private households and institutions and the decreasing cost of the technology. For this reason, the scheme was eventually considered unacceptable by the government and was revised in November 2012 which brought the growth back to its initial pace (IEA, 2013c).

1.5.6.2 Finland

Similar to Norway, also in Finland the share of solar power is extremely low (Saikku et al., 2017) with only 0.3% share in RES in 2016, whereas the other technologies are much more developed: hydropower with 46%, bioenergy with 31% and wind with 23% (Figure 1.6), also highlighted by the RD&D investments especially in bioenergy (Figure A1. 3). The plan for Finland is to eliminate production of energy from carbon sources and to cut greenhouse emissions by 95% by 2050. No national plan for the introduction of SPP is in act, but the SPP technology is considered attractive for self-consumption purposes whereas joint procurements might just lower the barriers to SPP adoption and overcome the absence of government support (Saikku et al., 2017).

1.5.6.3 Portugal

Also in Portugal, the 49% share of hydropower is followed by the 42% share in wind whereas bioenergy and solar count only respectively for 4.6% and 3.6% (Figure 1.6) despite high proportion of RD&D investments precisely in solar and bioenergy (Figure A1. 3). However, in Portugal are active highly automated factories of SPP module productions (IEA, 2016, p. 91).

Similar to Canada, also in Portugal we remark a two-year peak in the growth rate primarily caused by the application of the FIT scheme introduced in 2005 but revised in 2007 for a more complete coverage of all types of RES capacities [29] The FIT scheme continued, but the tariffs had been lowered over time and limitation to the installed capacity has been imposed (Dusonchet and Telaretti, 2010).

1.5.6.4 Spain

Spain is among the European countries with the highest number of hours of sunshine [30] which makes the SPP technology a strategic source to increase energy autonomy and, thus, gain independency from foreign suppliers. In Spain the energy context stabilised in the past few years and the RES market is divided in wind (45%), hydropower (39%), solar (14%) and bioenergy (2%) (Figure 1.6). Also in this case, as in Portugal, the RD&D was mostly directed to solar and bioenergy technologies and only in the last two decades also to wind (Figure A1. 3). The Spanish SPP industry registers some successful manufacturing companies at international level, but in general it suffers for the low domestic demand (IEA, 2016, p. 98).

Similar to Denmark, also in Spain the high FIT tariff induced high growth rates but with the arrival of the 2008 crisis the government encountered difficulties in supporting the large demand and cut the subsidies which caused the collapse of the SPP market (Dusonchet and Telaretti, 2010; Movilla et al., 2013). However, the country’s high irradiation and the decrease in SPP price makes the technology an opportunity especially at industrial levels which increases the probability for a second deployment of the market.

1.5.6.5 Sweden

Although it follows a general decreasing trend, the hydropower remains the main RES with a 59% share. Lately, the wind power (23%) surpassed the bioenergy (17.5%) while solar, although increasing is still at extremely low levels (0.5%) (Figure 1.6). Despite continuous and substantial RD&D in bioenergy (Figure A1. 3), the share in total RES installed capacity remained quite constant over time.

Similar to Switzerland, a carbon tax has been adopted to indirectly support RES technologies (Dusonchet and Telaretti, 2010) and green certificates were distributed in collaboration with Norwegian government. Because of the subsequent decline in SPP price, in 2014 the subsidy was lowered between 20 and 30%. Starting from 2016, an additional capital subsidy was introduced for self-consumption. Moreover, 80% of the population considers SPP a viable technology which deserves more attention (IEA, 2016, p. 99).

1.6 Discussion and future work

Our synthesis emphasizes that the success of the RES market, and especially of SPP technologies, is highly connected with each country's vision of the future. Only a few countries have developed a long-term energy framework and consistently managed their short-medium term energy policies. In general, countries with oil and gas reserves developed a market for the RES, and specifically of SPP, generally later or have low levels of installed capacity compared with the domestic electricity consumption. The evidence was found by studying the cases of: Mexico which is an oil exporter; Israel which has gas reserves, although the amount is insufficient to cover the domestic demand reason for which foreign oil is required to fill the gap; Norway and Canada which apart from the rich and diverse fossil fuel reserves they also possess great hydropower; Australia, USA, UK, the Netherlands which faced significant reductions in domestic production over the years show significant increases in SPP in recent years. Moreover, our findings are also in line with the study of Michaels and Tal, (2015) which indicates that Israeli politicians continue to support fossil fuel, especially after the discovery of large natural gas reserves in 2009 which led to the defunding of the national climate change engagement plan. Consequently, in Israel the adoption rate returned to the pre-incentives levels in the past few years. On the contrary, the presence of large coal reserves (Figure A1. 1) seems instead not to have delayed the SPP diffusion in some countries. In fact, still nowadays we observe large coal exploitations in Australia, Germany, USA, China and India, the top countries in terms of installed capacity.

On the other hand, some countries not disposing of such reserves invested as an alternative option in nuclear power as happened in Belgium, Finland, France, Germany, Japan, Korea, Sweden, Switzerland and UK, especially after the two oil shocks from the 1970s. However, following the Chernobyl catastrophic accident and, further on, the Fukushima disaster, many countries decided to eliminate nuclear either from their future energy perspective (Italy, Austria) or to eventually phase out their already active nuclear plants (Switzerland, Germany). Other countries, such as Austria, Finland, Canada, Norway, Sweden and Switzerland, also had the advantage of abundant hydropower, although in many cases insufficient to cover the generally increasing energy consumption.

With the acknowledgement of the global warming threats, many countries aligned their efforts in finding a common solution and prepared long-term strategic plans to change their energetic portfolio into an environmentally sustainable one. The latest reduction in SPP module price drove various countries to insert the SPP technology among their energy portfolio solutions (Kumar Sahu, 2015).

Nevertheless, in its initial stages the SPP technology was far from competitive with respect to the already well-integrated "dirty" technologies and needed a substantial support to become appealing to consumers and investors. Kumar Sahu, (2015) describes the evolution of the SPP installations in the top 10 SPP countries in terms of electricity production and emphasises that the success of the market is highly dependent not only on each country's policy schemes, but also on the involvement of manufacturing companies. In addition, Yang and Zou (2016) indicates the necessity of cooperation between all the members of the SPP chain, from manufacturer to government to consumer, in order to overcome he barriers to adoption. This is in line with the study of Lang et al., (2015) which indicates that regional interventions by themselves are not sufficient to influence SPP performance as occurred also in the case of Netherlands. Moreover, the policies should be technology-specific rather than opened to all types of RES and should include market conditions and technology stage (Polzin et al., 2015) on the diffusion curve.

Likewise, when designing a policy, the political dimension should be taken into consideration in order to guarantee continuous support as indicated by Stokes (2013) in referring to Ontario, Canada. Public opinion can also have a great influence of the political dimension. In the Italian case however, the government kept investing a lot of money in RD&D for nuclear technologies which were widely not accepted by the public opinion and formally rejected with two referendums in 1987 and 2011.

Avril et al. (2012) criticise the policy schemes in Japan, Germany, USA, France and Italy and recommend a policy scheme based on R&D in a first phase followed by a second phase of FIT or other demand-pull policies and the prolongation of R&D support even if at a lower level. Additionally, evaluating the case of Korea, Jeon et al. (2015) indicates an optimized subsidy by increasing the RD&D funding while reducing the financial subsidy. Moreover, among the policies studied in the literature, the most effective were discovered to be FIT, RPS and investment subsidies (Radomes and Arango, 2015; Solangi et al., 2011; Zhao et al., 2013).

Since the SPP market is very dynamic due to many unpredictable factors that might influence the SPP cost of adoption, a revision of policies once, twice or four times a year were clearly not sufficient to adjust the policies to the global SPP price reduction. A possible solution for a successful policy might be the creation of individual customised policies which should take into account the real price of the initial investment paid by each individual and the actual material and maintenance costs, instead of an estimated price based on past dynamics. This solution allows better government control over the continuous market changes and could avoid excessive SPP demand stimulated by high profitability caused by the gap between a sudden decrease in price and the slow adjustments in FIT tariff as it occurred during the Chinese overproduction.

If on one hand the SPP technology has been found to be profitable in some locations even without subsidies (Lang et al., 2015), on the other hand it still encounters barriers such as high priced and complex technology's perception by adopters, inadequate policies and inappropriate management, especially in the rural areas (Karakaya and Sriwannawit, 2015). Conversely, in other regions low "dirty" electricity prices are still obstructing the take-off of the SPP market (Lang et al., 2015).

Another issue is highlighted in Vasseur and Kemp (2015). They show that adopters consider the SPP an affordable technology while the non-adopters consider it non-affordable probably because the adopters perceive more benefits than the non-adopters. Technology awareness and energy cost saving impact significantly the probability to adopt an SPP which indicates the necessity of additional spread of information regarding investment criteria, policies and environmental attributes, but also of a scheme to speed up the imitative process (Islam, 2014). Orioli and Di Gangi (2017) also show that the DPB is lower nowadays than it was during the FIT scheme in Italy, but despite the economic advantage individuals' negative perception might prevents the deployment of the market in absence of strong incentives.

The research encountered some limitations due to incomplete RD&D data and the absence of data for China, India, Israel and Mexico. It would have been interesting to analyse China and India from this point of view because nowadays they are among the leaders of SPP adopters and producers. Also, in Israel the most popular RES technology is SPP and Mexico is planning the construction of mega solar farms. Data regarding imports from nuclear power was also not available. Moreover, Taiwan became the second producer of SPP technology in the World which makes it an interesting case to analyse, although only limited data is available.

A noteworthy analysis might be the investigation of the imitative behaviour of some countries compared to the leading position of others. In the case of the SPP market some imitative countries (e.g. China and India) seized the opportunity of the increasing international demand and eventually surpassed the leading countries in terms of industry (e.g. Germany and Japan).

Chapter 2. State incentive and the global adoption of solar photovoltaic panels: perspectives based on diffusion models

Abstract

Background. The fast worldwide spread of renewable energies is a major critical action among the international response towards mitigation of global threats such as global warming and climate change. So far however, the diffusion of solar photovoltaic panels is stalling in many countries due to a number of diverse factors despite the support of public incentive.

Objectives and main research questions. The main goal of this paper is to improve the general understanding of the main determinants of diffusion of solar photovoltaic panels worldwide, with special focus on the role played so far by public incentives, and of the resulting perspectives for the future evolution.

Methods and data. By upgrading previous research relying upon data up to 2006, i.e. before the main public interventions were undertaken in most countries, we applied the generalized Bass model to an extended dataset on adoptions of solar panels (26 countries between 1992-2016) in order to characterize the temporal profile of the major domestic shocks in SPP markets, mostly occurred after 2007, focusing on the role of public interventions in influencing scale and shape of SPP adoption curves. A review of the energy policy measures undertaken in the different countries was used to assist the interpretation of the results.

Results. (i) The SPP market started everywhere without the assistance of effective public media support, so that its initial phase was sustained by word-of-mouth communication only, (ii) the pace of word-of-mouth was however plainly insufficient to ensure the achievement of any target of market development within the time frame indicated by international agreements, (iii) most SPP market growth occurred by massive positive shocks which took place between 2007 and 2016, possibly following incentive measures in the various countries, iv) inspection of the parameter estimates describing the temporal pattern of the shocks revealed a lack of temporal persistence of the effects of incentive as well as a sharp trade-off between intensity and persistence of the actions.

Concluding remarks. A target of public policy in countries where the SPP lifecycle is still in its initial phase should certainly be that of supporting the market by adequate media communication. More in general, the SPP market appears as a frail and complicate one where public intervention represented a necessary resource to allow the market full take-off but, at the same time, showed little temporal persistency, thereby failing in going beyond their direct short-term effect and in providing a sustained momentum to the market. The temporal trend of the market, dominated by consecutive incentive-forced waves followed by negligible post-incentive adoptions until the next shock indicates that national incentive policies were in some cases badly designed, suggesting - by a simple game-theoretic argument - the emergence of a deleterious role of expectation where no-one will adopt in an incentive-free period because waiting for (and forcing, thanks to their non-adoption behaviour) the next incentive wave.

Keywords: global diffusion of solar photovoltaic panels, state incentive, generalized Bass model, perspectives on adoptions of renewable energies.

JEL: O33, C22, Q55

2.1 Introduction

The fast worldwide spread of renewable energies, including solar photovoltaic panels (SPP), wind energy, biomasses, etc, is a critical step in the international agenda aiming at mitigating the impact of global warming and global climate change (Kyoto Protocol 1997; Paris Agreement 2015; Intergovernmental Panel on Climate Change (IPCC), Bonn2017). With hindsight it is difficult to deny that renewable energies currently represent a growing reality whose rate of diffusion has been able to outperform that of all other energy technologies ever appeared on earth (Armaroli and Balzani, 2010; ITRPV, 2018) despite many obstacles, including the attempts to debunking global climate change from official science and policy (McCright and Dunlap, 2011, 2003; Oreskes, 2007).

Though the recent pace of growth of renewable energies might appear a great success, it is pairwise difficult to deny that the pathway towards their generalized use is still difficult to achieve. In the case of SPP, from the viewpoint of households these obstacles are intrinsic to the nature of SPP adoption as a long-term investment which is still perceived as unsustainably costly in view of high initial installation costs (Masini and Frankl, 2003; Palmer et al., 2015; Yamaguchi et al., 2013; Zhang et al., 2011); information costs and technical difficulties associated with management and maintenance (Vasseur and Kemp, 2015); constraint on financial resources (Palmer et al., 2015; Robinson et al., 2013); long payback period (Dharshing, 2017; Islam, 2014; Robinson et al., 2013), and finally, uncertainty about the future policies that governments would be following (Reddy and Painuly, 2004; Vasseur and Kemp, 2011) and uncertainty about future technological developments (Karneyeva and Wüstenhagen, 2017; Ruby, 2014).

Public incentives therefore represent the primary instrument to moderate these costs and to stimulate the domestic demand. Public incentives may help the SPP market - which is the only renewable energy technology currently available to households – competing successfully against the «dirty» alternatives, which are less costly but not environmentally friendly (Avril et al., 2012; Chowdhury et al., 2014; Ratinen and Lund, 2015; Zhang et al., 2011). Additionally, public intervention can move in a number of further directions. For instance, an infant SPP industry willing to enter a market which is already dominated by an incumbent foreign producer who is enjoying lower average costs thanks to the large market share it serves, would have a hard time being successful, given the high unitary cost due to the limited scale of its production – rather than by its inefficiency. Public incentives might help removing this obstacle. The supply side can also be favoured by improving the quality of the technology, for given costs, which, if allowing to charge higher selling prices, would increase profitability. Other important roles of public policies that have not been stressed enough in the literature are the need to provide a viable source of energy for countries with a low endowment of fossil fuels (oil and/or gas, in particular), especially when their market prices increase (Lee and Huh, 2017), and to acquire a technology leadership, as it is appears in all evidence for China which has become the major worldwide producer of solar modules since 2007 (IEA, 2016, p. 53).

The previous reasons have led many countries to introduce incentive measures, most of which are customer oriented (National Energy Reports, IEA), supporting the SPP market and allowing it to take off (IEA International Energy Agency, 2018; ITRPV, 2018).

The scale and pace of diffusion, however, are still too low (Karneyeva and Wüstenhagen, 2017) (despite the almost continuing decrease of prices (ITRPV, 2018)), compared to what would be necessary to respond effectively to the current societal challenges. In turn, this raises doubts as to the true obstacles discouraging the growth of the domestic demand, but also as to the role played by incentives and by the way they are assigned, that might have made the SPP market totally dependent on them and therefore being unable to develop any autonomous self-sustained diffusion pathway.

In the management sciences, the use of diffusion models to study the temporal shape of adoption patterns of new durables and technologies was fuelled by the celebrated Bass model (Bass, 1969). The success of the Bass model was due to two main reasons. The first one lies in its clear causal mechanism, identified in the social communication forces, namely public and media communication on the one hand, and imitation, or word-of-mouth, following spontaneous communication between agents (Bass et al., 1994; Mahajan et al., 1995; Mahajan and Muller, 1998). The second one lies in its ability to parsimoniously describe observed adoption trajectories, by using only social communication parameters (Bass et al., 1994; Mahajan et al., 1995; Mahajan and Muller, 1998). The basic Bass model (BM for brevity) was later generalized (Bass et al., 1994) to include the effects of marketing decision variables such as prize and advertising, represented through external time -dependent perturbations of diffusion parameters. However, the main strength of this Generalized Bass Model (GBM), as emphasized in a number of contributions by Guseo and co-workers (Guidolin and Guseo, 2016, 2014; Guseo et al., 2007; Guseo and Guidolin, 2009), possibly lies in its ability to incorporate in a parsimonious and manageable form external shocks forcing diffusion trajectories out of their natural pathway induced by communication forces including, among other, the effects of state interventions.

The main objective of this paper is to use diffusion models to improve our understanding of the main determinants of the diffusion of SPP worldwide, and to offer perspectives on the future development of the market and the possible role of public policy. Accordingly, we applied the generalized Bass model (GBM) to an extended dataset on SPP adoptions including the 26 countries which mostly contributed to worldwide SPP diffusion between 1992-2016), with special focus on the characterization of (i) the mutual role played by the communication drivers, namely the media and word of mouth, vs that of public incentives in influencing scale and shape of SPP adoption curves, (ii) the temporal pattern of the major shocks in SPP markets, which mostly occurred after 2007.

This work draws much inspiration from, and upgrades, previous work by Guidolin and Mortarino (2010) who first used the GBM to describe the effects of public incentive in a multi-country study focusing on the eleven countries which mostly contributed to SPP worldwide adoptions till 2007. However, as IEA data clearly show (IEA International Energy Agency, 2018), it has been in the last decade following their work that the world SPP market definitely took-off, showing more than 95% of the total SPP capacity installed so far worldwide, with unprecedented growth even in those countries, as Germany and Japan, which already experienced a large adoption history. This dramatic acceleration possibly stemmed from major policy efforts aimed to sustain the domestic SPP demand since 2007. Using the GBM to upgrade the previous work by Guidolin and Mortarino (2010), who considered an epoch where shocks in SPP data were taking place on a much smaller scale, will enable us to supply an updated assessment of the current perspectives of SPP markets, particularly of the impact of incentive policies, of their ability to persist over time and, finally, of their ability to bring final momentum to the market.

The rest of the chapter is organized as follows. Section 2 presents the methodology and the dataset. The main general results of the application of the GBM are reported in section 3. A more detailed discussion where the results for each single country are discussed in the light of the underlying national energy framework and policies, as discussed in the first chapter of this thesis, is reported in section 4. Concluding remarks follow. Further details and results are reported in the appendix.

2.2 Methods and data

2.2.1 Data

Yearly data over the period 1992-2016 on cumulative installed SPP capacity (in MegaWatt) in the 26 countries considered were gathered from published international sources (IEA, IRENA). The installation data cover the eleven countries included in the analyses in Guidolin and Mortarino (2010) (Australia, Austria, Canada, France, Germany, Italy, Japan, the Netherlands, Spain, the UK and the US) and fifteen additional countries (Belgium, China, Denmark, Finland, Israel, South Korea, Malaysia, Mexico, Norway, Portugal, Sweden, Switzerland, Thailand, and Turkey) overall representing 96.5% of the total worldwide capacity installed up to December 2016. Various published sources on national policy targets (reported in Appendix) were used to define scenarios for the market size for each country considered, as detailed in the next sub-section.

2.2.2 The Bass model for innovation diffusion

The original Bass model (Bass, 1969) describes an irreversible diffusion process where an item (a durable goods, a new technology, a new idea, etc) spreads in a fixed population of potential adopters of size m as a consequence of the action of the main communications channels. These are distinguished into (i) the "internal" channel, following the spontaneous communication between individuals as a consequence of their daily social "encounters" (be they real or virtual), also termed as word-of-mouth, and

(ii) the "external" channel, following the continued individual's intrinsic propensity to adopt from the publicly available information by the media, the public system, etc. The model is described by the following differential equation in the absolute cumulative number of adopters at time t, Y(t):

$$Y'(t) = \left(\alpha + \frac{q}{m} Y(t)\right)\left(m - Y(t)\right) \quad (1)$$

where α>0 and q>0 represent the *innovation coefficient* and the *imitation coefficient* respectively, and *m* is the *market potential*, representing the saturation level of the cumulative curve. In particular, q tunes the intensity of the agents' tendency to adopt following pressures arising spontaneously in the social structure i.e., in the absence of media communication or state incentive. The prime derivative of the cumulative function S(t)=Y'(t) represents the instantaneous adoption rate i.e., the absolute incidence of new adoptions per unit of time. Letting F=Y/m to denote the relative cumulative adoption curve, the corresponding hazard rate of adoption is given by:

$$\lambda(t) = \frac{F'(t)}{1 - F(t)} = \alpha + qF(t) \quad (2)$$

Equation (1) has the "natural" initial condition Y(0)=0, corresponding to the situation where no initial adopters exist at the moment where public communication starts. The resulting solution of (1) is

$$Y(t) = m \frac{1 - e^{-(\alpha+q)t}}{1 + \frac{q}{\alpha} e^{-(\alpha+q)t}} \quad (3)$$

Equation (3) depicts a monotonically increasing S-shaped curve for $q > \alpha$ and a concave one in the opposite case. In particular in the basic Bass model the growth rate $r(t) = Y'(t)/Y(t)$ is monotonically decreasing. In particular, for $\alpha = 0$ the Bass model simplifies into a *pure imitation*, or *internal*, model. In this case the relative growth rate $r(t)$ is essentially constant in the initial stages of the market, mirroring an underlying exponential growth of cumulative adoptions. On the other hand, for q=0, the Bass model simplifies into a model driven by media communication only, that we also term a purely *external* model.

2.2.3 The "generalized" Bass and internal models

The GBM extends the basic Bass model by including a general multiplicative, time-dependent, component h(t) in the hazard rate, yielding to the equation:

$$Y'(t) = h(t)\left(\alpha + \frac{q}{m}Y(t)\right)(m - Y(t)) \tag{4}$$

To cope with the fact that all diffusion processes typically become known only when some individuals have adopted, it is convenient to express the general solution of (4) for an arbitrary initial condition $Y(0)=Y_0$, obtaining

$$Y(t) = mF(t) = m\frac{1-e^{-(\alpha+q)\int_0^t h(s)ds}\rho_0}{1+\dfrac{q}{\alpha}e^{-(\alpha+q)\int_0^t h(s)ds}\rho_0}, \qquad \rho_0 = \frac{\alpha(m-Y_0)}{\alpha m + qY_0} \tag{5}$$

The initial condition can be taken as a further parameter to be estimated. In [GuidolinMortarino2010] a different but equivalent representation was used to incorporate a time span, having length d, between the true initialisation of the process (for Y=0) and the first positive observed datum on adoptions. For practical purposes it is convenient to represent function $h(t)$ in the form of additive perturbation i.e., as $h(t) = 1 + g(t)$ Guidolin and Mortarino (2010), where we term function g the "shock" function. For g=0 at all times the GBM reduces to the basic Bass model, while the case $g(t) \geq 0$ ($g(t) \leq 0$) over a given time interval describes a positive (negative) shock. For negative shocks it is necessary to add the condition that the time average of $g(t)$ must always exceed (-1) to preserve the non-decreasing character of the cumulative function. Note that for $\alpha = 0$ the GBM collapses into the generalised internal model (GIM). The GIM is of interest here because it will prove to be the appropriate model for SPP data in the countries considered. In particular, the relative rate of growth of the GIM model is given by:

$$r(t) = \frac{Y'(t)}{Y(t)} = h(t)q\left(1 - \frac{Y(t)}{m}\right) \tag{6}$$

Equation (6) tells that the relative rate of growth is the product of the word-of-mouth coefficient (q) times the shock function times the "surviving" fraction i.e., the fraction that has not yet adopted. For a shock restricted over a time interval the pre-shock and post-shock dynamics will approximately obey an internal model purely driven by word-of-mouth, whose relative growth rate is given by $r(t) = q(1 - Y(t)/m)$ i.e., it is proportional to the "surviving" fraction multiplied by the word-of-mouth coefficient. Therefore, the presence of a persistent (over time) difference between the actually observed growth rate and the theoretical growth rate which is expected to prevail at that stage of the market, can be taken as a crude indicator of the presence of a shock.

2.2.4 The shock function and its parametrization

For empirical analyses function g can be specified by appropriate parametric forms depending on a vector of parameters ϑ which can be estimated jointly with (α, q, m). In Guidolin and Mortarino (2010) both the constant shock function (form 1, F1)

$$g(t) = A \cdot I_{\{a,b\}}(t), \quad \vartheta = (A, a, b) \;\; 0 < a < b, \qquad A \in R \tag{7}$$

and the exponential shock function (form 2, F2)

$$g(t) = A \cdot e^{-c(t-a)} I_{(a,\infty)}(t), \; 0 < a, A \in R, c \in R \tag{8}$$

were considered, where $I_{(a,b)}(t)$ represents the indicator function of interval (a,b). Form F1 mirrors a shock uniformly affecting communication parameters (α,q) during a certain interval of time, while F2 describes a shock which initiates abruptly and subsequently decays, or inflates, exponentially over time. Another convenient form is the following (F3):

$$g(t) = A \cdot (t-a) e^{-c(t-a)} I_{(a,\infty)}(t) \quad a > 0, c > 0, A \in R \tag{9}$$

Form F3 is convenient for shocks (both positive and negative) which emerge gradually, rather than abruptly as F2, before being re-absorbed with an exponential-like pattern. This mirrors the realistic fact that an incentive policy will hardly result in a sudden change in adoption parameters, instead it will take time for a number of reasons e.g., for the policy to be communicated to the public and subsequently to "materialise" the intention to adopt following awareness of incentive into the actual decision.

Forms 1,2,3 represent single shock phenomena but can be readily extended to consider generalized shocks functions g_i over different time ranges I_i by considering e.g., $g(t) = \sum_i g_i(t) I_i(t)$, where each $g_i(t)$ term represents a single shock (Guseo et al., 2007).

As noted in Guidolin and Mortarino (2010) the GBM is valuable to provide diagnostics of external interventions and to summarize their temporal characteristics such as e.g., effectiveness, time persistency, etc.

2.2.5 Parameter estimation, criteria for inclusion of shocks and goodness of fit.

The vector of model unknown parameters β=$(\alpha, q, m, \vartheta)$ was estimated from available data by nonlinear least squares (NLS) by considering the standard nonlinear regression model (Guidolin and Mortarino, 2010; Seber and Wild, 1989):

$$z(t) = Y(t, \beta, Y_0) + \varepsilon(t) \tag{10}$$

where the observed response *z(t)* is the sum of the deterministic component, represented by the GBM cumulative curve (equation (5)) evaluated at time t, and the error term ε(t) which is taken as a standard white noise error (Seber and Wild, 1989). The white noise hypothesis is of course a simplifying one, but we maintained it for sake of simplicity as it was also used in Guidolin and Mortarino (2010).

Computation of estimates was carried out by using Excel solver for a "quick and dirty" exploration and nls function of software R for improving the results. The market potential (m) was estimated only for some countries namely those which showed clear symptoms of slowing down in the adoption path, which is necessary to avoid biased estimates (Van den Bulte and Lilien, 1997). In the other cases we preferred to consider a minimum and a maximum scenario with fixed m. In the *minimum scenario* we set m to the nearest short-term target established for SPP by the underlying state Energy Authorities, while in the *maximum scenario* m was set ad-hoc based on available information on long-term energy scenarios, such as EU and National Baselines.

Compared to the data used by Guidolin and Mortarino (2010) over 1992-2006, when SPP adoption was in most countries still in its early stage, our extended data show a number of further "candidate" shocks during 2007-2016 characterized by a much larger magnitude than those observed before 2006 (see the Results section). The inclusion of shock terms in the GBM was based on the following stepwise procedure : (i) visual inspection of the data, (ii) preliminary fit of a basic Bass model and examination of regression residuals (over its various «dimensions», primarily the cumulative curve, the annual curve, and the rate of growth of the cumulative); (iii) stepwise inclusion of shocks, to maintain parsimony, by accepting the next shock based on the incremental values of the squared multiple partial correlation coefficient, as in Guidolin and Mortarino (2010). Due to the need to include a number of shocks during the period 2007-2016, and therefore facing a rapidly increasing number of parameters to be estimated, we preferred - with a few exceptions (notably Germany and Japan) - not to include further shocks in the first stages of SPP lifecycle (<2006). This was motivated by the fact that in many countries data on growth rates of early cumulative installations indicated a coarsely constant trend suggesting the presence of an adoption pattern dominated by *word-of-mouth*. And even in those countries showing larger changes in the growth rate of cumulative adoptions, thus suggesting the possibility of shocks, these changes were not able to substantially perturb the baseline constant trend. Said otherwise, we preferred to interpret these deviations as a consequence of the large volatility (or other undetectable phenomena such as the presence of heterogeneity) which typically characterize early growth rates of diffusion curves rather than the consequence of well-established perturbations. We are aware that this might lead to slightly overestimating the true imitation rate. Pairwise, we did not include shocks occurring in the last two years of the data window given that all parametric forms considered (F1, F2, F3) always include three parameters. This is the case for Norway and Thailand. For these countries we only commented the estimates of parameters of earlier shocks.

To measure the improvements during the stepwise procedure from the current model (i-1) to the next one (i) the squared multiple partial correlation coefficient (SMPCC) was used (Guidolin and Mortarino, 2010; Guseo and Guidolin, 2009):

$$\tilde{R}^2_{i-1,i} = \frac{R_i^2 - R_{i-1}^2}{1 - R_{i-1}^2} \tag{11}$$

where R_i^2 represents the determination index of model i [Seber1989]. The measure (11) captures the relative reduction of residual deviance achieved through the fitting of the next GBM (Guidolin and Mortarino, 2010). As a rule, a model is considered to better explain the SPP trend if $\tilde{R}^2_{i-1,i}$ is larger than an appropriate threshold (here we set this threshold to 0.5), and the number of shocks included in the best model is determined by the stepwise inspection of the SMPCC. This rule needs however being used with care because the patterns of increment in the SMPCC are not simple. For example, in the presence of two apparent shocks the inclusion of just one shock term would only slightly increase the SMPCC because the model would detect the best single shock interpolating the two observed shocks, so that the relevant improvement in the SMPCC would only occur once one correctly includes both shocks into the model.

2.3 Results

2.3.1 General overview

A summary overview of the known story of SPP diffusion in terms of shape and scale of cumulative SPP adoptions (Y) based on data from the countries contributing most to the world SPP diffusion up to 2016 is reported in the next figures. The scale is represented in two different "metrics" namely, as installed MW of SPP per unit population (Figure 2.1), and as a share of the total electricity consumption in each country (**Error! Reference source not found.**). Both panels show marked heterogeneities in both take-off dates and stages of the SPP lifecycles. Note that among

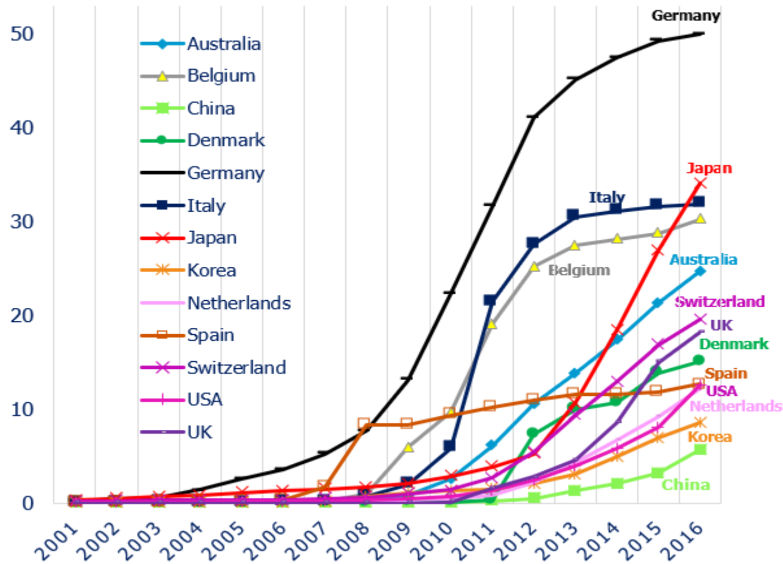


Figure 2.1 SPP cumulative Installed Capacity (MW) per 100,000 inhabitants 2001-2016 in the main countries considered. Own calculation using SPP data on Installed Capacity (source: IEA) and Population (source: UN)

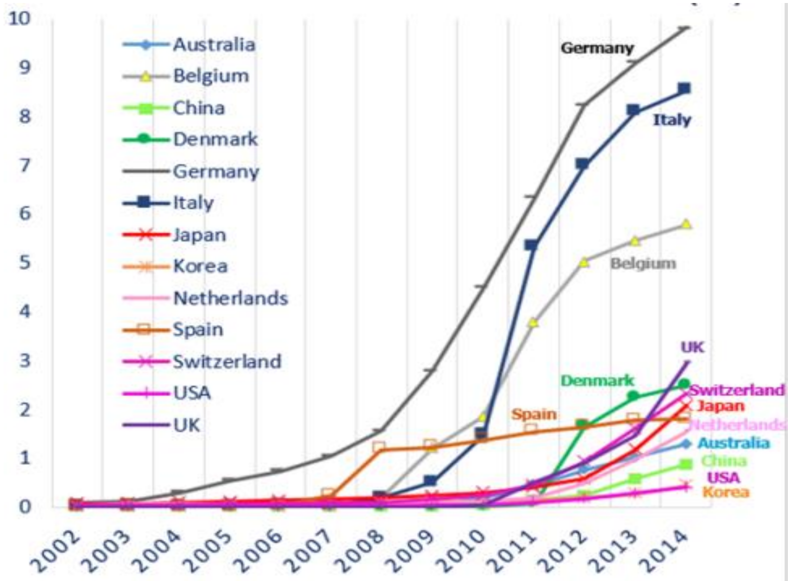


Figure 2.2 SPP cumulative Installed Capacity as share (%) of total electric power consumption 2002-2014 in the main countries considered. Own calculation using SPP data on Installed Capacity (source: IEA), Energy use & Electric Power Consumption (source: World Bank).

producers of fossil fuels only Australia, China and the US have reached a significant diffusion scale so far. A major point stemming from Figure 2.1 is that the three countries that so far represented the world leader in SPP adoptions (Germany, Italy and Belgium) are currently showing evidence of saturation, partly due to the achievement of short term national targets but possibly symptomatic of the exhaustion of the propulsive role of state incentive.

2.3.2 GIM fit to country-level data: the minimum scenario

Here we report summary graphical results of GIM fit to SPP adoption data focusing on the "minimum" scenario. We discuss this case in full detail because for most countries such minimum scenario corresponded to a well-defined short-term policy target. At the national level these targets are available for most countries considered (see Table A2- 2 in Appendix) and only in a few cases the minimum level had to be assumed based on the underlying energy framework. Results on the maximum scenario and on the case where the market potential was fitted are presented more briefly later by only stressing the main resulting differences. Numerical details on best parameter estimates and levels of the goodness-of-fit measure are reported in Appendix (see Table A2- 4).

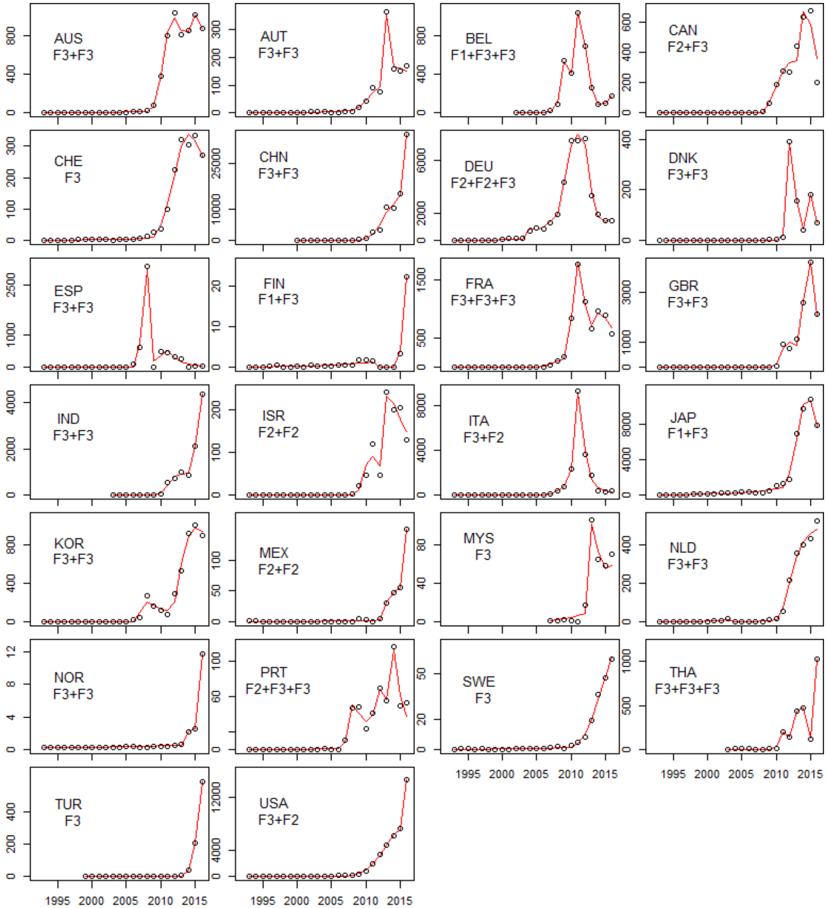


Figure 2.3 The GIM fit in the 26 countries considered: observed vs predicted annual SPP adoptions during 1992-2016. The fit is carried out based on the market potential assigned by the minimum scenario. The legend in each graph specifies the type of shock functions selected during model fit e.g., F3+F3 (as in the case of Australia) means that the first shock occurred in the data belonged to form F3 while the second one belonged to form F3.

The best GIM fits to annual data in all countries considered is reported in Figure 2.3. Figure 2.4 reports the corresponding fit to the (log-transformed, %) growth rates of cumulative adoption. Figure 2.7 shows the same fitted curve expanded with the resulting optimal forecast up to 2030. Finally, Figure 2.8 reports the fit to cumulative adoption data and future market evolution up to saturation under both the minimum and maximum scenario. The legend in each graph specifies the type of shock functions (in a temporal order) that were selected during model fit. For example, in the case of Australia, "F3+F3" means that both the first and the second shock occurred in the adoption trend, visually initiated around 2007 and 2012, belonged to form F3.

For ease of exposition we split the results of this sub-section into a number of further sections.

2.3.2.1 *Fit by the basic Bass model and the innovation coefficient*

The basic Bass model (equation (1)) resulted always inadequate to reproduce the complicate temporal trends of SPP adoptions, as was clear both graphically and from the values of the multiple partial correlation coefficients $\tilde{R}^2_{i-1,i}$, with the partial exceptions of Turkey and Sweden where no evident external shocks were detectable in the graphs and had to be identified by the goodness of fit measure. Nonetheless, the fit by the basic Bass model supplied useful information fully confirmed by subsequent GBM fits, first of all that the external component of adoption resulted negligible ($\alpha/q < 10^{-4}$) in all countries, a fact already noted in Guidolin and Mortarino (2010). This was confirmed also by subsequent GBM fits, actually implying that a generalised internal model (GIM) was fully adequate for the data considered. In substantive terms this result suggests that the SPP market was initiated without a pre-existing significant support from media or public communication sources, thereby implying that the effort of initial diffusion was entirely sustained by word-of-mouth communication only.

2.3.2.2 *GIM fit: structure of shocks and of adoption patterns throughout the different countries*

The combination of internal communication with public incentive in the GIM allowed to satisfactorily reproduce the temporal trends of both annual adoption data (Figure 2.3) as well as of the annual growth rates in all countries (Figure 2.4). As for the number and types of shocks, in four countries (Switzerland, Sweden, Turkey, and Malaysia) a single shock was sufficient to achieve an adequate reproduction of the data, in other five countries (Belgium, France, Germany, Portugal, and Thailand) three shocks were necessary, while in the remaining countries the data were adequately fitted by two shock functions.

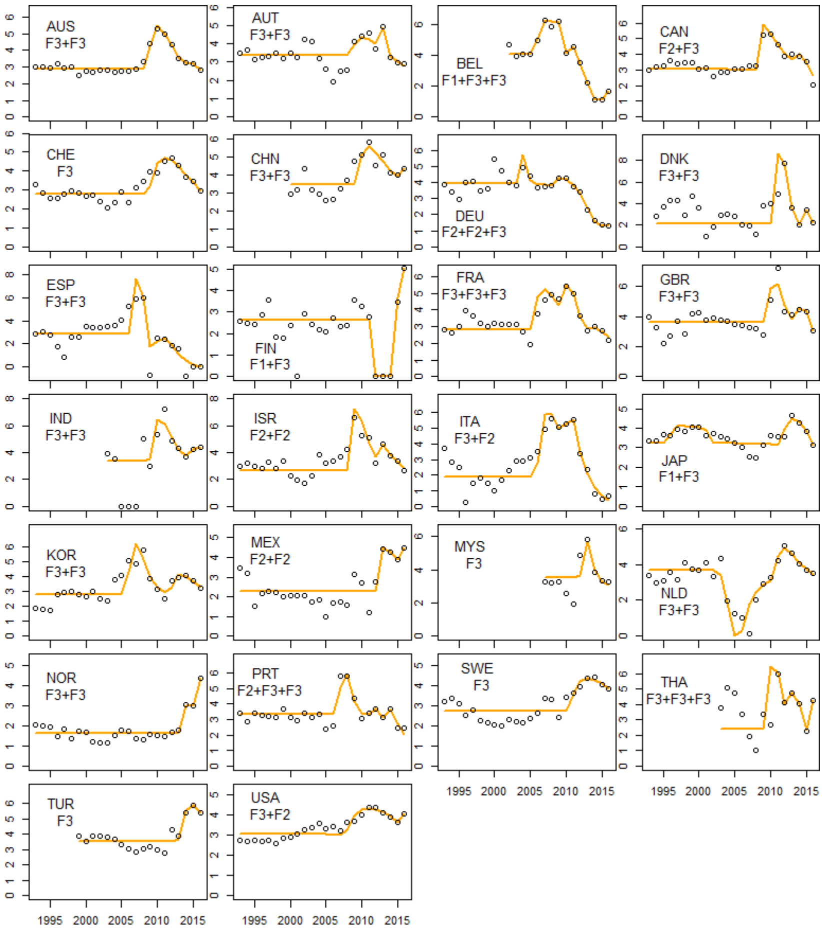


Figure 2.4 The GIM fit in the 26 countries considered: observed vs predicted annual (%) growth rates on adoptions of SPP during 1992-2016 (log scale) under the minimum scenario on the market potential. The legend in each graph specifies the number and type of shock functions selected by model fit.

The selected shock functions resulted essentially always positive and mostly belonging to forms F2 or F3, with the exception of Belgium and Japan, where an F1-shock was detected. No evidence of positive increasing shocks was detected for the period 2006-2016 (they were detected in some countries in Guidolin and Mortarino (2010) for the epoch pre-2006), as intuitively confirmed by inspection of the data. In the case of Belgium and Germany evidence of a negative shock initiated in the last epoch in the data (Figure 2.7) was found. Though short lasting, these negative shocks caused the predicted growth rate of adoptions to temporary fall below the level which was expected to occur at the given stage of the lifecycle (given the level of the market potential).

In more substantive terms, the major fitted shocks were associated, in most countries, to large adoption waves which initiated with a surprising synchrony around 2007, irrespective of the scale achieved at that time. These adoption waves occurred after a fairly long epoch where the pattern was characterised by oscillations around an essentially constant relative growth rate, as is typical of a pure word-of-mouth market in the initial phase of its lifecycle. These facts are apparent from annual adoptions (Figure 2.3) and especially from the dramatic post-2007 increase in growth rates (Figure 2.4) compared to the roughly constant trend prevailing almost everywhere prior to 2007. Exceptions to this pattern are (refer to the growth rates in Figure 2.4) Germany and Japan on the one hand, which were first in setting up robust incentive programs to SPP well before the 2000, later followed by Italy, Spain and Korea, and the two "delayers" Turkey and Mexico, which the major shock phase initiated a few years later, around 2010.

The reason for this synchronous take-off possibly lies in a plurality of factors. This certainly includes the documented expansion in the public support to SPP, which is discussed in the subsequent section 4. Nonetheless it is important to pinpoint the complicate framework within which this public support was initiated. For example, in many cases these measures were established quite lately under the cogent pressure of the deadlines set for 2008 by the Kyoto protocol targets in terms of abatement of emissions of greenhouse gases (UNFCCC). This suggests that the public intervention was partly carried out to fulfil, by a short-term action, standing international commitments, in the absence of a well-established long-term plan. It should also be mentioned the dramatic blow-up of the oil price (with a 5-fold increase between 2000 and 2007, figure in the appendix), that possibly forced a number of further countries to invest in the SPP technology by imitating those countries such as e.g., Germany, that acted as true innovators in this field. Specific situations were also affected by merely local circumstances, such as the dramatic increase in the Japan SPP adoption rate in 2013, the year following Fukushima disaster.

Some countries (Australia, Belgium, Denmark, Israel, Korea, Portugal, Spain and Thailand) clearly showed multiple waves in their annual adoption curve after 2007 (Figure 2.3). As also suggested above, there possibly is a plurality of underlying factors (see the Table on incentive measures reported in the appendix). These included (i) a lack of coordination in incentive programs between different districts of the same country, as happened in Australia, (ii) a massive sudden adoptions by public utilities, as was the case for Denmark, where the secondary peak is mostly due to the installation of a single large public solar park), (iii) public communication announcing a future reduction in the incentive benefit, causing a "run-to-adopt", as documented for France, (iv) lack of coordination and discontinuity in the incentive communication causing even in the short term a temporary lack of ability to sustain the adoption flow, as has been the case for Italy, where the availability of funding, though renewed every new year, was always surrounded by large uncertainty (Palmer et al., 2015), and possibly also of the Netherlands (Vasseur and Kemp, 2011).

As for the more recent years the patterns are more articulated. Focusing in particular on the early adopting countries included in the work of Guidolin and Mortarino (2010), there is a clear decline in the propelling role of incentive. This is apparent not only in absolute terms (Figure 2.3) but also in relative ones Figure 2.4). In particular, only the US were able to keep a growth rate persistently larger than in the pre-2007 period (Figure 2.4), as mirrored in an annual adoption curve still fast increasing at 2016 (though it should be remembered that the US started relatively late with a rather small adoption scale still at 2010). In a number of countries namely, Australia, Austria, Canada, France, Japan and the UK, growth rates have all returned by 2016 to their pre-2007 levels and show clear evidence of a potentially declining trend, with annual adoptions in sharp decline. For Germany we already mentioned above the evidence of a negative shock in the last phase. Finally, in Spain and Italy the flow of annual adoptions as well as the growth rate of the cumulative adoptions fell to negligible levels indicating a rapid stall in the adoption process. This stall did not require the inclusion of a negative shock because for both these countries the minimum policy target was low enough to allow the post -2007 incentive phase to essentially achieve the minimum target providing at the same time an excellent fit to the data despite the almost annihilation of adoptions. Notwithstanding the goodness of fit, the dramatic fall of adoptions in both countries is clearly a worrying phenomenon calling for explanations. We conjecture that, at least in the Italian case, the expectation argument cited in the Introduction might have played a key role in explaining these phenomena. This effect might be amplified in presence of governments' policies principally aiming at short-term results because missing a long-term perspective. A simple game-theoretic formalization of the expectation argument is reported in the Appendix.

As regards more recent adopters i.e., the countries not included in Guidolin and Mortarino (2010), it is important to recall that these countries either show lower adoption scales (in some cases negligible, as for Norway and Finland) because are still in an initial stage of the lifecycle, or are currently far more distant from their minimum target (or have set quite "low" minimum targets). Nonetheless Turkey, Mexico, Sweden and to a lesser extent China, India, Thailand and Korea, are showing by the end of the data window in 2016 growth rates that are still larger than in the pre-2007 period, and no clear evidence of a declining trend, suggesting, overall, a more persistent action of intervention compared to early adopters. Instead, the other countries with a non-negligible adoption scale (Portugal and Denmark among Europeans, and Malaysia) showed little persistence and rapid re-alignment to the pre-shock regime.

2.3.2.3 GIM fit: estimates of the imitation coefficient

In a GIM with well identified shocks occurring only after the initial phase, the estimate of the imitation coefficient q is approximately represented by the height of the initial portion of the predicted growth rates (Figure 2.4). Our estimates are in good agreement with previous results in Guidolin and Mortarino (2010) despite some differences in the computations. Substantial inter-country variation - up to an order of magnitude – was observed in q estimates (Figure 2.5), ranging from 5% per year in Norway and 6%/y in Italy up to a maximum of 47%/y in Belgium. This variation will in turn imply a wide variation in the time that would be necessary to saturate the market potential m when imitation is the only driving force of adoption. For example, the time t_(m,99) necessary to achieve the 99 percentile of the minimum target ranged between 18 years for Belgium and 145 years for Italy. As showed in the right panel of Figure 2.5 most countries would require at least 40 years to saturate the minimum target under imitation only.

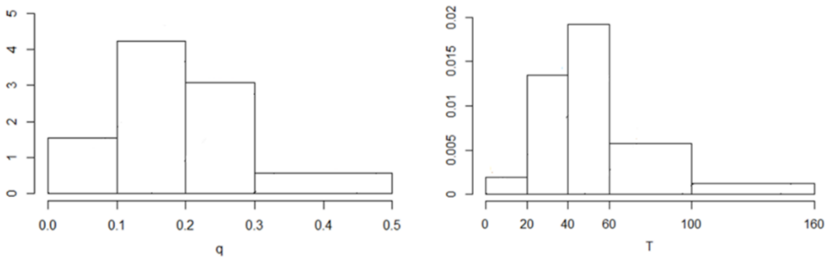


Figure 2.5 The GIM fit in the 26 countries considered. Distribution of the estimates of the imitation rate q and of the time T_(m,99) which is required to reach the 99th percentile of the minimum target in the absence of incentive.

Given that the true q values are likely to be over-estimated in many countries, because they likely embed the effects of interventions that occurred prior to the initiation of the life cycle or during its very early phases, which we deliberately ignored, the t_m values are consequently under-estimated. This result overall suggests that in SPP markets natural communication forces are not effective compared to the time scales which are required to respond to the global threats. This provides per se a strong motivation for the need for public incentive to SPP markets. Which might be the socio- economic and cultural factors underlying these wide differences in the imitation rates is currently unclear and an objective of future research might be to investigate e.g., by regression models, which are the best predictors of the values of the imitation rate across the different countries. However, considering that the q values found here come from a subset of the richest countries worldwide, also characterised by the largest endowments in social capital, it is straightforward to conjecture that perspectives might likely worsen in countries departing from less optimal conditions.

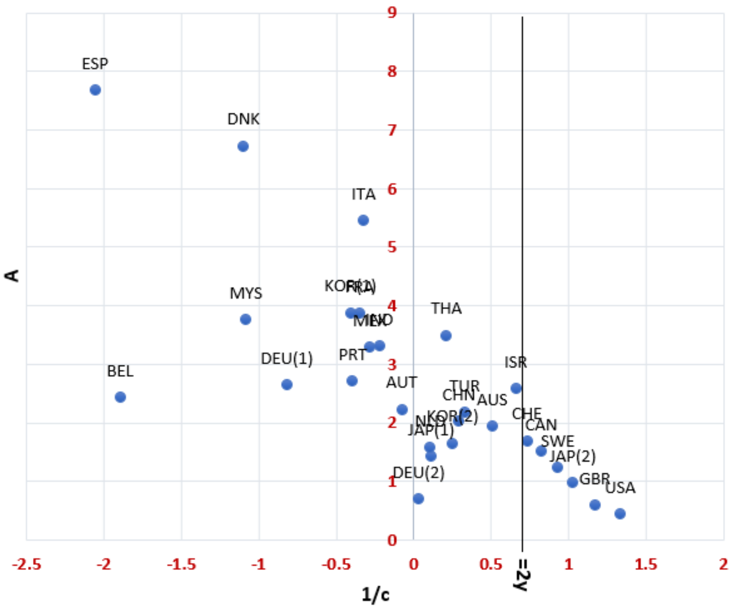


Figure 2.6 The GIM fit in the 26 countries considered. Scatterplot of the best estimates of the parameters (A,1/c) (reported in log-scale) of the F3-form shock functions that best fitted the data. The black line (=2y) represents the threshold of two years persistence of incentives, whereas the y-axe is the threshold of one-year persistence.

2.3.2.4 GIM fit: Relation between intensity and persistence of incentive

A merit of GBM and GIM is that of supplying valuable summary information about the effects of shocks on adoption trajectories, through the estimates of the characteristic parameters of the shock functions. Unlike Guidolin and Mortarino (2010) who found a richer combination of forms of the shocks, including negative shocks as well as positive increasing ones, we found a good degree of homogeneity of the structural characteristic of the large shocks occurred during 2006-2016 i.e., essentially all shocks resulted to be positive and not persistent, most of which belonging to forms F3 or F2. This allowed us to meaningfully compare the features of the shocks in the countries considered by comparing their key characteristics namely, the shock intensity, vs its time persistence. In order to investigate the relationship between the key parameters we made a number of standardizing hypotheses: 1) we homogenized the type of incentive adopted using form F3 only (the only drawback is a slight lack of fit when replacing other types of shocks), taking the estimate of parameter A as a measure of intensity, and the estimate of parameter (1/c) as a measure of time persistence; 2) for countries showing evidence of well-spaced incentive waves (Germany, Japan, Korea– documenting well separated incentive actions) we considered estimates from both incentives; 3) for countries showing very close adoption waves (e.g. the new wave arising just one year after the end of the previous one, suggesting an issue of lack of coordination in the policy rather than genuine different policy actions), we re-fitted a single shock model just in order to provide a feeling of the overall duration of the incentive period; 4) we deliberately disregarded incentives arising in the last year because this prevents to estimate the parameters of the involved shock component. Figure 2.6 reports the scatterplot relating persistence (horizontal axis) and intensity (vertical axis), showing a marked inverse relationship and therefore a trade-off between intensity and persistence. Also notable is the dramatic lack of persistence of shocks, whose average duration almost never exceeded two years. In fact, in twelve countries the average duration is under one year, in nine countries is between one and two years, whereas only in few cases the persistence exceeds two years, e.g. Switzerland, Canada, Sweden, Japan (second shock), the UK and US.

2.3.2.5 GIM fit: predicted future adoptions and time to the minimum target

Figure 2.7 reports the forecasted annual adoptions until 2030 based on the optimal estimates under the minimum scenario on the assumption that no further incentives are provided so that the subsequent dynamics are driven by word-of-mouth only. Besides Spain and Italy, whose level reached in 2016 was very close to the minimum scenario, and therefore just require a very few adoptions per year to achieve the target, most other countries show a more interesting dynamics. In particular Germany, Belgium, France and Korea will have a further local peak in adoptions around 2020-2025 which is driven by pure word-of-mouth dynamics, before reaching the target. On average the countries in the sample reach their targets in 2040, twenty years later than the established target (Figure 2.8 and Table A2- 7). The countries struggling to achieve their politically established targets are Italy, Mexico, France and Israel. Conversely, Belgium, China, Germany and Japan will reach their determined targets by 2026.

2.3.3 GIM fit to country-level data: fitting the market potential.

In this subsection we report results of the full fit of the model including also the market potential among the parameters to be estimated. Based on the warning reported in section 2 about the difficulties in identifying the market potential of Bass-type models without sufficient data, we only fitted the model on a subset of countries whose adoption curve showed clear symptoms of slow-down (i.e., approaching or overtaking a well-defined maximum point).

Thus, for these countries we estimated the optimal saturation level (Figure 2.7). The findings show that both Italy and Spain are in 2016 very close to the market potential which in the case of Italy (21GW) is smaller than the political target of 24GW to be reached by 2020, whereas political parties in Spain do not sustain the SPP market (Gabaldón-Estevan et al., 2018) and consequently did not established a target despite the great irradiation potential of the country. On the other hand, Germany and Japan seems to overpass the political target respectively of 51.7GW up to 58GW and 53GW to 62.5GW of installed capacity.

For countries such as France, Israel, Switzerland and the UK we observe that the estimated market potential is close to the minimum target (either slightly above or below). Moreover, Canada and Korea show evidence of market in mature stages since the optimal market saturation is estimated far under the minimum target. In fact, in Canada the drop in adoptions registered in the last period leads the model to estimate a saturation level close to the last estimated observation (3GW) whereas the political target was set at 6GW, twice higher. Instead, Korea has a general target, such as to reach 11% electricity from RES, thus assuming a minimum target of 20GW. On the contrary, the Netherlands although have set a target three times the installed capacity by 2016 (2GW vs 6GW), the market potential is estimated to exceed 15GW.

In other words, Canada, Italy, Korea, Spain and to a minor extent France, need further incentives in order to boost SPP adoptions. Without further incentives the target most likely will not be reached. In contrast, Germany, Japan, the Netherlands, the UK and Israel developed an SPP market in line with their targets, thus well sustained by the current incentives.

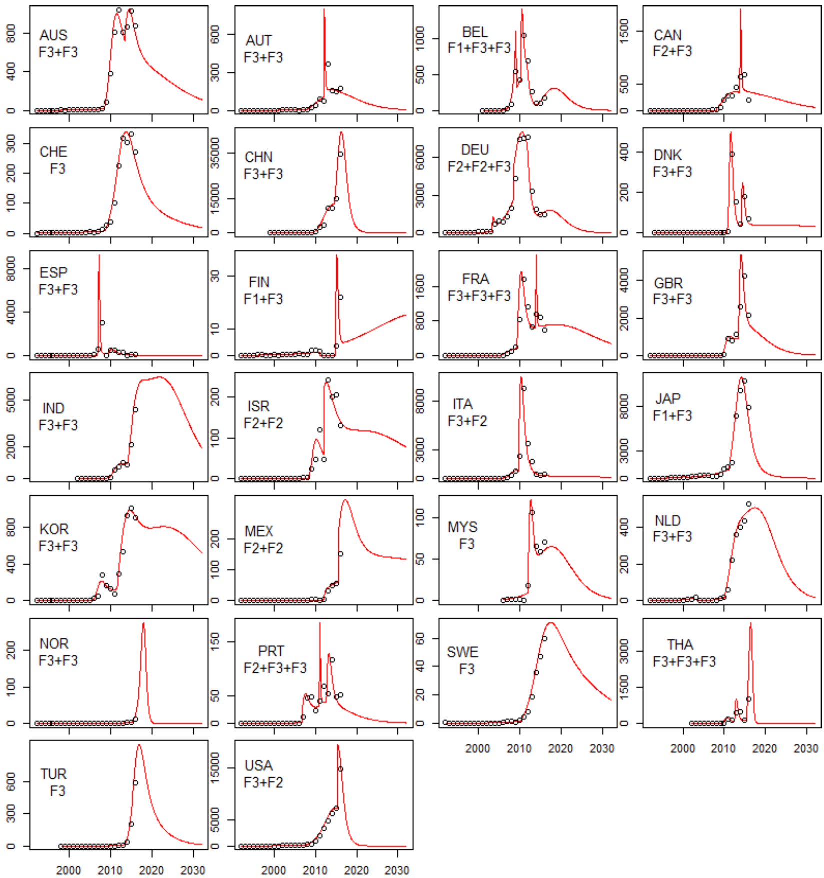


Figure 2.7 The GIM fit in the 26 countries considered: observed vs optimal forecasted annual SPP adoptions curves until 2030. The fit is carried out based on the market potential assigned by the minimum scenario. The legend in each graph specifies the number and type of shock functions selected during model fit. The predicted adoption curve is smoother than in Figure 2.3 because it has been drawn with a more accurate resolution (in Figure 2.3 we only reported observed vs predicted annual figures).

However, among all eleven considered countries, significant improvements in the SMPCC are found for Canada, France, the Netherlands and Korea, the countries with higher differences between market potential estimates and minimum target.

2.3.4 GIM fit to country-level data: the maximum scenario.

This scenario differs from the minimum scenario simply because the market potential is kept fixed and set to a higher level based, whenever possible, on long-term energy planning in the various countries. This scenario does not produce substantial changes in terms of estimates of key parameters and therefore we only briefly comment about the time lapse necessary for the market to reach this target given the current conditions, as shown in Figure 2.8 and Table A2- 7.

The choice of the market saturation level for the maximum scenario (Table A2- 2) is mainly chosen as three times the minimum scenario but it is also based on the energy framework, the total electricity consumption, the availability of different energy sources and the main political believes in each country. In fact, for some countries with insignificant targets but with high potential due to large levels of solar irradiance, such as Portugal and Malaysia, the maximum scenario was selected up to 18 times the minimum.

The parameter estimates are not necessarily the same as in the minimum scenario. What happens is that: a) q is always estimated effectively from the early exponential phase and its estimate is stable, b) the vector ϑ of shock parameters – which is estimated from the temporal profiles of shocks – is estimated in a stable manner only if the shock has been fully observed that is it disappeared before the of the observed period. In the opposite for shocks that were just appeared at the end of the data period the estimate of shock pars can be unstable.

Therefore, the additional information from the maximum scenario mainly regards the time necessary to saturation given the stage of the market at the end of the observed period, the level of the imitation rate, and on whether the last shock was still ongoing or not. For low values of the imitation rate additional incentives are required to reach the higher level of market saturation. On average, the maximum target will be reached by 2055, with an additional 14 years compared to the minimum scenario. The models estimated for the maximum scenario are mainly worse than the minimum scenario (Table A2- 6). Exception is the case of Netherlands where the maximum scenario performs better and is to be reached by 2031. This is in line with the fact that the optimal market potential has been estimated as almost three times the minimum target as highlighted in the previous section.

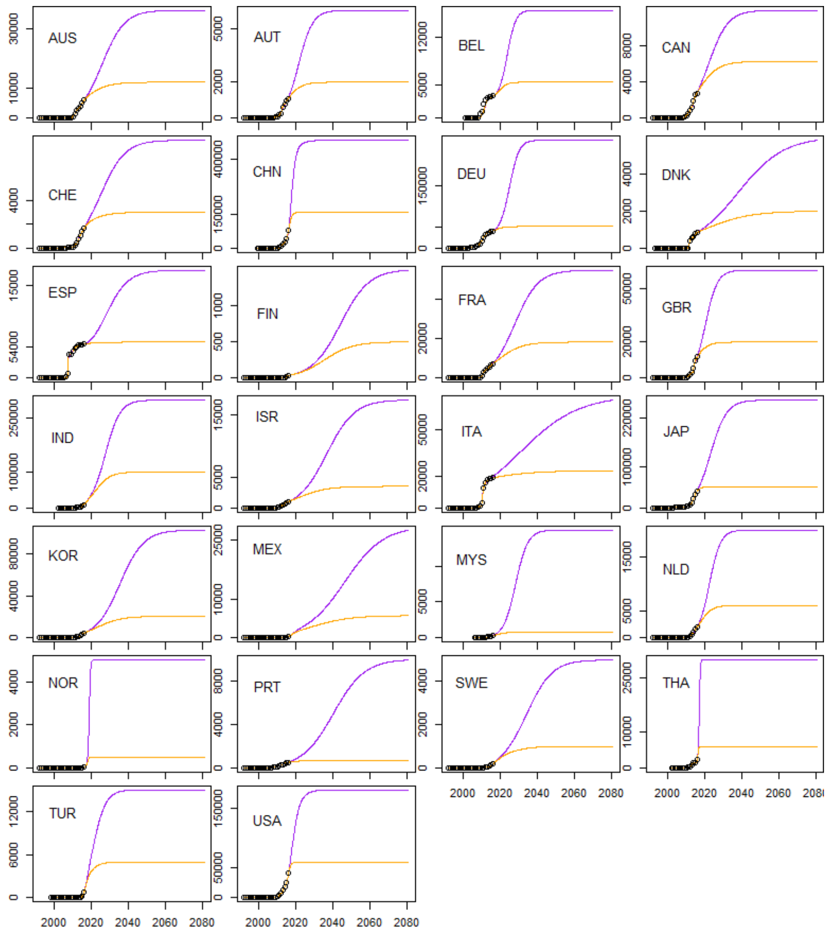


Figure 2.8 The GIM fit in the 26 countries considered: observed vs predicted SPP cumulative adoption data and subsequent evolution of the best-fit curves up to market saturation to the fixed potential level m under both the minimum (orange line) and maximum (purple line) scenarios (see Table A2- 7 for more details).

2.4 Individual countries discussion

In this section we discuss our analyses presented in section three by crossing our findings on the main determinants of SPP diffusion, with the available information on the corresponding main incentives actions adopted in each country considered as reported in Table Y in the Appendix. Incentives summary. We will also refer to Table A2- 4 for the parameter estimates and in Figure 2.3. This discussion principally relies on the findings from the minimum scenario analyses (section 3.2) and follows the classification adopted in Chapter 1, where we clustered the countries considered based on the underlying energy framework and on the availability of different types of energy sources in each country. We include Thailand and Malaysia in the first group because these countries mainly produce electricity from domestic fossil fuel reserves.

2.4.1 Countries with energy mainly provided by domestic fossil fuel

The first group consists of countries with large fossil fuel reserves and hydropower as main RES (Australia, China, India, Malaysia, Mexico, Thailand and USA). In 2016 all countries registered less than 2% share of electricity produced from SPP, except for China with a 5.5% share. However, all the countries, apart from Mexico, have production related incentive policies (FIT or similar). In particular, China and India have ambitious targets, i.e. over 11% of the electricity output produced from SPP in the medium-term (Table A2- 2).

Australia implemented from 2008 both local- and state-level FIT schemes for residential systems, which gradually covered the entire country by 2010. The resulting best-model showed a below average imitation coefficient (q = 16% [a][5]) and 2-shocks (F3+F3), both short-lasting (1/c1, 1/c2 ≈ 1.03), with a stronger effect in the first wave (A1 = 18, A2 = 2.4). The presence of the second shock is likely due to the delayed implementation of fit amongst different geographic areas (the issue we termed "lack of policy coordination" in the previous section). The minimum target, planned to be reached by 2020, is predicted by the model to be reached by 2040 only suggesting the need for further interventions.

[5] [a] = Results in line with G&M (2010)'s findings.

In China in 2010 were in act both FIT and investment subsidies schemes through the implementation of the "Solar Photovoltaic building project" and the "Golden Sun project". Later, in 2015, the Chinese government approved the Five Year Plan which outlines targets, strategies and policy mechanisms to support the SPP adoption. The best model showed an above average imitation effect (q = 28%) and 2 shocks (F3+F3), one persistent for more than one year (A1=7.6, 1/c1 = 1.33) followed by another persistent for almost two years and a half (A2=3.2, 1/c2 = 2.44). As pointed out in Chapter 1, the efforts of China to increase SPP domestic adoption were also a consequence of the over-production and the anti-dumping restrictions that affected SPP exports. Additionally, they established a 162GW target to be reached by 2020. Our findings show that China is the only country that will achieve the target in time.

Another ambitious country is India which aims at installing 175GW of RES by 2022, eventually reaching 100GW from solar energy of which 40GW from rooftop SPP (Goel, 2016; Kar et al., 2016). To do so, India focused on the construction of 25 huge solar parks (Kar et al., 2016) and offered production related incentives within the "Smart cities" project which supports the installation of RE up to 10% of total electricity production in selected cities. In India we estimated 2 short-lasting shocks (F3+F3) with a stronger effect in the first one (A1=27, 1/c1 = 0.8; A2=4, 1/c2 = 1.12) and a coefficient of imitation (q = 25%) similar to China. Our results point out the in absence of further incentives the Indian target will be reached in 2040.

The sample includes also countries with simple SPP adoption trends, with only one positive shock in the period after 2006. Malaysia is among these countries with a high word-of-mouth impact on the SPP trend (q = 31%) and with a four-month period of intense shock (A1=43, 1/c1 = 0.34) in 2012, after the implementation of a FIT scheme through the Renewable Energy Act 2011.

In Mexico the SPP installed capacity is still at very low levels. Only recently, due to the decrease in oil production and increase in energy consumption, Mexico showed interest in investing in RES (Mundo-Hernández et al., 2014). The SPP pattern estimate consists of two similar shock waves (F2+F2), both lasting around two years (A1=7.8, 1/c1 = 2.6; A2=8.5, 1/c2 = 1.85). The starting point of the first shock is in 2013 after the introduction of the General Law of Climate Change based on an RPS strategy, whereas the second shock from 2016 reflects the introduction of the Clean Energy Certificates. These efforts confirm the Mexican Government willingness to make fundamental changes to the current fossil fuel dependent energy framework. In fact, the Mexican government plans to add 5.4GW by 2020. However, our findings show that Mexico is among the countries that mostly struggle to reach their target. Without strong incentives which should to contrast the low imitation effect (q = 10%), the achievement is estimated for 2076.

Thailand adopted the FIT scheme in 2007, revised twice in 2009 and in 2013. The scheme was focusing especially on rooftop and community ground-mounted systems. In Thailand we find a 3-shock model (F3+F3+F3) with a low word-of-mouth impact (q = 11%), but with two short-lasting very intense incentives (A1=163, 1/c1 = 0.5; A2=182, 1/c2 = 0.24). Furthermore, the recent Alternative Energy Development Plan (AEDP 2015-2036) expands the RES target up to almost 20GW by 2036.

The USA has no national plan, however, there are several incentives at local or state level. For example, states such as California, Hawaii and Michigan, have in act production related policies, sometimes combined with investment subsidies and/or RPS. The latter policy was present in 29 states as in 2016, whereas 38 states implemented NMS. The USA is a particular case, with a 2-shocks (F3+F2) and a medium imitation effect (q = 19% [a]). Here we estimated the longest persistence of the sample for the first shock, lasting almost four years at low intensity (A1=1.6, 1/c1 = 3.85) from 2010. The political targets in US are established at state level and not at national level.

2.4.2 *Countries with energy mainly provided by domestic and imported fossil fuel*

The second group includes countries with a medium dependency on foreign fossil fuel (Germany, Israel, the Netherlands, Turkey, UK), and a share of electricity production from SPP ranging from 1.6% (for Turkey) to 11% (for Germany) in 2016. Nevertheless, all the countries are making efforts to reduce the dependency from foreign fossil fuel through the implementation of FIT policies and the pursuit of ambitious targets.

Germany is one of the SPP market pioneers, which put in act the FIT scheme for the first time back in 2000 called the EEG Program[6]. In 2004 it followed a revision which increased the value of FIT up to 0.57EUR/kWh. Another revision of the tariff took place in 2009. We estimated in Germany two well-separated shocks. Indeed, the first wave of incentives occurred long before 2005[7] [a]. For the best model we estimated 3-shocks (F2+F2+F3). The first is a very short-lasting positive shock with high intensity (A1 =8.2, 1/c1 = 0.3) starting in 2004, followed by a second long-lasting positive shock of a smaller intensity (A2 =0.95, 1/c2 = 3.3) from 2009. These suggests that the 2009 FIT scheme changes increased the policy efficiency. The third is a negative two-year lasting shock (A3 = -1.07, 1/c3 = 2.1) from 2012, after the FIT reduction. After the disappearance of the negative shock arisen in 2012, Germany will experience a further adoption wave, sustained by the recovery of the growth rate to its normal "imitation" speed (q = 40% [a]). However, this negative shock increased the time needed to reach the 51.7GW target set for 2020 by 5 years.

The lack of coordination seems to be also a problem in Israel which faced a highly intense one-year shock (F2) (A1=42, 1/c1 = 0.94), followed by a second (F2) less intense but more persistent one (A2=5.4, 1/c2 = 1.6). The peak in the SPP growth was reached in 2009 thanks to the implementation of FIT in 2008. The value of FIT was of 0.197NIS/kWh and decreased considerably over time but the growth continued to be sustained by the introduction in 2013 of NMS directed to all RES up to 5MW (IEA, 2016, p. 67). In the past few years the adoption rate returned to the low pre-incentive levels (q = 13%) probably because policymakers continued to support fossil fuel, especially after the discovery of large natural gas reserves in 2009. This also led to the defunding of the national climate change engagement plan (Michaels and Tal, 2015). At this pace Israel will reach the 10% energy from SPP, programmed for 2020, only in 2056.

Conversely, in the Netherlands we observe a significant imitation effect (q = 33%). (Guidolin and Mortarino, 2010) detected a large positive shock and concluded that the SPP market had by then largely overtaken its peak and

[6] The EEG (Renewable Energy Sources Act) Program is a FIT scheme implemented in 2000 which caused an initial "peak" highlighted in Guidolin and Mortarino (2010) but omitted in our research due to the low level of adoptions in the first stages.

[7] A detailed framework of the incentive schemes is described in Chowdhury et al. (2014)

was very close to saturation. The analysis of the extended dataset showed further shocks starting from a large negative shock over 2004-2008, documenting that the fall in the growth rate diagnosed by Guidolin and Mortarino (2010) as symptom of saturation was instead the aforementioned large negative shock probably caused by lack of coordination and limited success of some demonstration projects. Thus, we focused on the second, most significant, shock which is just over one-year lasting with average intensity (A1=4.8, 1/c1 = 1.1). The shock appears around 2011 when a significant amount of money was made available for the national FIT scheme (Stimulering Duurzame Energie +).

Turkey put in act the FIT scheme in December 2010 with a tariff of 0.133$/kWh for household for 10 years and 0.08-0.12EUR/kWh for industry (Dinçer, 2011). The resulting best model shows a high imitation effect (q=30%) and only one year and five months shock with a high intensity (A1=8.8, 1/c1 = 1.4). Although we estimate a delay in the achievement of the 2023 target of 5GW solar energy, i.e by 2031, recent efforts increased considerably the SPP cumulative installed capacity up to 3.4GW in December 2017.

For the case of UK, we estimated a 2-shock model (F3+F3) with a high imitation effect (q = 31% A1=33, 1/c1 = 0.57; A2=23, 1/c2 = 0.41). The public incentives that mostly impacted the SPP diffusion are the FIT scheme and the ROC. The FIT scheme was implemented in April 2010 leading to the sharp growth rate increase in 2011 up to 120 times higher than the previous year. The reduction in tariff the following year discouraged especially project developers of large solar installations who faced financial barriers due to the high cost of the system (Balcombe et al., 2014, 2013; Dusonchet and Telaretti, 2015). The ROC, addressed only to systems larger than 50kW, shows effects in the following years as we will highlight in detail in the next chapter. The UK established a target of 20GW by 2020. Our results show a delay in achieving the target until 2029 in absence of other incentives.

2.4.3 Countries with energy mainly provided by imported fossil fuel

The third group consists of countries strongly dependent on foreign fossil fuel for the energy production (Italy, Japan, Korea), but also with significant investments in SPP. For example, Italy ranks second among the countries considered in terms of share in total electricity produced from SPP in 2016 (9%), whereas Japan is a pioneer in the SPP adoption.

The structure of the Italian adoption trend is analogous to the Mexican one, including the low word-of-mouth impact (q = 10%). Italy has two very similar shock waves, both lasting nearly one year with strong intensity (A1=70.93, 1/c1 = 1.03; A2=53.4, 1/c2 = 0.9). The imitation effect among the lowest in the sample (q = 6% [a]) highlights the need of incentives. In fact, the technology had its true deployment in the years after 2005 with the introduction of the FIT scheme "Conto Energia". The fluctuations are even more consistent with the five phases of the scheme at monthly level and highlight that almost all of the installations benefitted from public support (Palmer et al., 2015). As the FIT ended in 2013 the diffusion returned to extremely low levels of growth rate sustained only by small programs such as net billing systems, electricity sales and later by the income tax deduction. In these conditions, the 24GW target set for 2020 will be achieved only in 2066.

Similar to Germany, also Japan follows a 2-shock model to estimate well-separated shocks (F1+F3) with a medium effect of word-of-mouth (q=23%[8]). The constant shock is extended over a period of five years during the investment subsidy program Residential SPP Monitor Program which minimized some financial constraints for small systems. The second incentive wave lasts two years and a half (A2=3.18, 1/c2 = 2.44) and started in 2012 with the replacement of the RPS by the FIT scheme when it became mandatory for the electric companies to acquire renewable energy at a fixed price for a certain amount of time. The forecast indicates a decreasing trend of adoptions until the reach of the 99th percentile of the minimum target after around 2023.

In the case of Korea, the 100,000 roof-top program allowed the installation of 2452 systems of an average capacity of 2.47kW with a 70% initial cost reduction, while the FIT scheme was applied until the achievement of a 100MW cumulative installed capacity. The resulting best model estimated two short-lasting shocks (F3+F3) (A1 = 48.6, 1/c1 = 0.66 = 8 months, A2 = 5.2, 1/c2 = 1.28), with a high intensity in the first shock, and a below average

[8] Whereas Guidolin and Mortarino (2010) estimated a model with parametric origin with a double value for the coefficient of imitation.

“imitation” effect (q = 16%). The second incentive results from substitution of FIT scheme for RPS (Chen et al., 2014). Although the FIT scheme had a higher impact on the growth rate, its effect was only temporary, whereas the RPS seems to have influenced more significantly the diffusion of RES in Korea along with the international increase in oil prices (Lee and Huh, 2017). Korea has no specific target for the SPP technology, but it is preparing a substantial plan to increase its energy produced by RES. However, without further proper incentives 5% of its electricity produced from SPP (mainly 20GW) is to be will be achieved only after 2050.

2.4.4 Countries with energy mainly provided by nuclear power

The countries which produce electricity mostly from nuclear power are France (80% of total electricity from nuclear) and Belgium (50%). Unlike France, Belgium increased significantly the production from RES in the last decade with shares of electricity production from SPP respectively equal to 2.1% and 6.5%.

In Belgium, the SPP regulation is different across regions. The first shock corresponds to the green certificate adoption in the Flemish region, which is a combination between a FIT scheme and RPS (Jäger-Waldau, 2007). Local incentives include premium amounts for investment costs and tax deduction (Huijben et al., 2016). Since 2012 there has been a reduction in support in all three regions induced by the decline in SPP price and the financial constraints of public services. The case of Belgium presents a mixture of shocks comparable to both Germany and Japan, thus a 3-shock model (F1+F3+F3) with the highest imitation effect in the sample (q = 47%). The findings show an initial constant shock which lasted 3 years and 5 months, followed by a short-lasting gradually increasing shock (1/c1 = 0.24) with strong intensity (A1 = 21.3) and a two-year-lasting negative shock (A3= -1.12, 1/c3 = 2.12) in the last period of the adoption trend. Furthermore, similar to Germany, also Belgium will experience a further adoption wave, sustained by the recovery of the growth rate to its normal “imitation” speed. Despite the high impact of word-of-mouth, the negative shock delays the 2020 target achievement of 5GW by six years (2026).

The French SPP market started growing significantly from 2006 when a new FIT and income tax credit were implemented, along with various support from local authorities (Guidolin and Mortarino, 2010; Solangi et al., 2011). Because of the fear of abusive practices, the French government announced the revision of FIT for 2010 which boosted demand and resulted in the SPP growth rate peak in 2010. After the reduction in incentives since September 2010 a limit to annual installed capacity was set at 500MW (Jacobs, 2012) and slowed market growth. In France (F3+F3+F3) the parameters increase progressively from more to less persistence and from weak to strong intensity (A1=14.2, 1/c1 = 1.18; A2=55.34, 1/c2 = 0.46; A3=106, 1/c3 = 0.1; q = 16%). Recent target established by the Decree of 24th April 2016 and set to 18.2 GW by the end of 2023, (Duan et al., 2014), is estimated to be achieved only by 2048.

2.4.5 Countries with energy mainly provided by RES

The fifth group includes countries with energy mainly produced from hydropower (Austria, Canada, Norway, Switzerland), hence less stimulated to massively adopt other types of RES. The SPP share in electricity in 2016 is negligible for Norway, small for Canada (1.3%) and Austria (2.6%), whilst in Switzerland we observe a higher share (3.9%).

A 2-shock model was estimated for Austria (F3+F3) with an above average imitation effect (q = 26% [a]). The first shock presents a high persistency (1/c1 = 1.58) starting from 2009 and a low intensity (A1 = 2.2), corresponding to the implementation of the FIT scheme in February 2009, revised in 2010 and 2012. The second shock persists only for one month (1/c2 = 0.1) in 2013 with a remarkably high intensity (A2 = 272). The last FIT revision as well as investment subsidies for small SPP systems in 2013 might have influenced the SPP trend. The SPP target in Austria was of only 1.25GW which was almost exceeded in 2016. However, the new assumed target of 2GW will be reached only in 2032.

In Canada, at the country level the government does not directly invest in solar power but supports the interested provinces in doing so (Moosavian et al., 2013). In fact, approximately 98% of the SPP installed capacity is concentrated in Ontario [26]. Here the FIT scheme offered a very high payment for the electricity production, of 0.802 CAD/kWh in 2009 [27] which explains the registered peak. On one hand, the scheme attracted many local consumers but, on the other hand, it faced political oppositions. (Stokes, 2013). The resulting best model has a two-year-lasting of medium intensity first shock (F2) (A1=9.7, 1/c1 = 2.04), whilst the second shock (F3) is short-lasting and of high intensity (A2=162, 1/c2 = 0.12). The coefficient of imitation is at medium levels (q=19% [a]). Nevertheless, the 6GW target establishes din 2012 for 2020 is to be achieved only after 2040.

The low SPP adoptions in Norway are caused both by low levels of imitation effect (q = 0.5%) and lack of significant incentives. Only in the last few years the presence of Green Certificates increases adoptions, producing a positive shock at the end of the period.

Various important policies help the deployment of SPP in Switzerland. First, the Government set in 2007 a target of 20% reduction in fossil fuel consumption by 2020. Second, in 2008 a CO_2 tax on stationary fuels was introduced and further increased in 2010 and 2016. Third, a FIT scheme was adopted in 2008 (Weibel, 2011), regularly revised over time until it phased out in 2014 when a direct subsidy for small installations up to 30kW was launched. Finally, allowing self-consumption draws numerous commercial installations (Karneyeva and Wüstenhagen, 2017). In Switzerland only one shock was needed (q = 15%, A_1=5.5, $1/c_1$ = 2). The are no political targets regarding the SPP diffusion in Switzerland and only 4% of the total electricity was produced from SPP in 2016.

2.4.6 *Countries with mixed portfolios*

For countries without a prevailing energy source (Denmark, Finland, Portugal, Sweden, Spain) the SPP installed capacity in 2016 is minor with SPP shares in total electricity below 3.4%.

In Denmark was put into act a NMS scheme (Dusonchet and Telaretti, 2010) meant to support Denmark ambitious goal announced in 2011, i.e. to produce energy only from renewable sources by 2050 (Ratinen and Lund, 2015). This policy along with the global decrease in SPP price led to the extraordinary SPP diffusion in 2012 (Pyrgou et al., 2016). Consequently, the government considered the scheme unacceptable and revised it in November 2012, slowing the growth in the following year. The resulting best model (F3+F3) estimated two very short-lasting shocks ($1/c_1$, $1/c_2 \approx 0.3$) with an extremely high intensity for the first shock (A_1=840, A_2=53). The second shock corresponds to the opening of the WIRSOL solar park, the largest in north Europe with 61.5MW equal to one third of the installed capacity in 2015. Although the previous target of 200MW for 2016 was achieved in advance, Denmark has a low word-of-mouth impact (q = 8%)

reason for which it will struggle to reach even only 2GW (equivalent to less than 8% share in electricity consumption), estimated after 2070.

Like Norway, also Finland has few SPP adoptions caused by low levels of imitation effect (q = 13%) and lack of significant incentives. In fact, SPP was excluded from the FIT scheme implemented in 2010 which caused a negative constant shock, with no adoptions from 2012 to 2014. Only recently, Finland implemented investment subsidies and tax credit for SPP.

The FIT scheme implemented in Portugal in 2005 and revised in 2007 [29], continued for years, but it was not constantly effective due to reduction of tariffs over time (i.e. Decree 284/2011, Portarias 430/2012 and 431/2012). This limited the SPP installed capacity (Dusonchet and Telaretti, 2010). In the best model (F2+F3+F3) we estimated one-month-period of highly intense incentive (A2=154, 1/c2 = 0.1) between two shocks more persistent, yet with weaker intensities (A1=15, 1/c1 = 0.7; A3=11, 1/c3 = 0.5). Despite the extremely low target (670MW equivalent to only 1.2% of total electricity output), without further incentives Portugal is not going to achieve it before 2029.

In Sweden no specific target was set for SPP, but a general target of 63% share of electricity demand generated by RES is sustained by the acquisition of Green Certificates, capital subsidies and the introduction of a carbon tax (Dusonchet and Telaretti, 2010). A capital subsidy of 60% of the SPP costs was introduced in 2009 and later lowered between 20% and 30%, due to the decline in SPP price. Starting from 2016, an additional capital subsidy was introduced for self-consumption. The imitation effect is relatively small (q = 15%) and we observe an above average persistence, but a lower intensity (A1=3.4, 1/c1 = 2.6).

In Spain, the implementation of a high FIT value (Royal Decree 661/2007) resulted in a demand spike, which was unexpected by the Spanish government. With the 2008 crisis, the government faced difficulties in supporting the large demand and it eventually reduced the subsidies, causing the collapse of the SPP market (Dusonchet and Telaretti, 2010; Movilla et al., 2013). Spain presents an extremely intense first shock (F3) which persisted for less than two months (A1=2122, 1/c1 = 0.125, q=16%). After the significant revision of the FIT value (Royal Decree-Law 14/2010), there is a second smaller shock (F3) (A2=7, 1/c2 = 0.96). Spain is one of the countries estimated to be close to saturation (m=5500) in absence of further incentives.

2.5 Discussion and concluding remarks

In the present chapter we have applied the generalised Bass model to an extended dataset on installed SPP capacity in the 26 countries that mostly contributed to SPP worldwide adoptions between 1992 and 2016 with the goal to offer perspectives on the future evolution of the market based on an improved understanding of the main determinants of diffusion. In other words, this work attempted at disentangling the contributions to SPP adoptions due to the main drivers of diffusion processes, namely the mediatic vs word-of-mouth communication vs external perturbing factors, including the incentivating actions from the public system. In particular, the analysis paid special attention on the major shocks occurred over the decade 2007-2016, during which the installed SPP capacity worldwide experienced an unprecedented growth, possibly stemming from a period of major policy effort aimed to sustain the domestic SPP demand.

This work has drawn much inspiration from a previously published work by Guidolin and Mortarino (2010), who applied the GBM to describe and forecast SPP adoptions in the eleven countries that represented the major SPP adopters worldwide up to 2006. In that paper, besides characterising the rich nature of the shocks occurred in the various national SPP markets, it was found, among other things, that some SPP markets, for example Japan, the Netherlands and the UK, had already entered their maturity phase. This conclusion, which was perfectly correct based on the adopted model structure, was soon denied by reality, which already since 2007 showed a dramatic growth in SPP adoptions in all countries considered, possibly corresponding to large effective incentive schemes introduced quite synchronously in most countries. We therefore believed that this, far from representing a forecasting failure of the Bass model, was instead evidence of the complexity prevailing in the SPP market, which deserved an upgrade of their work with the purpose to add further insight and understanding of the main determinants, and possible barriers, to SPP adoptions.

Our principal findings in this chapter were the following. First, in all countries considered the media communication proved to have no relevant effect in "pushing" the SPP market, suggesting that this technology started its lifecycle without the support of public media. This finding, that confirms on our extended dataset a previous result by Guidolin and Mortarino (2010), consequently implied that the growth of SPP markets was completely sustained by word-of-mouth communication only. However, the magnitude of word-of-mouth communication proved to be generally small that is, resulted in most countries insufficient to ensure the achievement of any target of market development within the time frame indicated by international protocols and agreements. The previous two findings show that the communication forces acting on the SSP market are weak or insufficient, thereby calling for the need for external interventions. Further, most of the growth in the market adoption curves has occurred everywhere in the form of massive positive shocks which took place initiated in a synchronous manner in 2007, possibly following incentive measures in the various states. Nonetheless, inspection of the parameter estimates describing the temporal pattern of the shocks showed, as a rule, a lack of temporal persistence of the effects of incentive, as well as a sharp trade-off between intensity and persistence of the actions that is to say, the more intense actions were also those lasting short.

From the individual country discussion, we generally observed that mainly the production related policies, present in 20 out of 26 analysed countries either in FIT or NMS form, impacted the most on SPP diffusion, as their initiation, or the implementation of drastic changes in their rules, corresponded to the main estimated shock waves. However, the lack of ability of shocks to persist occurred despite the fact that in most cases incentives were based of FIT which typically should ensure an enduring benefit.

Crossing our model-based results with the available information about public incentive programs in the countries considered, our findings overall suggest a number of points that might be useful for future policy interventions in both the countries analysed in this work as well as in countries where the adoption of this technology is in its infancy. A first one regards the generalised lack of media support in the different countries during the early SPP lifecycle, in turn mirrored by the slow early growth of SPP markets, which is in fact characteristic of diffusion processes mostly driven by word-of-mouth only. Indeed, in Bass-type diffusion models, sustained media communication is of importance especially in the initial stages of the market, by rapidly creating an initial cohort of adopters which subsequently allow to “initialise” the word-of-mouth component from a much larger contingent of spreaders. Therefore, a target of public policy in countries where the SPP lifecycle is still to be initiated or is in its early phase might be that of relevantly supporting private communication on the media in order to encourage the development of this initial cohort of true "innovators" (Mahajan and Muller, 1998). While this had completely failed is, to the best of our knowledge, still unclear.

A second main point regards the nature of the SPP market and the role of public incentive. The SPP market appears from our results as a frail and complicate one where public incentive were a necessary resource to allow the market full take-off but, at the same time, showed little temporal persistency, thereby failing in going beyond their direct short-term effect and in providing a sustained momentum to the market in the medium and long-term. Indeed, the characteristic temporal trend of the market, dominated by consecutive incentive-forced waves followed, in many countries, by much lower, sometimes negligible post-incentive adoptions until the next shock – besides removing any predictive ability of the model - suggests that the use of incentive was often badly designed i.e., aimed to produce fast results in the short-term but under a lack of awareness of the possible detrimental consequences over the longer term. This is documented for instance with the timing with which all countries launched their main intervention phase in 2007, which appears to be completely correlated with the need to "document an effort" to fulfil Kyoto protocol targets (though of course other factors concurred, including the fact that in the same epoch the oil price reached its maximum over the last 50 years).

This in turn leads, as a further point, to better identify the current key barriers to adoptions. In relation to this, a straightforward but possibly critical consequence of such discontinuous badly planned policies, seems to be the emergence of a deleterious role of expectations. Indeed, the dramatic drop in adoptions observed in many countries in the periods in between subsequent incentive actions really seems to mirror the situation where no-one will adopt in an incentive-free period while waiting for (and forcing, thanks to their non-adoption behaviour) the next incentive wave. A simple game-theoretic formalization of the expectation argument providing a simple explanation to our findings has been reported in the Appendix. We also remark that the expectation effect might be amplified in presence of governments' policies principally aiming at short-term results (i.e., fulfilling the targets of international agreements) because missing a long-term perspective.

Strictly related to the latter point is the issue of the SPP market as a complex one, which emerges from the comparison of our results with those in the work of Guidolin and Mortarino (2010). In the same way they inferred in their study - from the evidence of market slowing-down suggesting the achievement of its long-term equilibrium - that in some countries the SPP technology already entered its maturity phase, we might conclude from the current evidence that the market has finally entered maturity e.g., in countries as Italy, Spain and Germany. We are surely wrong. Indeed, what we now expect is that this market will proceed through a number of "pulsations", mostly related to the pumping of further resources and incentive measures, unless the vicious cycle of expectations is broken-down. This is an instance of the dichotomy between shapes and scale in diffusion processes. Since the publication of Bass model much of the emphasis of the research on diffusion models has been placed on the temporal trends of diffusion (and the role of its determinants) i.e., on the "shape" issue, disregarding the "scale" issue. This is simply the consequence of interpreting the model-based estimate of the market potential as the true underlying size of the population of potential adopters. However, in complex markets as the SPP one there is a critical scale issue. In all countries considered the achieved share of energy consumption provided by SPP is still dramatically low (just above 10% in Germany) meaning that the market has large space for further development. The possibility to occupy this space by reaching the larger scale that would be required for successfully confronting with the current global challenges in a reasonable time-horizon obviously depends, other things being equal, on future ability to remove the current barriers.

The present results and conclusions suggest a number of future research directions. A first one is about the determinants of the magnitude and variability of imitation rates as the key baseline trigger of SPP markets. The socio- economic and cultural factors underlining the variation in q are currently unclear i.e., might them depend on the ability of different communities to favour such processes in view of e.g., a more developed environmental sensibility, or to a deeper social capital endowment? The increasing number of countries adopting the SPP technology might allow to investigate this issue e.g., by regression models, looking at the best predictors at the aggregate level of the values of the imitation rate across the different countries.

A second one deals with the causes underlying the full failure of media communication in supporting SPP markets. We feel that this depended on the lack of systematic public support to the sector which did not supply the resources to encourage domestic firms (for example, potential importers of SPP) in taking the risk to investing in a costly technology. An understanding of this issue might offer better perspectives to future newcomer countries that are still doubtful on investing in the SPP market.

Another interesting issue lies in the fact that the evolution of SPP markets has been characterised, before the large incentive epoch, by a long early phase primarily driven by word-of-mouth with an essentially constant growth rate, notwithstanding the marked decline in the price of the technology. We conjecture that this might be consequence of the initial presence of more active individuals (that is, a heterogeneity effect) who adopted first and were subsequently replaced by new, less active, cohorts, which were still prone to invest but required easier financial conditions.

Also, our main conjecture about the key role of expectations should possibly be expanded beyond the toy model reported in the appendix, and appropriately grounded against data.

We wanted to conclude this discussion by a short remark on the main limitations of this work. Given the criticality of the issue of the fast development of RE worldwide, a major disappointing problem lies in the quality and availability of public data. This study could only rely on aggregate data on total installed power because, with a few exceptions, no publicly available harmonized international data disaggregated by type of agent (households vs firms vs public enterprises) are currently available. The next chapter of this thesis will analyse in more depth the case of the UK where data on installations disaggregated by type of agents are available.

Chapter 3. Patterns of sectoral diffusion of solar photovoltaics: a comparative analysis in UK

Abstract

This chapter aims at deepening the analysis of chapter 2 to a disaggregated level comparing adoption trajectories based on installation vs capacity data, and distinguishing between household vs firms vs public utilities adoptions. Hence, to understand how the government efforts towards the different sectors influenced the diffusion over the years. Consistently, we focused on the UK as a case study providing highly disaggregated monthly data, to characterise adoption patterns among household, firms and utilities, still by the aid of the generalised Bass model, in order to understand how the government efforts towards the different sectors influenced the diffusion over the years. Results broadly confirm the pattern detected in chapter 2. However, a number of interesting issues appear when disaggregating by type of agents. The estimated magnitude of the word-of-mouth effect in the residential market appeared to be dramatically low, suggesting a non-vital market, capable to grow only as a consequence of public support. The situation is quite different for the utilities and commercial sectors where the size of the word-of-mouth effect resulted an order of magnitude higher than for residentials. By correlating the temporal trends of the two main types of incentive adopted for the SPP market in the UK in this phase, we argue that the UK incentive policy for households is an example of a badly handled policy that should never be used in the same way in a strategic market as the one for SPP.

Keywords: diffusion of residential solar photovoltaics, household adoptions, commercial photovoltaic adoptions, feed-in tariff, renewable portfolio standards, industrial photovoltaics

JEL: O13, O38, Q48, Q58

3.1 Introduction

The planet increasing population and consumption brought critical threats regarding global climate change. In recent decades, these pressures gained the attention of important international agencies which encouraged numerous countries to search for mitigation alternatives that better suit their needs in terms of electricity production. In this regard, the solar photovoltaic power (SPP) is considered the most attractive solution among the renewable energy sources (RES), especially for households (Schleicher-Tappeser, 2012; Strupeit and Palm, 2016). In fact, the SPP market has experienced a great expansion globally, being present in 178 countries in 2016 (IRENA, 2017), reaching 303GW installed capacity (Sawin et al., 2017)with nearly 33% growth compared to the previous year. The growth was mainly driven by five countries (China, USA, Japan, India and UK), counting for 85% of SPP installed capacity in 2016 (IEA PVPS, 2016).

In this Chapter, we focus on the UK as a case study as it is one of the top countries in terms of SPP installed capacity (2.1 GW in 2016). In 2016, the UK ranked sixth globally in terms of SPP cumulative installed capacity, seventh in terms of number of MW installed per capita, whereas in terms of share of electric power consumption provided by SPP it ranked fourth with almost 3% in 2014 (see Chapter 2).

Though the UK still makes predominant use of fossil fuel for generating electricity, the RES have made significant progress in the last two decades reaching 21% share of total electricity output in 2016. The solar power had a later deployment compared to the wind power, but it increased considerably from 2010 covering 31% of total RES installed capacity in 2016 (see Chapter 1).

The main goal of this Chapter is to understand how the UK government efforts influenced the SPP diffusion across sectors (households, firms and utilities) in terms of persistence and intensity of adoption shocks, highlighting the differences between two communication channels, i.e. the spontaneous communication among individuals and the publicly available information supplied by the media. In addition, we test how the aggregate information of installed capacity is predictive of the adoptions in the different sectors.

To do so, we apply the generalised Bass model (GBM), as presented in Chapter 2, exploiting a highly disaggregated dataset from the UK government, with information on both installed capacity and number of installations from January 2010 to May 2018. The use of GBM allows to deal also with large utilities adoptions still by appropriate shocks.

The structure of this chapter is as follows. In the first section we review the literature on SPP in the UK. In the second section we briefly present the SPP policies and targets in the UK. In the third section we describe the data, followed by fourth section where we highlight the methodology adjustments to monthly data and shock inclusion in contrast to the previous chapter. We present the results in the fifth section. Finally, we provide concluding remarks.

3.2 Literature review

This Chapter adds to the growing literature on SPP technology diffusion, considering several sectors in the UK country-case. Country-specific research on SPP diffusion in the UK is still limited (Balcombe et al., 2014, 2013; Balta-Ozkan et al., 2015; Hammond et al., 2012; Keirstead, 2007a, 2007b) but there are several cross-country studies, which encompass the UK, being one of the leading countries in SPP technology (Dusonchet and Telaretti, 2015; Guidolin and Mortarino, 2010; Olaniyan and Evans, 2014).

In order to reduce carbon emission and meet renewable energy targets, the UK government has fostered the uptake of SPP microgeneration, that is energy generation within the home. Keirstead (2007a) highlights the importance of households' awareness and monitoring systems for the effectiveness of microgeneration. In fact, they find that domestic SPP can improve overall efficiency through reduction in energy consumption and it can also lead to demand shifts in energy use to times of peak generation.

Household attitudes to renewable energy, residential consumption behaviour as well as lifestyle and cultural factors play a key role in the design of successful policies and the diffusion of SPP technologies (Olaniyan and Evans, 2014). However, extant research efforts agree that the deployment of the SPP market in the UK necessitates considerate and stable adoption incentives to compensate the sunk costs of the investments and relax financial constraints.

Though British households value renewable energies significantly, a market development policy based only on technology subsidies is insufficient to reduce financial barriers. Relying on surveys, Faiers and Neame (2006) identify several barriers to technology diffusion (financial, economic and aesthetic) and argue that grants are not sufficient to stimulate a widespread adoption of domestic SPP among households. In fact, installation costs of microgeneration technologies of renewable energy are substantially higher than household willingness-to-pay for them. Scarpa and Willis (2010) estimate that household willingness-to-pay for solar photovoltaics is less than 30% of total installation investments (GBP 2,831 compared to GBP 10,638, on average). Moreover, both from a household and societal perspective, the payback period of the investment exceeds 25 years, that is the average guaranteed functioning period of the SPP technology (Hammond et al., 2012). Larger incentives could facilitate the uptake of SPP among households, if the financial benefits from the adoption of microgeneration more than compensate its sunk costs.

Applying a generalized Bass model, Guidolin and Mortarino (2010) results show that the SPP diffusion process in the UK reached a mature stage in 2007, with a peak of installations just below 30MW. In fact, the market was mostly supported by the Non-Fossil Fuel Obligations with minor impact on SPP diffusion. They forecast a consistent reduction in subsequent years in the absence of further government measures. As emphasised in the previous chapter, the SPP market is frail and complicated being driven mostly by public incentives. Thus, any significant increase in incentives, e.g. the adoption of the FIT scheme, might (re)boost the SPP diffusion, causing a difficulty in forecasting the market.

Before 2010, the UK policymakers have stimulated the adoption of SPP technology mostly through government grants. Starting from April 2010, the Feed-in-Tariffs (FIT) incentivisation scheme was introduced. The early stage of the FIT incentives was studied by (Balcombe et al., 2014, 2013). In their earlier paper they analyse the motivations and barriers to adoption after the introduction of FIT in 2010. They conclude that capital costs still represent a major obstacle especially for younger adopters. Nevertheless, in their more recent work, using a best-worst scaling survey, they find clear evidence that FIT stimulated financially-motivated groups to adopt microgeneration technologies. Dusonchet and Telaretti (2015) argue that diffusion and profitability of large SPP installations in the UK are lower compared to smaller residential and commercial installations, due to less FIT incentives for large-scale systems (above 250kW).

The SPP diffusion in the UK after the introduction of FIT schemes have been analysed under socio-economic and spatial aspects. Richter (2013) suggests that social effects, such as imitative behaviour, have influenced the SPP installation rate moderately. Adding to that, Balta-Ozkan et al. (2015) use a spatial econometric approach (*Durbin model*) to identify the drivers of SPP adoption at a regional level. Demand for electricity, population density, pollution levels, education and housing types are found to be significant determinants of adoption patterns.

Incentive persistence as well as policy and environment stability are particularly crucial for the development of SPP technologies in the UK. Keirstead (2007b) argues that policy complexity and poor coordination of resources and process streams among different UK government actors and industry stakeholders restrict the potential of support mechanisms and effective policy promotion. Moreover, policy coordination with other initiatives matters. Though alternative renewable technologies in several countries are mutual beneficial to each other, the diffusion of solar technology in the UK is hindered by a predatory-prey relationship with the wind technology. The UK is considered one of the best locations for wind power worldwide, which contributes to wind's role of predator (Duan et al., 2014).

Our work adds to the SPP literature an analysis at the sectoral level which highlights the different impact of the main policies on the residential, commercial and utility sectors. Furthermore, the availability of data just before the launch of the FIT scheme in 2010 until 2018, the year before phasing out (2019) [10], offers valuable information on the impact of this type of policy overtime, from launch until almost the end.

3.3 SPP policies in UK

In the UK in the very beginning the indirect policies were the only incentives supporting the SPP market. Substantial RD&D were dedicated to solar technologies, especially from 2000 with peaks in 2005 and 2010 (Figure 3.1). In the latest decade the RD&D trend remained for 4 years around 10 million GBP, following a slow increase in the last 2 years.

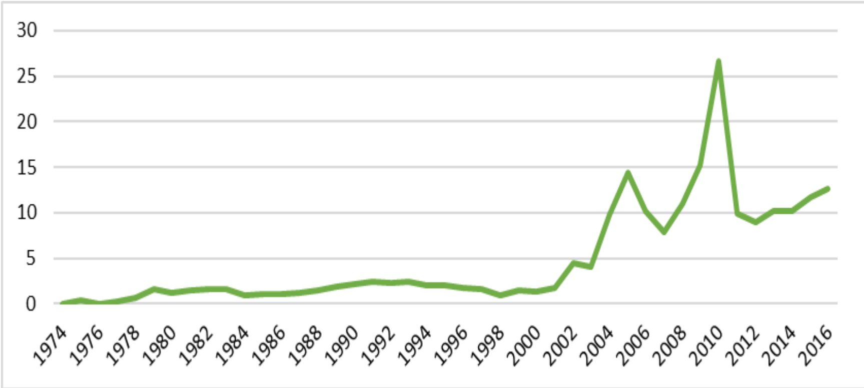


Figure 3.1 Annual RD&D investments for solar power in Million GBP (nominal) from 1974 to 2016. Data from IEA Online Data Service[1].

Other indirect incentives were in the form of projects, demonstration and field programmes. Among the numerous programmes, the most successful was the Low Carbon Building Programme (LCBP) (IEA, 2009, p. 11) which started in 2006 and ended in 2010. The programme was presenting the relationship between microgeneration RES technology efficiency with low carbon buildings and it was dedicated to households, community organisations, schools and public sector. The main goal of these kind of programmes is to increase technology awareness among the possible adopters, especially in early stages (Yamaguchi et al., 2013).

The third indirect incentive is a type of the Renewable Portfolio Standards, first in act under the "Non-Fossil Fuel Obligation" since 1990 [11] and replaced by "Renewable Obligation Certificates" (ROC) in 2002. The policy aims at encouraging firms and suppliers to invest in systems larger than 50kW so as to produce "clean" electricity above a yearly pre-established minimum target in terms of share in total electricity. The obligation share increased from 3% in 2002, at a slower pace until 2012 (1 p.p./year on average), to 46.8% in 2019, with a faster rate (5 p.p./year on average) (see Table A3- 1 in Appendix) [7].

In order to meet their obligations, suppliers need to provide the certificates with the amount of energy produced from RES. The suppliers that not achieve the required share must pay a fixed price per MWh to a buy-out fund, which will consequently be paid by the consumers through higher energy costs. On the contrary, the successful suppliers will receive a direct proportional fund with their share in total number of certificates submitted in a certain period which decreases their consumers' electricity tariff. The obligation period starts from 1st April until 31st March of the following year (UK Government [12]). Although the ROC is in act since 2002, the neutrality of the scheme in the first decade, i.e. without distinguishing between the various types of RES, led only to the adoption of the more economic technologies (UK Government [13]). Consequently, overall the RES market did not develop as expected and put at risk the achievement of the long-term carbon emissions reduction targets. Due to this issue, the government revised the policy in 2012 focusing the technologies that mostly needed the incentives to develop a market, such as SPP (UK Government [14]).

The ROC scheme for new SPP systems larger than 5MW is due to an end by 1st April 2015, while for new smaller systems the deadline is set for 1st April 2016 [5], following one-year grace period. The ROC is gradually replaced by Contracts for Difference (CfD) starting from 2013 to 2017 as announced in the Energy Act 2013 (UK Government [15]). The latter is a system of reverse auctions[9] aiming at creating certainty among the RES market investors through fixed electricity prices (Uk Government [16]). However, the government considers the SPP an already developed technology and excluded it from the auctions (PV Magazine, 2016 [17]).

The UK government provides also direct incentives in terms of production related policies. The FIT consists of the payment of a pre-established tariff for the electricity generated by an implant usually until the warranty of the plant expires, mainly after 20-25 years. The incentive is directed only to plants smaller than 5MW for three levels of the tariffs (high, medium and low) based on the commissioned date and overall number of installations (UK Government). The high values are presented in Figure 1. We observe that the value of the tariff is generally decreasing from small installations to large systems. Indeed, this is in line with Dusonchet and Telaretti (2015) which highlight the unprofitability of utility-scale systems in early stages.

[9] In a reverse auction the roles of the buyer and the seller are reversed.

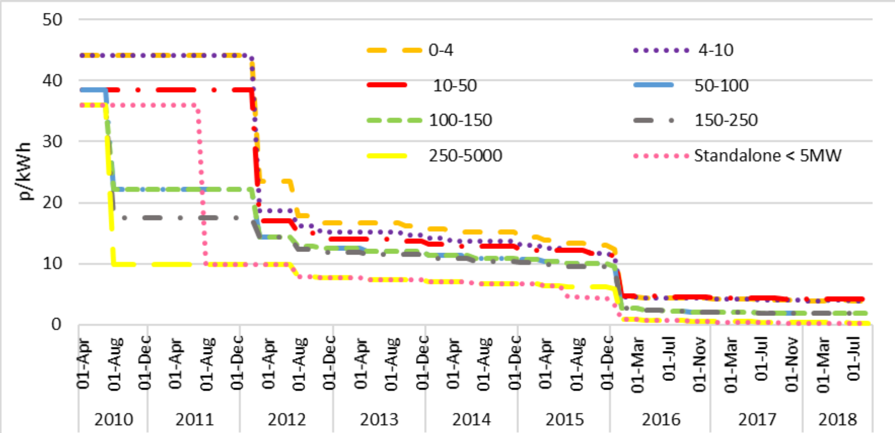


Figure 3.2 Standard Solar FIT values (high rate) by capacity range in kW from Aprile 2010 to September 2018. Source: UK Government Statistics

There have been two dramatic reductions in the value of FIT, at the beginning of 2012 and in January 2016 due to the excessive number of installations compared to the government expectations and to the technology decreasing price. Indeed, the module price for the systems under 4kW decreased from £15,000 in 2010 to £6,000 in 2016 [3]. The FIT is forecasted to phase out to new applicants on 1 April 2019 [4].

The UK government also set a target to adopt 20GW of SPP by 2020 [2]. The goal aims at reducing carbon emissions by 35% in 2020 and to further achieve a 80% reduction by 2050 compared to the 1990 baseline (Dusonchet and Telaretti, 2010; Hammond et al., 2012).

3.4 SPP adoptions data

We use monthly UK government data on cumulative installed capacity (Figure A3. 2) and cumulative number of installations (Figure A3. 3) from January 2010 to May 2018. [1][10]. Although the SPP launch occurred in the early 1990s, the time span of our dataset is fit for the purpose of our analysis as 2010 represents the starting year of the rapid SPP diffusion.

[10] The number in brackets refer to the sitography of Chapter 3 at the end of the document

Based on previous classifications of the SPP market (CEBR, 2014; International Finance Corporation, 2015; Keirstead, 2007b) we classify installations in terms of capacity size as follows: installations with less than 10kW are considered residential sector, installations between 10kW and 5MW are considered commercial sector[11] while installations above 5MW are considered utility sector.

Although SPP installations go back to 1992, it was not until the beginning of this decade that the technology started a fast growth deployment going from 26MW of cumulative capacity in 2009 to almost 1GW in 2011. The yearly peak of installations was only recently achieved, in 2015, counting for 4.2GW (IEA data). The cumulative installed capacity in May 2018 was of 12.8GW while the number of installations was just under 940,000 [1].

3.5 Methodology

For this study we use the generalized Bass model (GBM) as in the previous chapter.

The estimation of the market potential "m" raises many issues due to potential bias (Van den Bulte and Lilien, 1997) given the fact that the SPP markets mainly develop due to public incentives (as explained in Chapter 2). Consequently, this particular market is unpredictable and difficult to forecast. For this reason, we will not focus on the estimated market potential.

The monthly patterns, compared to the yearly trends in the previous chapter, present numerous short-lasting oscillations, especially in the case of commercial and utility sectors, which require the application of instantaneous rectangular shocks (form F1). Thus, the procedure for the inclusion of shocks is the following. First, we visualise the data and determine the number of instantaneous shock. Second, we fix the parameters of the beginning (*a*) and the end (*b*) of the instantaneous shock. Third, in the preliminary phase we choose the same value of intensity (A) for all the rectangular shock, gradually adding other values to the model

---

[11] According to a different classification by IEA (2016, p.45), installation capacity for commercial scale ranges from 10kW to 500kW.

until the analysis based on the multiple squared partial correlation coefficient (SMPCC) detects the number of different intensity parameters (A) which better fit the model (last SMPCC > 0.5). In the case of long-lasting shocks, we proceed, as in Chapter 2, by gradually including one shock at the time.

3.6 Results

The first stage of the UK SPP adoption, between 1992 and 2010, was analysed in Chapter 2. In this initial phase the growth rate was essentially constant (31%/year) under the presence of low intensity incentives (LCBL) with few adoptions which overall did not exceed 26MW (5736 systems).

At the disaggregated level, considering the number of installations, the residential sector is vastly dominant with a constant share above 96% (Figure A3. 3). On the contrary, in terms of installed capacity the framework changed dramatically over time. The first significant change occurred after the announcement in March 2011 that cuts into the value of FIT would be made to standalone systems starting from August 2011 [8]. This affected especially the commercial sector which pushed many companies to apply for the higher FIT before the reduction. The utility sector began its growth from 2012 with the SPP technology price reduction and increased considerably up to a 56% share at the beginning of 2015. The SPP market seems to have become more stable during 2017 when the shares of the residential, commercial and utility sectors in total installed capacity were respectively 22%, 33%, and 45% (Figure A3. 4).

The findings from the previous chapter show how all the SPP markets developed in absence of any relevant mediatic support. From this point of view the UK makes no exception. To further support this statement, we applied the "classical" Bass model (Figure A3. 5) and obtained sufficiently low values of the coefficient of innovation (α) in all sectors (Table A3- 2). Therefore, following Chapter 2 methodology, we applied a Generalized Internal Model (GIM) instead of the Generalized Bass Model (GBM).

For the estimation of the best fit model we needed at least 3 different shocks to predict the SPP curves, with significant variations among sectors. The results are reported in and can be visualised in Figure 3.3.

3.6.1 *Residential sector*

In January 2010, the first month available, the residential time series data starts from 5500 systems, a very low number considering the almost 920,000 systems registered by May 2018. The patterns for the installed capacity and number of installations are very similar and can both be interpreted in the following way.

The resulting best model of the residential sector presents 3 shocks ( ). First of all, a constant shock (F1) at the beginning of the series. This is in line with the fact that the FIT incentive started in April 2010 and remained constant for 2 years (Figure 3.2). The introduction of FIT yields a monthly growth rate around 18% which indicates a 550% growth per year, a significant increase compared to 37% from the previous period.

The second incentive is an exponential one (F2) with starting point in November 2011, highly intense (A = 145) lasting more than two months (1/c = 2.2). The shock was clearly caused by the government's announcement of FIT cuts during October 2011 [6], thus the spike is the consequence not of a positive incentive but of the announcement that the FIT will be reduced by February 2012 and therefore of the «run» to install taking profit of the reduction of the single installation cost. Following the drastic cuts by August 2012, successive gradual small reductions were frequently made. Hence, the presence dramatic short-term increase in monthly growth rate up to almost 50% with subsequent dramatic decline to very low levels, 2-3%, by August 2012. Therefore, we note that the positive effect of the reduction in the cost is clearly secondary to the negative effect of the announcement of the FIT reduction.

Although estimated with a constant long-lasting shock, in the period between August 2012 and December 2016 the monthly adoption (and also the growth rate) curve shows evidence of several (4) very small shocks lasting about 1-year until Dec 2016. These temporary annual phases of growth might for example reflect the presence of small groups of adopters which have already decided to adopt but fear the possibility of a further reduction of the FIT. None of the shock forms (F1, F2, F3) from the previous chapter manage to capture the pattern of the small shock. Therefore, an ad-hoc form that gradually increases until a sudden drop might have been more appropriate.

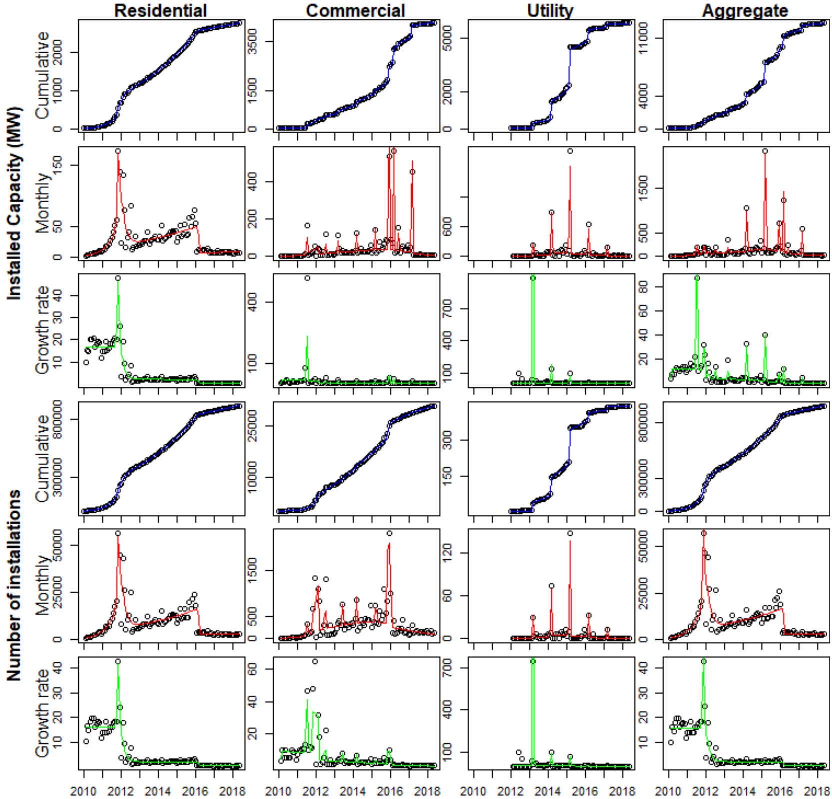


Figure 3.3 Cumulative, Monthly and Growth rate (in log scale) observed versus fitted curves for both Installed Capacity and Number of Installations by type of sector: Residential, Commercial, Utility and Aggregated level.

Starting from January 2016 until May 2018 growth rate falls to negligible levels (< 0.3%) despite the presence of incentive (FIT still around 15%) compared to 45% at the beginning. Estimating q from 2010 to 2016 data indicates a dramatically low level of the imitation rate given that the monthly observed GR of 0.2-0.3% (yearly 3-4%) still reflects the presence of incentive at a non-negligible rate.

3.6.1 Utility sector

The SPP diffusion among the utility sector started later compared to the other sectors. In 2012 the first system of 6MW was installed in January, followed by other two in June and August. The absence of installations prior to 2012 might be explained by the high installation cost, as pointed out also by Hammond et al (2012) along with the revision of the ROC scheme which brought the share to 15.8% (3.4 p.p. compared to 2011) and increased the buy-out price to 0.64p/kWh (see Table A3- 1). Moreover, in 2012 was registered a dramatic drop in SPP technology price.

The adoption pattern in the utility sector required a 5-shock model in both installed capacity and number of installations, with no 4 different persistence values (the first and the last instantaneous shocks are similar A = 91). In fact, we notice an identical shape patterns for the cumulative curves (Figure 3.3). All five shocks are positive rectangular and repetitive as they are "detached" observations which occur at the beginning of each year, just before March (Figure 3.3). The visible shape of a stairway in the case of utility sector is explained by the fact that the ROC's obligation period goes from 1 April to 31 March of the following year [7], thus it seems that many electricity suppliers postpone the installations until just before the deadline instead of gradually fulfil their obligations.

The highest growth rate has been registered in March 2013 with 980%. In fact, the buy-out price from the 2012-2013 obligation period increased by 0.16p/kWh, 33% compared to the previous period. The next peak occurred in March 2014 although with only 138% increase in growth rate, represents the month with most adoptions: 147 installations counting for more than 2GW. In this period the buy-out price grew substantially by 36%. Another interesting remark is the absence of adoptions in 2018: only two systems with respectively 26MW and 6MW installed capacity. This suggests that the end of the ROC scheme along with the government's decision to block SPP from the CfDs [18] brought the market to a stall. Moreover, the "word-of-mouth" effect in the utility sector is above 4.4%/month (52%/year), much higher compared to the residential sector.

3.6.1 *Commercial sector*

Considering the installed capacity, the commercial sector appears to have a unique trend shaped as a combination between residential and utility sectors. This is explained by the fact that this particular sector benefits from both FIT and ROC (>50kW) incentives. On the contrary, in the case of the number of installations we notice a shape more comparable to the residential sector because systems with capacity between 10 and 50kW eligible only for FIT, counted on average for approximately 90% of the commercial installations. Consequently, the significant differences between the shape of the capacity and number of installations led to estimations of a respectively 10-shock and 7-shock models in both cases with an initial two-year lasting constant shock during the first stage of the FIT scheme, followed by only instant rectangular shocks with respectively 4 and 3 variable A values.

The analysis of the installed capacity pattern shows a highly intense shock ($A_1 = 31$) corresponding to the highest growth rate (515%) in July 2011 after the announcement of the dramatic drop in FIT value for standalone panels from August 2011 [8]. The shock is followed by 4 smaller shocks ($A_{3,4,5,6} = 3.4$): in July 2012, before a further FIT reduction in August and September; and around March of each year from 2013 to 2015 consistent to the ROC deadline. Other shock follows in December 2015 before another drop in the FIT value, again in March before the 2016 and 2017 ROC deadlines. On average, the growth rate caused by the ROC deadline lies around 13%.

Similar instant spikes can be observed also considering the number of installed capacities, again consistent with dramatic changes in FIT and ROC deadlines, with the difference that the latter registered lower growth rate spikes.

The low levels of medium-large commercial installations prior to 2012 might be explained by the low FIT values for medium-large systems unable to cover for the high installation cost (Hammond et al., 2012). This emphasize the fact that both FIT and ROC schemes have significantly impacted the commercial sector over the years. In fact, the stairway pattern, although smoother than in the utility sector, is consistent with both FIT reduction announcements and ROC deadlines. Another similarity with the utility sector is the value of the imitation rate, above 3.5%/month (42%/year).

	Installed capacity				*Number of installations*			
Sector	*R*	*C*	*U*	*Agg*	*R*	*C*	*U*	*Agg*
Best model	*3-shock (F1+F2+F1)*	*10 F1 (4 A)*	*5 F1 (4 A)*	*12 F1 (3 A)*	*3-shock (F1+F2+F1)*	*7 F1 (3 A)*	*5 F1 (4 A)*	*3-shock (F1+F2+F1)*
q	0.003	0.035	0.044	0.043	0.003	0.044	0.049	0.004
m	25,092	4,439	5,789	13,140	19,768,022	33,236	448	11,621,670
A1	49.9	3.20	91.19	1.67	42.20	1.01	110.71	37.93
a1	0.00	1	13	1	0	1	13	0.0
b1	21	25	14	20.8	21	21	14	22
A2(c2)	0.46	31.07	33.57	15.11	0.5	6.03	40.11	0.4
a2	21	17	25	17	21	17	24	21
b2(A2)	145	18	26	18	114	18	25	102
A3	6.20	3.39	77.60	5.27	4.90	6.03	136.79	4.56
a3	24	29	36	21	24	21	36	24
b3	74	30	37	23	74	25	37	74
A4		3.39	30.39	1.67		1.787	25.2	
a4		37	49	24.5		40	49	
b4		38	50	25.5		41	50	
A5		3.39	91.19	1.67		1.787	110.7	
a5		49	61	29		49	61	
b5		50	62	30		50	62	
A6		3.39		1.67		1.787		
a6		61		37.0		61		
b6		62		38.0		62		
A7		31.07		5.27		6.03		
a7		70		49		69		
b7		71		50		72		
A8		17.34		15.11				
a8		73		61.0				
b8		74		62.0				
A9		3.39		5.27				
a9		76		70				
b9		77		71				
A10		31.07		15.11				
a10		85		73				
b10		86		74				
A11				1.67				
a11				76				
b11				77				
A12				15.11				
a12				85				
b12				86				

Table 3-1 Estimated values of GIM parameters for Installed capacity and number of installations by sector: Residential (R), Commercial(C), Utility (U) and Aggregated (Agg) level. The best model describes the type and number of shocks, e.g. "10 F1 (4 A)" refers to 10 instant rectangular shocks (form F1) estimated with 4 different intensities (A)

3.6.2 Aggregate level

At the aggregate level, our findings show that considering the cumulative number of installations the residential sector is representative with very similar results (F1+F2+F1) for the parameter estimates. If we consider the cumulative installed capacity the residential sector is no longer representative. Instead, the best fit model consists of 12 shocks (a two years lasting constant shock followed by eleven instant shocks with only 3 diverse intensity parameters (A)). The similarities are also reflected in the imitation rate estimates: 0.4%/ month (number of installations) compare to 4.3%/month (installed capacity).

3.7 Concluding remarks

This chapter aims at deepening the analysis of chapter 2, by coping with a major drawback of the data used therein, namely the fact that adoption data publicly provided by IEA are available only in an aggregate form as total installed capacity per year. This aggregation does not allow to distinguish between household adoption vs those attributable to firms and the public utilities. In fact, the argument has not been stressed in the literature, to the best of our knowledge.

Consistently, we focused on the UK as a case study providing highly disaggregated monthly data, to characterise adoption patterns among household, firms and utilities, still by the aid of the generalised Bass model, in order to understand how the government efforts towards the different sectors influenced the diffusion over the years. In addition, we aimed at testing how the aggregate information of installed capacity is predictive of the adoptions in the different sectors.

Results broadly confirm the pattern detected in chapter 2 regarding the absence of media support in all the sector and the key role of incentives as main drivers of the SPP diffusion. Additionally, the estimated magnitude of the imitation effect in the residential market appeared to be dramatically low, suggesting a non-vital market, capable to grow only as a consequence of public support. The situation is quite different for the utilities and commercial sectors where the world-of-mouth effect is ten times larger. This might be explained by the fact that companies make more rational decisions based on economic factors rather than being led by perception.

By correlating the temporal trends of the two main types of incentive adopted for the SPP market in the UK in this phase, are an example of a badly handled policy.

Therefore, it seems that the SPP market in UK suffers not only the structural difficulties of this sector, but also the consumer perception of relative penalisation compared to the past cohorts who benefited high rates of FIT. The value about 0 of the imitation rate (q) suggest that in absence of incentives the market is essentially dead possibly because agents believe in the expectation of further future increasing in the value of FIT and therefore in the return of the investment.

A more effective and easy to implement solution for a successful policy might be the creation of individual customized policies which should take into account the real price of the initial investment paid by each individual and the actual material and maintenance costs, instead of an estimated price based on past dynamics. This solution would allow a better government control over the continuously occurring market changes and could avoid excessive demand stimulated by high profitability caused by the gap between a sudden decrease in price and the slow adjustments in FIT tariff as it occurred during the Chinese overproduction.

Discussion and concluding remarks

The main goal of this thesis is to use the diffusion models to improve our understanding of SPP markets, with special focus on (a) identifying the main determinants of the diffusion of solar photovoltaic panels worldwide, particularly the role played so far by public incentives, (b) characterising the scale and temporal profiles of the major domestic shocks in SPP markets which mostly occurred after 2007, (c) discussing the resulting perspectives, and the involved role of public policies, for the future development of the market.

Chapter 1 is introductory and preparatory for subsequent ones. In particular, this chapter was useful to pinpoint that (a) the presence of shocks is an intrinsic and often dominating feature of energy markets, thereby motivating the use of tools as the GBM, (b) only a few countries have developed long-term energy plans towards which to manage consistently their short-medium term policies, as documented in the proposed analyses by the evidence that a number of public interventions were carried out as mere responses to external stimuli, such as the deadlines of Kyoto protocol; (c) the concept of energy framework was useful to inform the discussion on individual countries SPP adoption trajectories reported in subsequent chapters, which indicated a number of commonalities e.g., countries with oil and gas reserves developed a market for the SPP generally later compared to countries lacking such reserves (while availability of coal reserves seems not to have delayed the SPP diffusion).

Chapter 2 contains the main work of the thesis, which led to the following concluding remarks. First, in all countries considered the media communication proved to have no relevant effect in "pushing" the SPP market, suggesting that this technology started its lifecycle without the support of public media. However, the magnitude of word-of-mouth communication proved to be generally small that is, resulted in most countries insufficient to ensure the achievement of any target of market development within the time frame indicated by international protocols and agreements. The previous two findings show that the communication forces acting on the SSP market are weak or insufficient, thereby calling for the need for external interventions. Further, most of the growth in the market adoption curves has occurred everywhere in the form of massive positive shocks which took place initiated in a synchronous manner in 2007, possibly following incentive measures in the various states. Nonetheless, inspection of the parameter estimates describing the temporal pattern of the shocks showed, as a rule, a lack of temporal persistence of the effects of incentive, as well as a sharp trade-off between intensity and persistence of the actions that is to say, the more intense actions were also those lasting short.

From the individual country discussion, we generally observed that mainly the production related policies, present in 20 out of 26 analysed countries either in FIT or NMS form, impacted the most on SPP diffusion, as their initiation, or the implementation of drastic changes in their rules, corresponded to the main estimated shock waves. However, the lack of ability of shocks to persist occurred despite the fact that in most cases incentives were based of FIT which typically should ensure an enduring benefit.

A second main point regards the nature of the SPP market and the role of public incentive. The SPP market appears from our results as a frail and complicate one where public incentive were a necessary resource to allow the market full take-off but, at the same time, showed little temporal persistency, thereby failing in going beyond their direct short-term effect and in providing a sustained momentum to the market in the medium and long-term. Indeed, the characteristic temporal trend of the market, dominated by consecutive incentive-forced waves followed, in many countries, by much lower, sometimes negligible post-incentive adoptions until the next shock – besides removing any predictive ability of the model - suggests that the use of incentive was often badly designed i.e., aimed to produce fast results in the short-term but under a lack of awareness of the possible detrimental consequences over the longer term. This is documented for instance with the timing with which all countries launched their main intervention phase in 2007, which appears to be completely correlated with the need to "document an effort" to fulfil Kyoto protocol targets (though of course other factors concurred, including the fact that in the same epoch the oil price reached its maximum over the last 50 years).

The present results and conclusions suggest a number of future research directions. A first one is about the determinants of the magnitude and variability of imitation rates as the key baseline trigger of SPP markets. The socio- economic and cultural factors underlining the variation in q are currently unclear i.e., might them depend on the ability of different communities to favour such processes in view of e.g., a more developed environmental sensibility, or to a deeper social capital endowment? The increasing number of countries adopting the SPP technology might allow to investigate this issue e.g., by regression models, looking at the best predictors at the aggregate level of the values of the imitation rate across the different countries.

A second one deals with the causes underlying the full failure of media communication in supporting SPP markets. We feel that this depended on the lack of systematic public support to the sector which did not supply the resources to encourage domestic firms (for example, potential importers of SPP) in taking the risk to investing in a costly technology. An understanding of this issue might offer better perspectives to future newcomer countries that are still doubtful on investing in the SPP market.

Chapter 3 aims at deepening the analysis of Chapter 2. Consistently, we focused on the UK as a case study providing highly disaggregated monthly data, to characterise adoption patterns among household, firms and utilities.

Results broadly confirm the pattern detected in chapter 2 regarding the absence of media support in all the sector and the key role of incentives as main drivers of the SPP diffusion. Additionally, the estimated magnitude of the imitation effect in the residential market appeared to be dramatically low, suggesting a non-vital market, capable to grow only as a consequence of public support. The situation is quite different for the utilities and commercial sectors where the world-of-mouth effect is ten times larger. This might be explained by the fact that companies make more rational decisions based on economic factors rather than being led by perception. By correlating the temporal trends of the two main types of incentive adopted for the SPP market in the UK in this phase, are an example of a badly handled policy.

Therefore, it seems that the SPP market in UK suffers not only the structural difficulties of this sector, but also the consumer perception of relative penalisation compared to the past cohorts who benefited high rates of FIT. The value about 0 of the imitation rate (q) suggest that in absence of incentives the market is essentially dead possibly because agents believe in the expectation of further future increasing in the value of FIT and therefore in the return of the investment.

A more effective and easy to implement solution for a successful policy might be the creation of individual customized policies which should take into account the real price of the initial investment paid by each individual and the actual material and maintenance costs, instead of an estimated price based on past dynamics. This solution would allow a better government control over the continuously occurring market changes and could avoid excessive demand stimulated by high profitability caused by the gap between a sudden decrease in price and the slow adjustments in FIT tariff as it occurred during the Chinese overproduction.

The following part of the discussion section is a reply to the points raised by the referees after their evaluation.

The suggested paper of Meade and Islam (2015) regarding the possible determinants of the differences in growth rates of RET usage in European countries is very useful to understand the renewables' market from different points of view, using different approaches. In fact, they study the determinants by analysing the sample of countries as a hole, and not separately, maintaining the non-linear S-shaped characteristic of the RE curves. Among the determinant variables of the renewable energy technologies, Meade and Islam (2015) highlight the fact that in presence of other variables the increase in latitude negatively affected the growth in RE usage, a point not addressed in the thesis. Similar effect has the amount of carbon-free electricity generation within a country, point stressed also in Chapter 1 as the substantial presence of nuclear power in countries like France and Belgium does not leave much space for RE. Meade and Islam (2015) also show how the differentiation among countries by the use of different incentive schemes (with binary variables) was not as explanatory as dividing by the velocity with which the countries adopted the renewable energy technologies. This is in line with the choice of combining the countries by the usage of different energy sources and not by types of incentive schemes, which after a preliminary analysis of the individual countries resulted in no marked similarities.

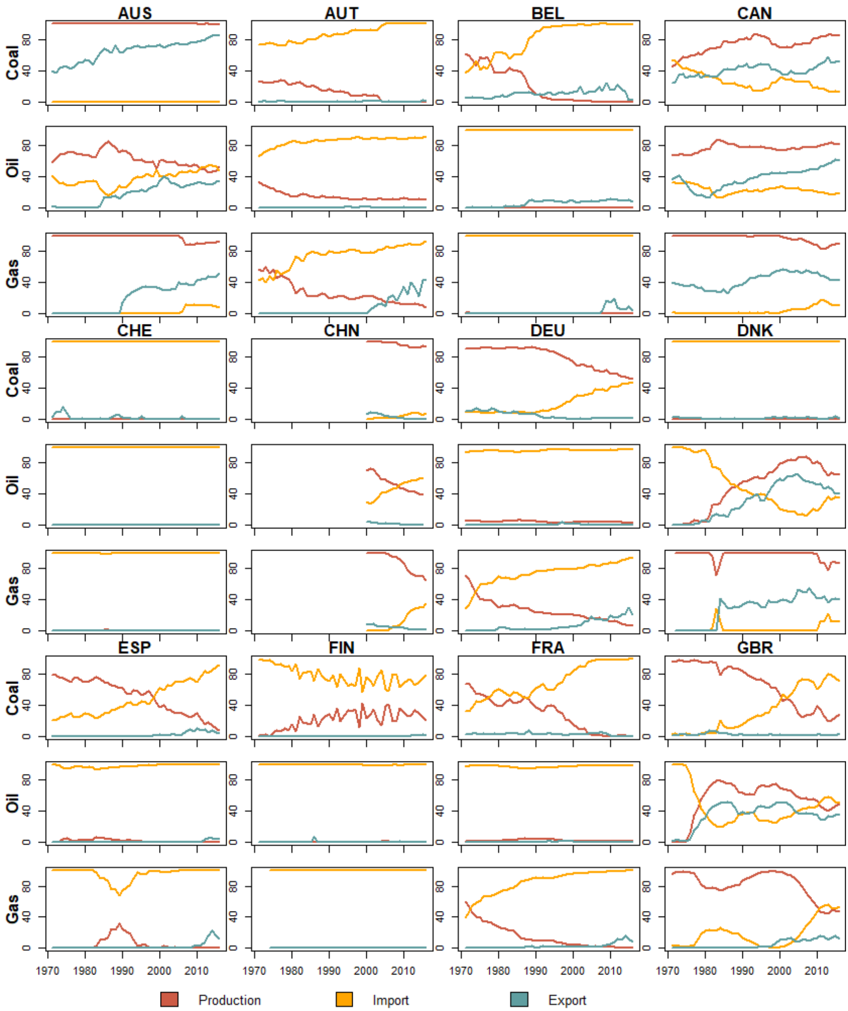
The point raised by the reviewer regarding the technological, economic and behavioural aspects is a fascinating and quite far-reaching one, going at the roots of both the concept of technology lifespan and its interplay with the adopters' lifespan, but also at those of the Bass model and its usage (i.e., explanation & learning vs forecasting). Perhaps the point is also very complicate to respond. Abstractly, renewables considered as energy production technology produced "globally" (i.e, by large scale plants, as opposed to "local" i.e., plants used by a single household for her own consumption) might have a very long life span going far beyond the lifespans of humans (an obvious example is hydro-electric power). However, the individual (or anyhow, low-scale) nature of the photovoltaic technology combined with its medium –term duration (a solar panel is guaranteed for a physical life of at most 25 years at current scientific knowledge) makes it – from practical purposes – quite similar to a durable investment good (though possibly one with a longer payback time, that is more similar to houses than other durables as e.g., cars). Moreover, there has not been much innovation differentiation within the photovoltaic market and, additionally, state incentives were mainly directed to photovoltaic technologies in general, without any differentiation between the different types of technologies. We believe that, putting the problem this way, provided one looks at the evolution of the market over horizons that are comparable to those of the duration of the physical life of the durable (this is certainly the case for our minimum scenario where the resulting horizons are shortly longer than the time series of data, which was exactly 25 years), then the use of the Bass model shouldn't substantially violate the basic hypothesis of being a "first-purchase" model. However, over time horizons longer than those considered in this thesis – which might well appear in the future when longer time series will become available, or even right now if policy might like to use models for longer-term projections - things will obviously be different. In this case models for repeated purchases (still, in a finite number during lifetime) or models for different generations of the technology (say, along the strain originated by the Norton-Bass model) would be necessary. We note however that such refinements, though of interest, would still need more refined recipes for handling the complicate issues of the competition between different renewable technologies exactly as we are missing for simple models.

In addition, but still related to this, there is the issue of "who is m" in the SPP market. The basic classical Bass model is an amazingly simple cohort model describing diffusion over time in a fixed cohort of size m (: the "market potential") where the m final adopters were already "programmed" since the very beginning of the product lifecycle. Clearly, the process model for determining the market size in SPP markets seems to be far more complicate compared to the basic Bass model. First, given the long characteristic time scales of the market, there are necessarily demographic effects related to the fact that the population of potential adopters has a number of renewal mechanisms. Second, and more important, in the SPP market there has been a substantial competitive pressure over time on the price of the technology, which has dramatically reduced the unit price, therefore weakening budget constraints and eventually contributing to gradually expand the size of the population of potential adopters. This would clearly call for a more complicated modelling representation, including a temporal trend (say, m(t)) for the size of the population of potential adopters, be this exogenous (see e.g., Centrone et al., 2007 and references therein) or endogenous e.g., related to the trend of the price of the technology. Both latter alternatives, though interesting, would have however implied the need to resort to a further complicate model, therefore sacrificing further degrees of freedom for estimating the parameters representing the function m(t) in addition to the many parameters representing the temporal dynamics of shocks. Our final choice in relation to this has been to go along Occam's razor, and therefore to use the simplest hypotheses for the market potential namely, (i) to take it as a constant determined by the SPP policy targets in the different countries, (ii) to take it as a parameter to be estimated only for countries for which evidence was available suggesting that the parameter could be estimated appropriately.

The basic classical Bass model is an amazingly simple cohort model describing diffusion over time in a fixed cohort of size m (: the "market potential") where the m final adopters were already "programmed" to adopt since the very beginning of the product lifecycle. Clearly, the process model for determining the market size in SPP markets seems to be far more complicate compared to the basic Bass model. First, given the long characteristic time scales of the market, there are necessarily demographic effects related to the fact that the population of potential adopters evolved over time through its renewal mechanisms. Second, and more important, in the SPP market there has been a substantial competitive pressure over time on the price of the technology, which has dramatically reduced the unit price, therefore weakening budget constraints and eventually contributing to gradually expand the size of the population of potential adopters. This would clearly call for a more complicated modelling representation, including a temporal trend (say, m(t)) for the size of the population of potential adopters, be this exogenous (Centrone et al., 2007) or endogenous e.g., related to the trend of the price of the technology. Both latter alternatives should be seriously considered in future research work. However, though interesting, both alternatives would have implied the need to resort to a more complicate model, therefore sacrificing further degrees of freedom for estimating the parameters representing the function m(t) in addition to the many parameters representing the temporal dynamics of shocks. Our final choice in relation to this has been to go along Occam's razor, and therefore to use the simplest hypotheses for the market potential m namely, (i) to take it as a constant (the "minimum" vs the "maximum" scenario reported in Chapter 2) determined by the SPP policy targets in the different countries, (ii) to take it as a parameter to be estimated only for countries for which evidence was available suggesting that the parameter could be estimated appropriately, namely those which showed – disregarding shocks - clear symptoms of slowing down in the adoption path (Van den Bulte and Lilien, 1997).

Appendix A1 – Chapter 1

Part A



Part B

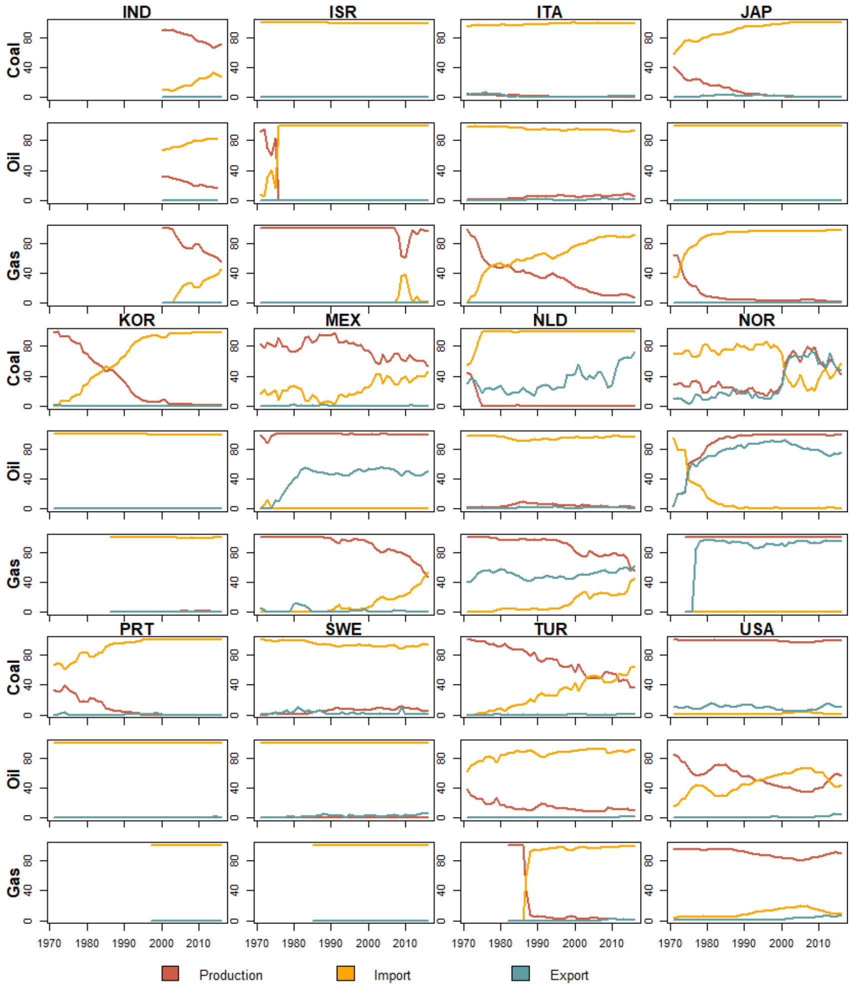


Figure A1. 1 Part A & B Production versus Imports versus Exports of Coal (coal, peat and oil shale), Oil (crude oil, NGL and feedstocks) and Natural gas. Own calculation based on data from IEA Headline Global Energy Data 2017; all three variables are computed as share of Production + Imports

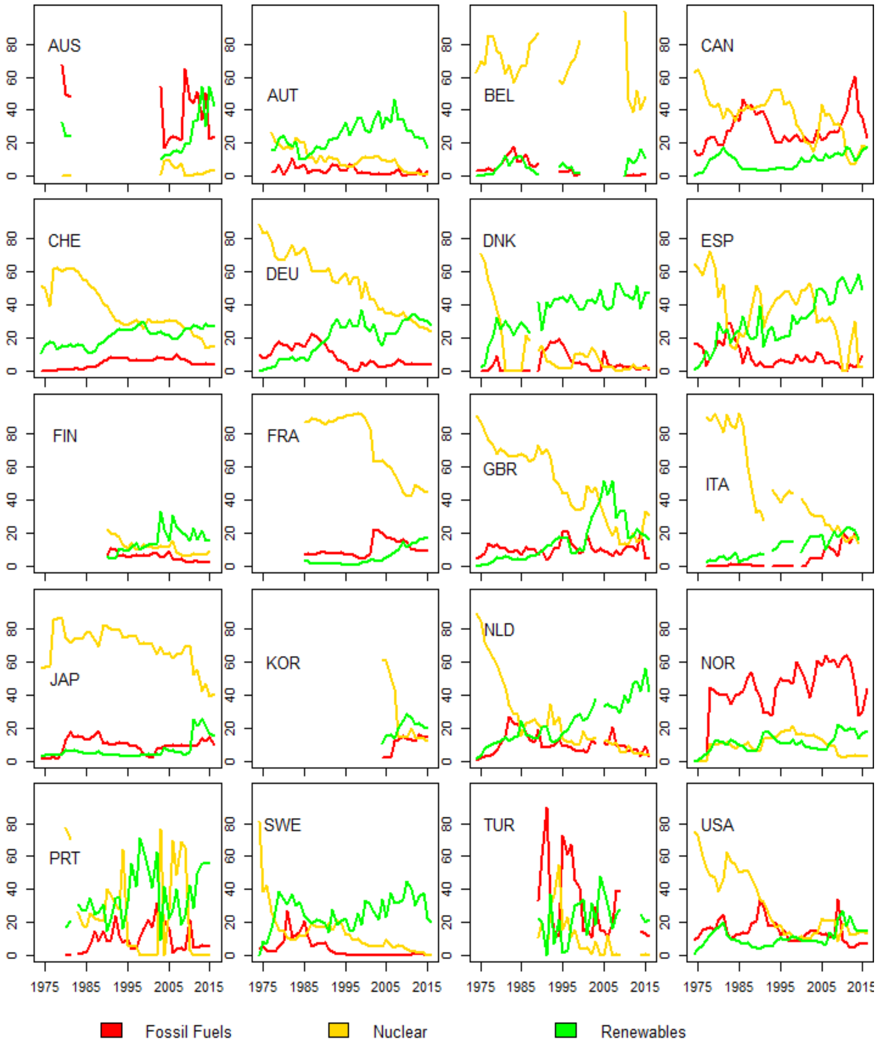


Figure A1. 2 Share in RD&D by type of main energy source 1974 - 2016. Own calculation based on data from IEA Online Data Service. The total amount of RD&D included also the following categories: energy efficiency, hydrogen and fuel cells, other power and storage technologies, other cross/cutting tech & research and unallocated

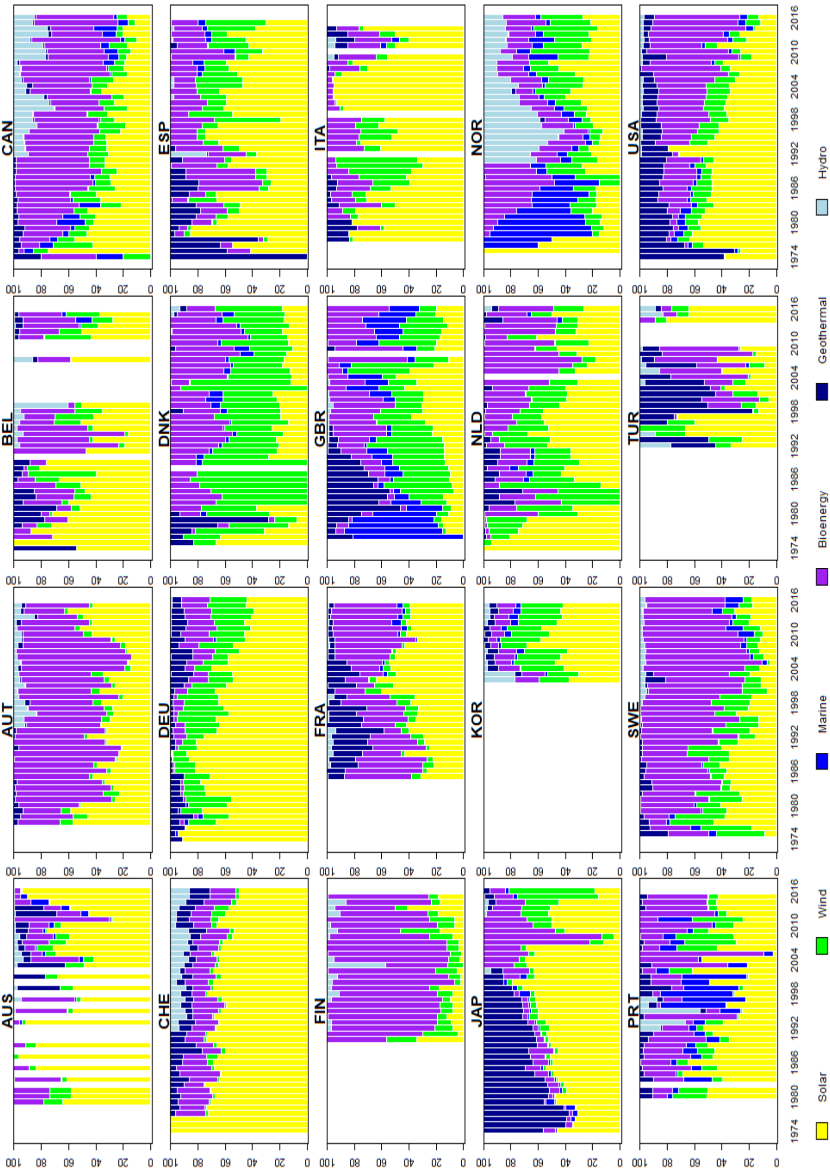


Figure A1. 3 Share in total RD&D dedicated to RES technologies by category, period: 1974 - 2016. Solar includes all technologies (i.e. photovoltaic, thermal, etc). Own calculation based on data of Total RD&D in Million of UDS (2016 and PPP) from IEA Online Data Service

Appendix A2 – Chapter 2

Supplementary Materials

This appendix reports a number of details on the data used and various further results supporting the analyses reported in the main text. These further analyses are listed in the following index of contents:

1. The expectations argument as a barrier to SPP adoptions and the optimal design of incentive policies: a simple game-theoretic interpretation

We have systematically observed during the development of this thesis the strict dependency of SPP diffusion on economic incentives, namely the fact that SPP adoptions mostly occurred in the presence of subsidies and they tended to regress, or even to stop (e.g., in the cases of Italy and Spain) when incentives decline (as showed in the UK case in chapter 3), as also pointed out in Guidolin and Mortarino (2010).

This phenomenon could be explained rather easily in the case in which the fuel parity of renewable sources of energy is only realized thanks to government subsidies, so that SPP installations can only take place in the presence of appropriate government incentive policies.

It might well be the case, however, that subsidies make the private sector "addicted" to them and that the expectation of future incentives and subsidies prevents current private sector's RES investments.

This mechanism will be shown formally below with the help of a simple game-theoretic representation. It is easy, however, also to explain it first in plain words. The comparison that the private sector makes, when deciding to undertake an investment, may not be between the payoff obtained when doing it, compared to the one obtained when not doing it, in which case, being the difference positive, the investment would be undertaken with certainty. As a matter of fact, knowing that subsidies can be expected in the future, the comparison may well be between the payoff obtained when not undertaking the investment initially, but waiting to do it at a later stage (when some government subsidies will be granted), and the payoff obtained when undertaking the investment immediately without enjoying any subsidy. The conclusion would be that it is preferable to undertake investments only at a later stage, when they will be further encouraged by the expected economic incentives.

For this to happen, however, the Stackelberg leadership will have to be in the hands of the private sector, with the government playing as follower. This is the case any time the government cannot commit firmly to its actions, but it is subject to re-optimize them, in which case it will prevent, or at least delay the undertaking of SPP installations.

On the contrary, when it is the government that takes the Stackelberg leadership, the private sector has no chances to force it to change action, given the credible commitment that has been taken initially.

What precedes explain with clarity some facts. It explains, for example, the success of the long term (20 years) German FIT policy. Chowdhury et al. (2014) underline the fact that "a long-term policy with incentive can make a countries domestic market grow bigger" since it affects agents' expectations. Moreover, the German FIT reduces the pay-back period to just a few years, thereby extending the number of SPP adopters beyond those who install SPP systems because of environmental concerns.

Such policy, however, does more than that, since it has clearly outlined the future slow digression rate (5% per year or in any case depending on the rate of growth of the market, Solangi et al., (2011) of the tariff, devised in order to accommodate for the technological progress. The rational of such a policy is quite clear: by announcing credibly, in the year 2000 that the FIT would be reduced by 5% per year, there is no incentive for economic agents to wait and install the SPP system in the future in order to enjoy the reduced cost made possible by technological progress, since such a lower cost would be compensated by the lower subsidy.[12]

Also in Japan, since 2011, the FIT system has helped the relaunching of SPP installations.

This is what would be necessary in order to develop a self-sustained market that would not need any support anymore (Chowdhury et al., 2014).

The examples of Spain and Austria show clearly how a FIT policy that is not clearly spelled out in the long term, not being part of a clear communication strategy, produces totally different results: in those countries the unexpected reduction of subsidized FITs had a negative impact on adoptions, precisely because of the expectation of a higher future subsidy that induces the perception of a current loss in the case in which an investment is undertaken, so as to hinder the SPP diffusion.

A similar conclusion can be reached by comparing the policy followed by the Italian government, with the one of the German government. The Italian economic incentives for the installation of SPP systems have been repeated over time, have been characterized by a short span and have not been presenting any clear time outline nor regularity (applying today to a sector, and tomorrow to a different one).

The importance of state financial incentives is also stressed by Sarzynski et al. (2012). The role of expectations emerges also by considering the fact that in presence of policies that target off-grid applications, people may prefer to wait for the grid extension, rather than installing SPP systems that are off-grid.

Trappey et al. (2008) consider the role of pessimists, who think that technology will improve significantly in the future, so that it would not make sense to adopt its current version given that once the "sunk cost" of investment is undertaken it will not be possible to go back.

[12] An alternative interpretation is provided by CPI, 2011, arguing that the 5% digression rate should provide an incentive to the solar industry to develop more cost-effective panels, in order to grant to the customers, the same real price year after year). Once more, this shows the relevant role played by the expectations of the private sector in deciding to install a solar plant.

This also confirms the intuition provided by Karakaya and Sriwannawit (2015), according to whom perceived costs are as important as effective costs.

Public communication might reduce the share of pessimists and favour a positive word-of-mouth transmission mechanism. An important question to ask, then, is whether it would be more efficient to provide direct monetary incentives and subsidies or to strengthen the channels of public communication and information.

What precedes can be shown in a very simple and intuitive way. Let us start by considering the case in which the installation of SPP may be convenient even without subsidies, but in which economic agents anticipate the possible availability of future government subsidies, like those that had taken place in the past: the apparently counter-intuitive and paradoxical result that we obtain is that if the private sector (economic agents) plays as a Stackelberg leader, it may decide not to install SPP but rather wait, so as to force the government to reintroduce the subsidies.

Let us consider a simple normal form game (therefore played simultaneously) between the government and the private sector that for simplicity we consider as an atomistic player. The government can subsidize or not the installation of SPP that are installed by the private sector, and the private sector can install them or not. The first of the two numbers reported in the boxes of the matrix is the (positive) payoff of the government, while the second number is the payoff of the private sector.

The highest payoff for the government (4) is the situation in which the private sector installs SPP without any subsidy, namely (NS, I); the second best (3) can be assumed as the one in which SPP are installed, although with subsidy (S, I); the third one (2) is obtained in the case in which, when the private sector does not install, subsidy is paid, so as to favour a future installation (S, NI), and the worst one (1) is when no subsidies are paid, so that no panels will be installed (NS, NI).

Let us analyse now the payoffs of the private sector. The first best (4) can be assumed as the one in which the private sector installs SPP and receives a subsidy (S, I), assuming therefore that the subsidy is such as to produce a profit. The second best (3) can be assumed to be the one in which the government pays a subsidy, but the private sector does not install immediately SPP but waits to do it in the future (S, NI); the third best (2) is the one in which no subsidy is paid but panels are installed (NS; I) and the worst case (1) can be reasonably assumed to be the case in which no subsidies are received and no SPP are installed (NS, NI).

The situation described above is represented in Figure 1. As it is easy to verify by simple inspection, the outcome of this simultaneous game is a unique Nash equilibrium (that in the matrix below is indicated with a *), in which the private sector installs SPP without the encouragement of a subsidy.

		Private Sector	
		Install	Not Install
Government	Subsidize	3, 4	2, 3
	Not Subsidize	4, 2 *	1, 1

Table A2- 1 A normal form game in which the government and the private sector move simultaneously and in which SPP installation is convenient even without subsidies

The situation might change, however, if we consider an extensive form game, in which the two players move sequentially, rather than simultaneously (the first payoff refers to the player who moves first).

Let us see what the equilibrium of the game is when investors move first, so that they can force the government to cope with their action. The private sector knows that if it invests, the government's optimal response will be not to subsidize (in which case the payoff of the latter will be 4, against 3 obtained when subsidizing). Private sector's payoff, then, will be 2. If the private sector does not invest, however, the government will have the option of subsidizing, in which case the former will get a payoff of 3, and not subsidizing, in which case still the former will get 1. The payoff of economic agents, then, will be 3. Given that the private sector will prefer to get 3 rather than 2, the only subgame perfect equilibrium of this extensive form game, then, is the one in which economic agents do not invest and the government will be forced to provide economic incentives.

It is easy to see instead that in the case in which the leader of the game is the government, namely the government decides its best action by moving (irrevocably) first and taking into account the actions of the private sector, the equilibrium goes back to the one identified in the simultaneous moves game, as we are going to show below.

The private sector will find it convenient to install SPP both if the government subsidizes and if it does not do it (it gets 4, rather than 3, in the first case, and 2 rather than 1 in the second case), so that the latter will have the convenience not to subsidize.

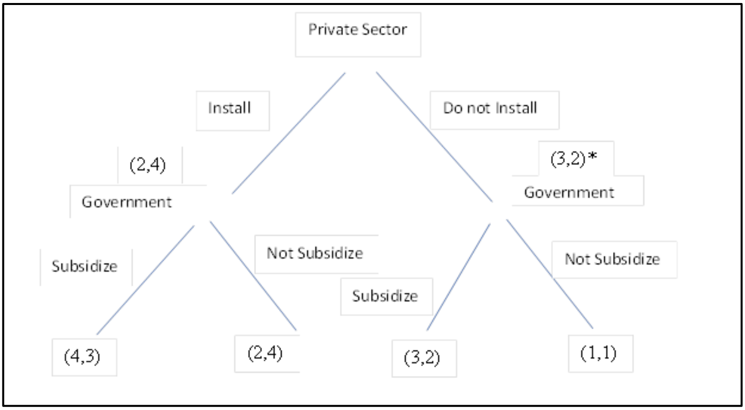


Figure A2. 1 An extensive form game with the government moving second, or not being able to commit credibly to a given action, so that it is expected to re-optimize after the move of the private sector.

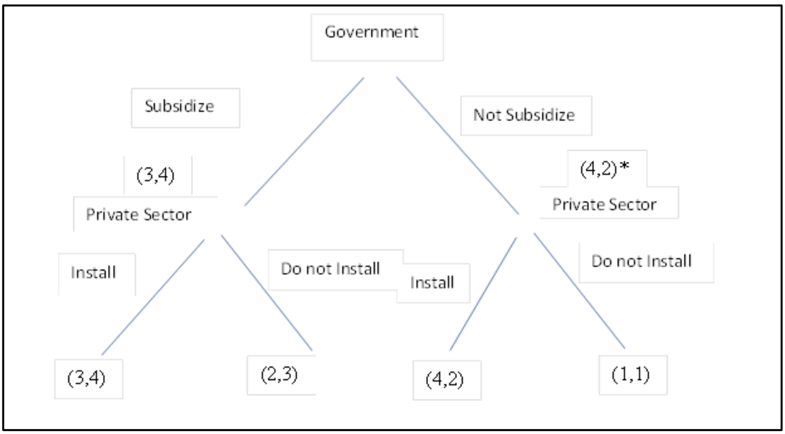


Figure A2. 2 An extensive form game with the government being able to commit credibly to a given action

To summarize, focusing on the role played by expectations, we have provided an explanation to the fact that long term and credible policies, like the 20-years span German FIT, would prove more effective than not clearly announced nor spelled out like those adopted by the Netherlands or Spain, even if similar in the content.

We have also explained why subsidy policies may actually prevent the self-deployment of investments in SPP systems. This may well be due to the fact that technological market developments are still insufficient to reach the fuel parity. However, it might also be due to the fact that a non-credible government may allow the private sector to gain Stackelberg leadership, in which case the only equilibrium that would realize in the market would be the one in which the private sector waits for the introduction of economic incentives. We have concluded, then, that in order to increase the efficiency of public policies, the government should carefully guide the expectations of the private sector.

2. Trend in the oil price

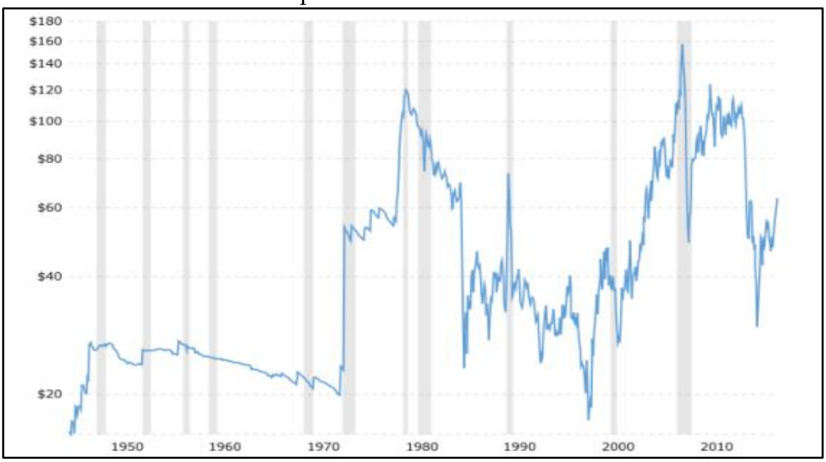


Figure A2. 3 Oil price trend from 1940 to 2016. Source: Trans FS https://www.transfs.com/should-you-invest-in-oil/

3. A note on the data

As pointed out in the main text the data were principally drawn from the Trends, Snapshots and Annual Reports of the International Energy Agency (IEA). During data collation we found some discrepancies in the data reported in the Trend Reports with earlier reports containing more detailed data than more recent ones which in some cases included trivial approximations or even missing values. For such situations, other sources (IRENA, UN, World Bank, OECD, EUROSTAT, and national energy agencies) were used to check and fill the missing data.

4. **The minimum and maximum scenario**

The minimum and maximum scenario adopted in this paper for each country considered are reported in the table below with related sources.

Country	Minimum Scenario	Maximum Scenario	Source for minimum target
Australia	12000	36000	http://reneweconomy.com.au/australian-solar-capacity-now-6gw-to-double-again-by-2020-2020/
Austria	2000	6000	No political target - assumption
Belgium	5350	16050	IRENA:http://irena.org/remap/IRENA_REmap_RE_targets_table_2014.pdf
Canada	6300	12000	http://www.cansia.ca/uploads/7/2/5/1/72513707/cansia_roadmap_2020_final.pdf
Switzerland	3000	6000	No political target - assumption
China	162000	486000	IRENA:http://irena.org/remap/IRENA_REmap_RE_targets_table_2014.pdf
Germany	51700	258500	IRENA:http://irena.org/remap/IRENA_REmap_RE_targets_table_2014.pdf
Denmark	2000	6000	Assumption, because it surpassed the political target https://www.solarguide.co.uk/denmark-to-smash-2020-solar-energy-target
Spain	5800	17400	No political target - assumption http://www.idae.es/eu/node/12480
Finland	500	1500	Assumption - No SPP taget, only general http://www.vtt.fi/inf/pdf/technology/2015/T217.pdf
France	18200	54600	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000033312688&dateTexte=&categorieLien=id
UK	20000	60000	https://www.bre.co.uk/filelibrary/nsc/Documents%20Library/Not%20for%20Profits/KTN_Report_Solar-PV-roadmap-to-2020_1113.pdf
India	100000	300000	India Solar Mission: https://en.wikipedia.org/wiki/Jawaharlal_Nehru_National_Solar_Mission
Israel	3500	17500	https://www.pv-magazine.com/2017/05/19/israel-to-

			hold-tender-for-over-150-mw-of-distributed-generation-pv-in-july/
Italy	24000	72000	IRENA:http://irena.org/remap/IRENA_REmap_RE_targets_table_2014.pdf
Japan	53000	265000	http://www.univergy.com/en/mercados/japon/15-privacidad
Korea	20600	103000	Assumption and IRENA: http://irena.org/remap/IRENA_REmap_RE_targets_table_2014.pdf
Mexico	5720	28600	https://www.pv-magazine.com/2017/01/02/mexico-targets-addition-of-5-4-gw-of-pv-in-next-3-years/
Malaysia	854	15000	http://www.irena.org/remap/RE%20Targets_Summary%20REmap_14mar2016.pdf
Netherlands	6000	20000	http://transrisk-project.eu/sites/default/files/page-files/JIQ%20Magazine%20on%20Climate%20and%20Sustainability%2C%20Special%2C%2017%20November%202016.pdf
Norway	500	5000	No political target - assumption
Portugal	670	10000	https://www.pv-magazine.com/2014/09/05/portugal-adds-33-mw-of-pv-for-330-mw-cumulative-solar-capacity_100016340/
Sweden	1000	5000	No target - http://www.renewableenergyworld.com/articles/2016/10/sweden-set-to-launch-residential-energy-storage-scheme.html
Thailand	6000	30000	http://thailand.ahk.de/fileadmin/ahk_thailand/Projects/PV-Solar/2016/9.45_20160523_Thailand_PV_Policy_AHK.pdf
Turkey	5000	15000	https://www.rvo.nl/sites/default/files/2015/10/Renewable%20Energy%20Turkey.pdf
USA	60000	180000	No target: http://www.irena.org/remap/RE%20Targets_Summary%20REmap_14mar2016.pdf

Table A2- 2 Minimum and maximum scenarios and related sources in 26 considered countries

5. **Figures and graphics**

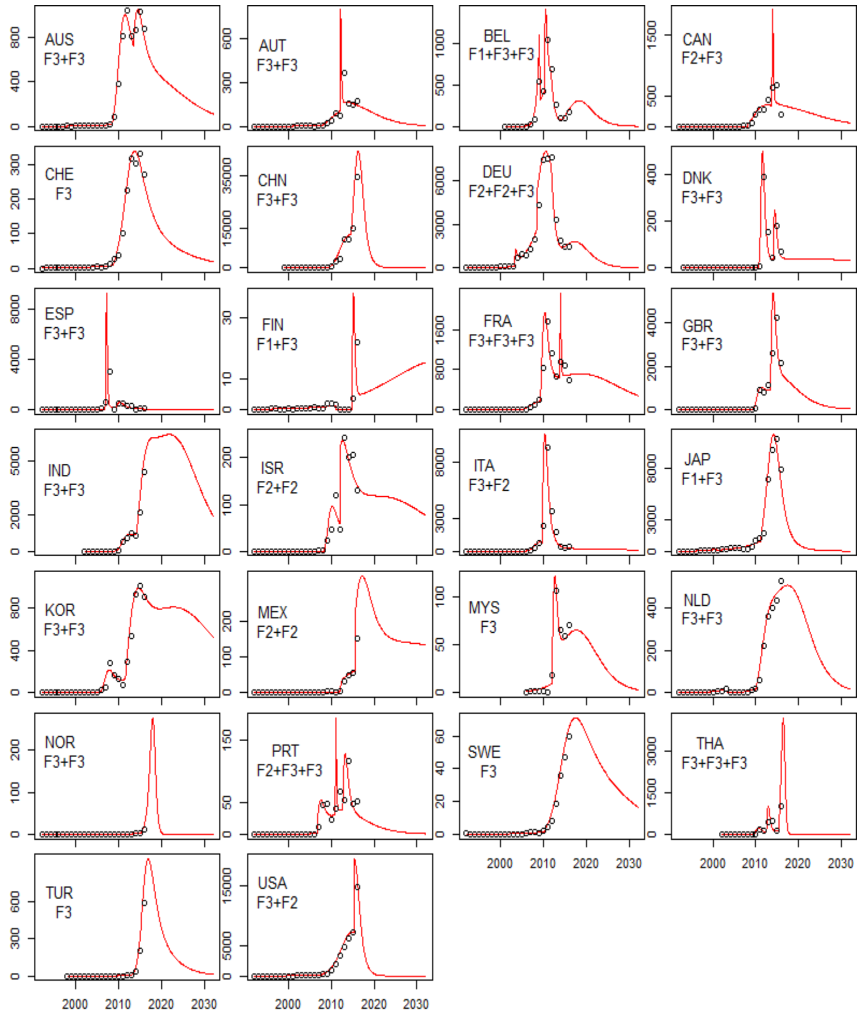


Figure A2. 4 GIM fit of SPP adoptions during 1992-2016 with forecast up to 2030 in the 26 countries considered. The graph reports observed vs predicted average monthly figures (instead of the annual figures).

Comparison between GIM and BM fits

Figure A2. 5 compares the fit by the GMB with that provided by the basic Bass model (BM). To appreciate differences the comparison is carried out using in terms of the graphic reproduction of the shocks experienced in the adoption paths is reported in Figure_SM 1 (details on the improvement in goodness of fit are postponed to the subsection on "Numerical details".

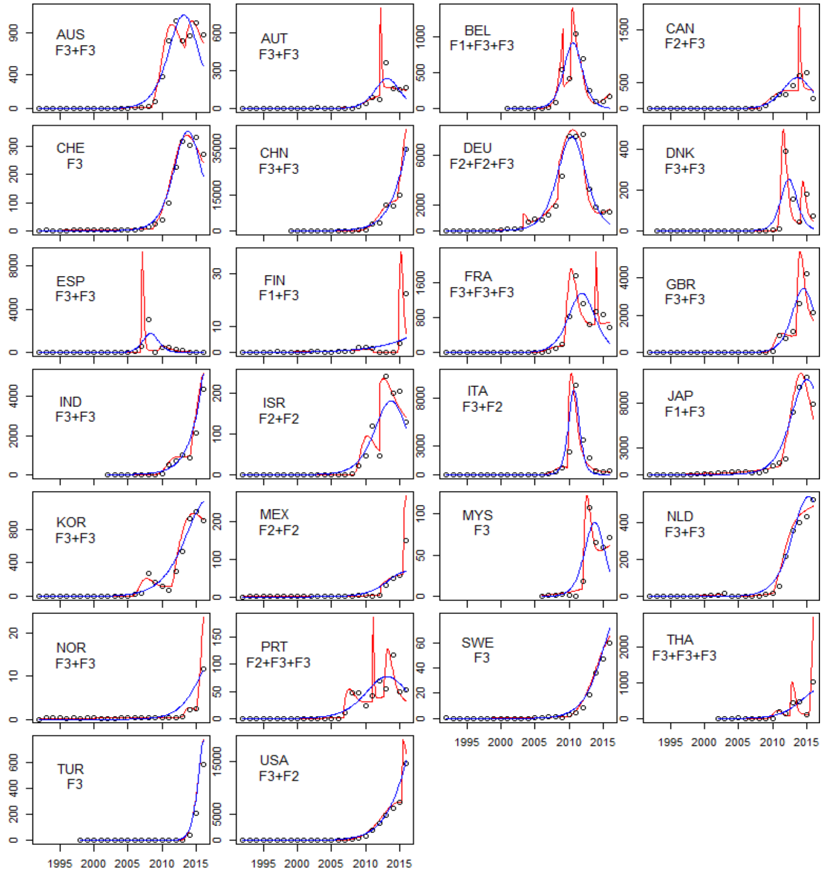


Figure A2. 5 GIM fit of SPP adoptions during 1992-2016 in the 26 countries considered compared with the corresponding best fit by the basic Bass model under the minimum scenario on the market potential. The legend in each graph specifies the number and type of shock functions selected by model fit.

The maximum scenario

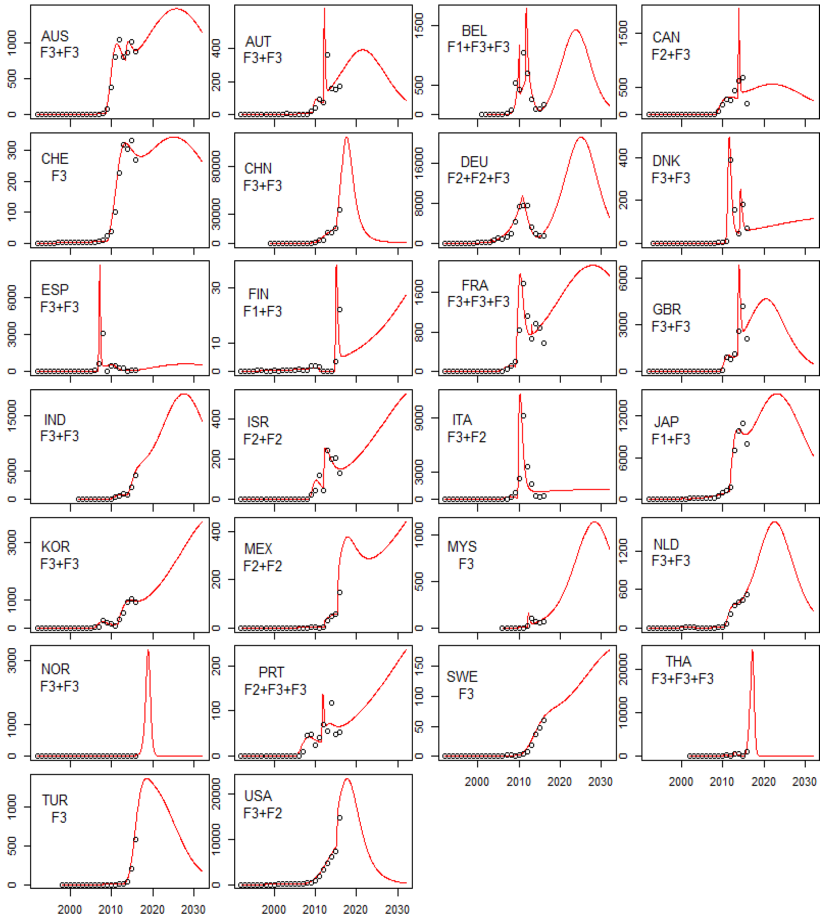


Figure A2. 6 GIM fit of SPP adoptions during 1992-2016 in the 26 countries with forecast up to 2030 considered under the maximum scenario on the market potential. The graph reports observed vs predicted average monthly figures (instead of the annual figures) in order to depict a smoother temporal profile. The legend in each graph specifies the number and type of shock functions selected by model fit.

The minimum scenario

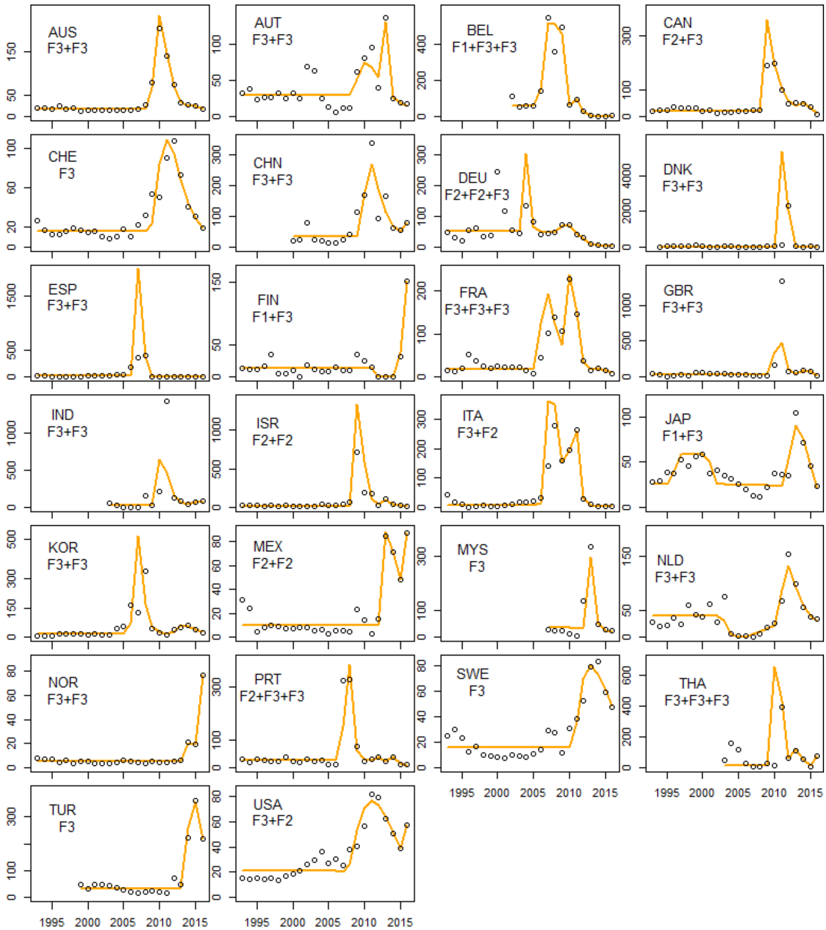


Figure A2. 7 The GIM fit in the 26 countries considered: observed vs predicted annual (%) growth rates on adoptions of SPP during 1992-2016 (in natural scale) under the minimum scenario on the market potential. The legend in each graph specifies the number and type of shock functions selected by model fit.

6. Numerical details on GIM estimates for all countries

	R^2 Bass	*Best Model*	*R^2 Best model*	*SMPCC*
AUS	0.996805943	*F3+F3*	0.999978	0.993201
AUT	0.994352412	*F3+F3*	0.999779	0.960906
BEL	0.998131094	*F1+F3+F3*	0.9999986	0.999267
CAN	0.997786959	*F2+F3*	0.9991066	0.596284
CHE	0.998810612	*F3*	0.9998458	0.870354
CHN	0.996353251	*F3+F3*	0.9997044	0.918935
DEU	0.99869749	*F2+F2+F3*	0.9999682	0.975556
DNK	0.978947293	*F3+F3*	0.9999488	0.997569
ESP	0.984451734	*F3+F3*	0.9997668	0.985003
FIN	0.903685498	*F1+F3*	0.9965364	0.964039
FRA	0.993735394	*F3+F3+F3*	0.9999446	0.991159
GBR	0.996825472	*F3+F3*	0.9998456	0.951375
IND	0.986320924	*F3+F3*	0.9999336	0.995145
ISR	0.997968846	*F2+F2*	0.9996171	0.811496
ITA	0.998361828	*F3+F2*	0.9999531	0.971381
JAP	0.99363425	*F1+F3*	0.9998285	0.973066
KOR	0.995212601	*F3+F3*	0.9997888	0.955882
MEX	0.92184071	*F2+F2*	0.9995842	0.994680
MYS	0.98856044	*F3*	0.9987969	0.894831
NLD	0.997349815	*F3+F3*	0.9996921	0.883804
NOR	-0.70168166	*F3+F3*	0.9996104	0.999771
PRT	0.995806055	*F2+F3+F3*	0.9998023	0.952865
SWE	0.995908702	*F3*	0.9997855	0.947574
THA	0.984482043	*F3+F3+F3*	0.9996265	0.975929
TUR	0.999620618	*F3*	0.9999890	0.970981
USA	0.998352283	*F3+F2*	0.9999708	0.982258

Table A2- 3 Squared multiple partial correlation coefficient (SMPCC) between Bass and the resulting best model values for the minimum scenario in the 26 considered countries.

	α/q	q	m	R^2 Bass	Model	R^2 Best fit model	SMPCC (Bass vs Best model)	q	c1	a1	A1 or b1	c2	a2	A2	c3	a3	A3
AUS	0.00000	0.67	6674	0.996676569	F3+F3	0.999978	0.993466	0.16	0.97	16.41	17.99	0.97	21.33	2.44			
AUT	0.00000	0.81	1178	0.994088309	F3+F3	0.999779	0.962652	0.26	0.63	16.07	2.19	10.45	20.00	272.05			
BEL	0.00003	1.11	3309	0.997827306	F1+F3+F3	0.9999986	0.999369	0.47	2.89	4.66	8.09	4.22	9.17	21.37	0.47	10.71	-1.12
CAN	0.00000	0.70	3362	0.997786959	F2+F3	0.9991066	0.596284	0.19	0.49	16.09	9.74	8.67	21.75	161.99			
CHE	0.00000	0.72	1955	0.998706745	F3	0.9998458	0.880767	0.15	0.48	16.59	5.47						
CHN	0.00001	0.56	507627	0.995527338	F3+F3	0.9997044	0.933905	0.28	0.75	9.95	7.59	0.41	15.61	3.17			
DEU	0.00000	0.71	41670	0.998701091	F2+F2+F3	0.9999682	0.975488	0.40	3.20	11.23	8.20	0.30	16.43	0.95	0.47	19.78	-1.07
DNK	0.00000	1.27	804	0.978894543	F3+F3	0.9999488	0.997575	0.08	3.00	17.42	840.29	3.32	21.06	52.73			
ESP	0.00000	0.99	5328	0.972795619	F3+F3	0.9997668	0.991429	0.16	7.99	14.76	2122.18	1.04	17.38	7.04			
FIN	0.00001	0.21	13610	0.858771561	F1+F3	0.9965364	0.975475	0.13	-1.00	19.00	22.90	5.25	22.80	251.45			
FRA	0.00000	0.77	7150	0.993675884	F3+F3+F3	0.9999446	0.991243	0.16	0.85	13.00	14.18	2.18	17.25	55.34	12.02	21.82	105.81
GBR	0.00000	0.90	15110	0.996805708	F3+F3	0.9998456	0.951676	0.31	1.75	17.28	33.06	2.43	21.43	23.18			
IND	0.00001	0.56	438583	0.995528685	F3+F3	0.9999336	0.985148	0.25	1.25	6.90	27.59	0.89	12.08	3.90			
ISR	0.00000	0.62	1175	0.992079479	F2+F2	0.9996171	0.951660	0.13	1.06	16.39	42.46	0.63	20.00	5.43			
ITA	0.00000	1.89	18700	0.998361828	F3+F2	0.9999531	0.971381	0.06	0.97	13.80	70.93	1.11	17.78	53.40			
JAP	0.00000	0.64	66170	0.993068858	F1+F3	0.9998285	0.975263	0.23	1.04	3.58	8.76	0.41	19.06	3.18			
KOR	0.00002	0.44	10580	0.995425736	F3+F3	0.9997888	0.953826	0.16	1.51	13.61	48.63	0.78	19.46	5.23			
MEX	0.00000	0.53	505	0.92184071	F2+F2	0.9995842	0.994680	0.10	0.38	20.15	7.79	0.54	23.52	8.57			
MYS	0.00043	1.00	355	0.988877084	F3	0.9987969	0.891837	0.31	2.96	5.92	42.99						
NLD	0.00000	0.62	3503	0.995559177	F3+F3	0.9996921	0.930657	0.33	0.43	10.34	-1.18	0.90	18.07	4.82			
NOR	0.00000	0.56	100	-0.55597017	F3+F3	0.9996104	0.999750	0.05	1.29	21.00	12.29	0.08	22.96	18.91			
PRT	0.00005	0.48	645	0.995745453	F2+F3+F3	0.9998023	0.953537	0.25	1.48	14.78	15.05	11.42	18.93	153.95	1.90	20.66	10.89
SWE	0.00000	0.56	596	0.995908702	F3	0.9997855	0.947574	0.15	0.39	18.09	3.44						
THA	0.00042	0.52	6281	0.984934781	F3+F3+F3	0.9996265	0.975206	0.11	2.08	7.22	163.03	4.16	10.51	181.61	0.09	13.32	29.60
TUR	0.00000	1.56	2064	0.999620618	F3	0.9999890	0.970981	0.29	0.72	14.83	8.82						
USA	0.00000	0.46	246500	0.998352283	F3+F2	0.9999708	0.982258	0.19	0.26	15.41	1.58	0.06	23.32	4.24			

Table A2- 4 Parameter estimates for the Bass and Best fit Model in the 26 considered countries

Country	*Model*	*Installed capacity by 2016*	*Minimum target*	*m* (estimate)*	*R^2 Optimal*	*R^2 Best Fit*	*SMPCC*
DEU	***F2+F2+F3***	41186	51700	58484	0.9999734	0.999968	0.166
ESP	***F3+F3***	5483	5800	5500	0.9998091	0.999767	0.181
ITA	***F3+F2***	19279	24000	21049	0.9999566	0.999953	0.074
CAN	***F2+F3***	2780	6300	3005	0.9997991	0.999107	0.775
FRA	***F3+F3+F3***	7164	18200	15432	0.9999876	0.999945	0.776
GBR	***F3+F3***	11830	20000	21818	0.999853	0.999846	0.048
JAP	***F1+F3***	42041	53000	62583	0.9998524	0.999829	0.139
CHE	***F3***	1664	3000	3671	0.9998562	0.999846	0.067
ISR	***F2+F2***	1016	3500	3500	0.9996172	0.999617	0.000
NLD	***F3+F3***	2085	6000	15237	0.999965	0.999692	0.886
KOR	***F3+F3***	4397	20600	5747	0.9999508	0.999789	0.767

Table A2- 5 Estimated market saturation (m*) for selected countries where the peak of adoptions has been overcome

	Model	R^2 Best Fit MIN	R^2 Best Fit MAX	SMPCC
AUS	*F3+F3*	0.999978	0.999955	0.514663
AUT	*F3+F3*	0.999779	0.998257	0.873321
BEL	*F1+F3+F3*	0.9999986	0.999977	0.939244
CAN	*F2+F3*	0.9991066	0.998315	0.469722
CHE	*F3*	0.9998458	0.999813	0.176993
CHN	*F3+F3*	0.9997044	0.999663	0.122574
DEU	*F2+F2+F3*	0.9999682	0.999678	0.901086
DNK	*F3+F3*	0.9999488	0.999931	0.259867
ESP	*F3+F3*	0.9997668	0.998955	0.776919
FIN	*F1+F3*	0.9965364	0.996587	-0.01489
FRA	*F3+F3+F3*	0.9999446	0.999458	0.897853
GBR	*F3+F3*	0.9998456	0.999087	0.830861
IND	*F3+F3*	0.9999336	0.999934	-0.00668
ISR	*F2+F2*	0.9996171	0.999554	0.141145
ITA	*F3+F2*	0.9999531	0.999029	0.951719
JAP	*F1+F3*	0.9998285	0.999594	0.577538
KOR	*F3+F3*	0.9997888	0.999752	0.147468
MEX	*F2+F2*	0.9995842	0.999583	0.003574
MYS	*F3*	0.9987969	0.997716	0.47331
NLD	*F3+F3*	0.9996921	0.999884	-1.65632
NOR	*F3+F3*	0.9996104	0.999562	0.110392
PRT	*F2+F3+F3*	0.9998023	0.998516	0.866759
SWE	*F3*	0.9997855	0.99979	-0.02133
THA	*F3+F3+F3*	0.9996265	0.999586	0.096992
TUR	*F3*	0.9999890	0.999987	0.148089
USA	*F3+F2*	0.9999708	0.999899	0.71123

Table A2- 6 Squared multiple partial correlation coefficient (SMPCC) between the minimum and the maximum scenarios

	99% min target	Year MIN target	99% of max target	Year MAX target	GW to cover elect. cons.	MW in 2016	% elect. from SPP in 2016	% elect. from SPP in MIN	% elect. from SPP in MAX
AUS	11880	2043	35640	2053	272	5985	2.2	4.4	13.2
AUT	1980	2032	5940	2039	43	1108	2.6	4.7	14.0
BEL	5296	2026	15889	2032	53	3423	6.5	10.1	30.3
CAN	6237	2041	11880	2046	208	2779	1.3	3.0	5.8
CHE	2970	2041	8910	2055	43	1664	3.9	7.0	21.0
CHN	160380	2020	481140	2027	1412	78070	5.5	11.5	34.4
DEU	51183	2025	255915	2036	381	41186	10.8	13.6	67.9
DNK	1980	2074	5940	2091	26	858	3.4	7.8	23.5
ESP	5742	2026	17226	2055	266	5483	2.1	2.2	6.5
FIN	495	2070	1485	2079	55	37	0.1	0.9	2.7
FRA	18018	2048	54054	2057	335	7164	2.1	5.4	16.3
GBR	19800	2029	59400	2035	199	11830	6.0	10.1	30.2
IND	99000	2040	297000	2046	836	9658	1.2	12.0	35.9
ISR	3465	2056	17325	2071	29	1015.6	3.5	12.2	60.8
ITA	23760	2066	71280	2103	222	19278	8.7	10.8	32.5
JAP	52470	2023	262350	2043	1156	42041	3.6	4.6	22.9
KOR	20394	2052	101970	2065	360	4397	1.2	5.7	28.6
MEX	5662.8	2076	28314	2094	140	322	0.2	4.1	20.4
MYS	845.46	2032	14850	2043	75	332.5	0.4	1.1	20.0
NLD	5940	2031	19800	2036	68	2085	3.1	8.9	29.5
PRT	663.3	2029	9900	2079	56	517	0.9	1.2	17.9
SWE	990	2050	4950	2065	81	205	0.3	1.2	6.2
TUR	4950	2031	14850	2037	54	850	1.6	9.2	27.5
USA	59400	2020	178200	2030	4112	40658	1.0	1.5	4.4

Table A2- 7 First four columns: estimates of the year in which the 99% of the minimum and maximum targets are reached. Next five columns: the cumulative installed capacity in 2016 vs the necessary capacity (in GW) to provide electricity only from SPP, share in total electricity output (%) for installed capacity in 2016, minimum and maximum target.

Table A2- 8 Description of incentives during the shock periods in the 26 considered countries

First incentive

Country	*Year*	*Shock Form*	*Type*	*Info*	**Source**
AUS	2009	F3	Investment subsidy	**Solar Homes and Communities Plan**: 2000- June 2009 refund up to AUD 8 000 for 1 kWp of PV installed on residential buildings and up to 50% of the cost of PV systems up to 2 kW installed on community buildings. Nat Rep AUS 2009;	1
			FIT	**State and territory FIT**: Began from 2008 but in 2010 had covered most of the states, directed to the residential sector.	2
AUT	2009	F3	FIT	New FIT were determined in February 2009 for RES. In the case of SPP the rates were up to 5kWp: 45.98; 5-10kWp: 39.98; over 10kWp: 29.98 cents/kWh. The tariff was recalculated in 2010 and 2012.	3
BEL	2006-2009	F1	Investment subsidy	**Investment subsidy in Flanders**: Between 29/10/2004 and 16/05/2007, but replaced in October 2007 and ended on 31th January 2011. It provided 40% of additional costs for SMEs, and 20% for large enterprises, with variations over the years.	4
			Target	**Flemish Government Second Climate Policy Plan in 2006**: Funding 1522million, covers the 2006-12 period and aims at achieving the Flemish Kyoto target and establishing the short, medium and long term strategies for Flanders;	5
CAN	2009	F2	FIT	Increased rate of FIT from 0.42CAD/kWh in 2006 to 0.802CAD/kWh in 2009 in Ontario (98% of the SPP market).	6
CHE	2011	F3	FIT + Investment subsidy	Feed-in Tariffs for RES and Investment Aid for Small PV. Small photovoltaics plants are being promoted from 2014 with investment aids. The tariff is applicable for 20 years (10 years for biomass infrastructure power plants) and is regularly reviewed.	7
CHN	2010	F3	FIT + Investment subsidy	**Solar PV building project**: 91MWp, subsidy 15-20Yuan/kWp; FIT at the price of sulfur coal-fire generation unit.	8
				Golden Sun project: 632MWp, subsidies 50-70% of investment cost, FIT; Also FIT for utility-scale 1.15Yuan/kWh in 2011 and 1.0Yuan/kWh in 2012	
				China Power Investment Corporation Huanghe Hydropower PV station: 500MW 2013-2014.	9

DEU	2004	F2	FIT	**EEG Program**: The FIT scheme was implemented in 2000 and paid 0.52EUR/kWh with a 5% decrease every year. The rates were revised in 2004 and increased to 0.57EUR/kWh	10
DNK	2011-12	F3	NMS	In 2012 NMS of 0.08EUR/kWh; Only generators under 6 kW are eligible to participate in the scheme.	11
			Target	**Danish 2050 Energy Strategy:** achieve 100% independence from fossil fuel in the national energy mix by 2050.	12
ESP	2007	F3	FIT	**Royal Decree 661/2007.** In September 2008, new tariffs and a new cap were established for solar PV. Systems registered prior to 29 September 2008 are eligible for a feed-in tariff of between approximately EUR cents 23/kWh and EUR cents 44/kWh.	13
FIN	2011-12	F3 (negative)	FIT for other RES	Solar is excluded for the FIT scheme implemented in 2010. Only wind, bioenergy, timber chip and wood-fuelled power plants are eligible.	14
FRA	2007	F3	Investment subsidy	In 2006 the Financial Act subsidy program reimbursed to household rooftop or façade up to 50% of the costs of the materials (installation costs are excluded).	15
			FIT	FIT was implemented in 2005 and had a rate increased in 2006.	16
GBR	2010	F2	FIT	In act from April 2010. Had higher values until 2012 when the tariffs were revised and decreased drastically.	17
IND	2010-11	F3	FIT	In 2008 **Production related incentives for grid connected solar**: promoted systems above 1 MW of capacity at a single location. The scheme was limited to 5 MW per developer across India and a maximum of 10 MW per state 5% decrease each year for new installations. In 2011 State level initiatives: Solar parks, FIT different by region.	18
ISR	2009	F2	FIT	FIT scheme from 2008 to 2012 for small and medium systems. The tariff slightly decreased in 2009 at 0.197NIS/kWh	19
ITA	2006	F3	FIT	**Conto Energia**: divided in 5 stages.	20

JAP	1996-2001	F1	Investment subsidies	**Residential SPP Monitor Program**: covered 50% of the cost from 1994 to 1996 and one third of the cost from 1997 to 1999. In 2000 the subsidy rate was JPY 270 000 per kW in the first half of the year, up to 10kW and JPY 180 000 per kW, up to 4kW in the second half of the year. It was further reduced to JPY 150 000 per kW, (up to 4kW) before the end of the fiscal year. In 2001 the subsidy was reduced to JPY 120 000 per kW. In 2002 the subsidy was further reduced to JPY 100 000 per kW. The subsidy rate continued to decline, and was JPY 20 000 per kW when the programme ended in 2006.	21
KOR	2005-2006	F3	Investment subsidies	**100,000 roof-top program**: 2452 systems with a total capacity of 6469kW were for single-family houses, the average capacity being 2,47kW. General Deployment Program: the government supports 70% of installation cost.	22
			FIT	**FIT Scheme**: rate per kW-hr changed from 716,40 KRW to 677,38 KRW for systems larger than 30 kW with a ceiling of cumulative 100 MW since Oct. 2006 guaranteed for 15 years for the PV system over 3 KW	
MEX	2013	F2	RPS	**General Law of Climate Change** (Ley General de Cambio Climático) on 10th October 2012: The Law defines several GHG mitigation targets that directly incentivise the development of renewable energies. These are: 1) To generate at least 35% of power with clean technologies by 2024. 2) To reduce emissions by 30% by 2020, and 50% by 2050 compared to 2000.	23
MYS	2012	F3	FIT	**The Renewable Energy Act 2011** was enforced on 1st April December 2011. Costs of the system are transferred onto electricity consumers who pay an additional surcharge of 1% on top of their electricity bills collected by the distribution licensees and deposited into the RE Fund. Existing RE power plants under the existing Small Renewable Energy Programme (SREP) under the RE Act 2011 are allowed to convert to the current FiT system. FITs are for over a 21 year period for PV. 2014 - new, lowered FIT announced; 2015 - lowered FIT for solar PV announced entering into force on 1st of January 2016;	24
NLD	2010-12	F3	FIT	**Feed-in Premium Programme SDE (Stimulering Duurzame Energie +)**: Grant scheme available for solar panels buyers in a private sector. EUR 50.000.000 were made available for this scheme. From 2011 to 20th December 2013. Small and large systems. FIP contracts are signed for 15 years.	25

NOR	2014	F3	Green Certificates (GC)	**Norway-Sweden Green Certificate Scheme for electricity production**: 1 January 2012 a common Norwegian-Swedish certificate market for renewable electricity production was established. The overall target for new renewable electricity production in the common electricity certificate market is 28.4 TWh by the year 2020. The certificate scheme is an important measure in the strategy to reach Norways national energy target in accordance with the renewables directive, which is 67.5 % renewable energy by 2020.	26
PRT	2007	F2	FIT (increase)	**Decree Law 33- A/2005** establishes FIT for Photovoltaics less or equal to 5 kW 44.4 euro cents/kWh for the first 21 GWh/ MW injected in the grid or 15 years whatever comes first. For installations bigger than 5 kW 31.7 euro cents/kWh for the first 21 GWh/ MW injected in the grid or 15 years whatever comes first. **Decree Law No. 225.2007** of 31 May 2007, revised the feed-in tariffs established by the previous Decree Law No. 33 A/2005. Photovoltaic Up to 5 kW: EUR 450/MWh 5 kW to 5 MW: EUR 317/MWh Above 5 MW: EUR 310/MWh micro-generation photovoltaic Under 5 kW: EUR 470/MWh Between 5 and 150 kW: EUR 355/MWh.	27
SWE	2011	F3	Target	**Renewable energy target** for Sweden is to have at least a 50 % of share of energy generated from renewable sources in gross final energy consumption. Also, the electricity goal for renewable energy by 2020 is 63% of electricity demand met by electricity generated from renewable energy sources;	28
			GC	(see Norway)	26
THA	2009	F3	FIT	In 2007, feed-in premiums or "adders" on top of the regular electricity tariff of THB 2.0-2.5/kWh (THB 35 = USD 1). The aim is to add 2 GW of large solar installations by 2021. Above was modified in March 2009 to BHT 1.00/kWh for all technologies, except wind and solar for which they reach BHT 1.50/kWh.	29
TUR	2014	F3	Targets	**Renewable Energy Law 2010**. In a move to meet its target of reaching 30% of its power from renewable sources by 2023, Turkey implemented a long-awaited renewable energy law.	30
			FIT	The law first adjusts and increases the Turkish Feed-in tariffs, fixed for all system sizes at 0.133USD/kWh for solar for PV. Also other RES obtained FIT.	

USA	2009	F3	Various: Incentives to companies + FIT & RPS at local level	**No national program**. The incentives are at local or state level. Examples of incentives: **Section 1603 grants**: gives federal grants to solar companies for 30 percent of investments into solar energy. The federal government has given solar companies over $25 billion in grant money through this program until 2011. **California enacted a feed-in tariff** which began on February 14, 2008. Washington state has a feed-in tariff of 15 ¢/kWh which increases to 54 ¢/kWh if components are manufactured in the state. Hawaii, Michigan, and Vermont also have feed in tariffs.	31

Second incentive

Country	***Year***	***Shock Form***	*Type*	***Info***	**Source**
AUS	2015	F3	FIT	Victoria State offered a tariff of 6cent/kWh (1Jan 2013 - 31Dec 2015) and 5cent/kWh (1 Jan 2016 - 30Jun 2017) for systems <100kW.	32
AUT	2013	F3	Investment subsidy	Investment subsidy for SPP <5kW peak from 12th April to 30th November: EUR 36 million is available to be distributed as an investment subsidy to the individuals owning small solar PV installations	33
BEL	2011	F3	Target	**National Renewable Energy Action Plan** (NREAP) in 2010: Belgium 2020 targets: Electricity: 21% of electricity demand met by electricity generated from renewable energy sources; Support for renewables offered in Belgium (federal level only): Green Certificates schemes; Tax reduction on energy-saving investment for individuals; Tax deductions for investments for the benefit of companies.	28
CAN	2014	F3	FIT reduction	FIT unchanged from 2013 to 2015, then reduction in 2016. The FIT scheme ended in 2017	6
CHN	2016	F3	Target	**Five Year Plan**: defined the short term PV development goals, positioning and focus points, especially policy adjustment mechanism and direction of innovation	34

DEU	2009	F2	FIT (reduction)	2009 Amendment of the Renewable Energy Sources Act (EEG 2009) : For solar PV, tariffs under the new law decreased for all capacity sizes.	10
DNK	2015	F3	Solar park	WIRSOL: the largest solar park in the north Europe was created with 61.5MW (out of 181.4MW installed that year).	35
ESP	2010-11	F3	FIT (reduction)	Correction of the tariff deficit in the electricity sector (**Royal Decree-Law 14/2010**): reduce the tariff deficit currently burdening the electricity sector with emergency measures ranging form 2011 to 2013.	36
FIN	2015-16	F3	Investment subsidy	Investment subsidy: 30 % investment subsidy of the total costs of grid-connected PV projects. At the beginning of 2016, the subsidy level decreased to 25%.	37
			Tax Credit	Tax credit: 45% of the total work cost, including taxes, component of the PV system.	
FRA	2009-10	F3	FIT reduction	The change was announced in 2009 therefore many rushed into applying for the old FIT which actual installations in 2010. Decrease of 12% in FIT due to the fall of prices	38
			Target	**National Renewable Energy Action Plan**: 27% of electricity demand met by electricity generated from renewable energy sources by 2020;	28
GBR	2013-14	F3	FIT + RPS	The FIT scheme continues and the Renewable Obligation Certificates (ROC is a sort of RPS) is implemented for systems above 50kW.	17 + 39
IND	2015	F3	Target (RPS)	"Smart cities" project: Installation of solar energy up to 10% of the total electricity of selected cities	40
ISR	2013	F2	NMS	From 2013, for RES systems. Max. 400 MW capacity. For the use of the grid by the consumer, a tariff charge for "Grid integration costs" (e.g. NIS 0.013-0.014/KWh for high-voltage consumers) will be reduced from the value of credit to the consumer in accordance with the consumer's grid voltage line (high/low), and the time of grid-use.	41
ITA	2010-11	F2	FIT	Another stage of Conto energia	20
JAP	2012-13	F3	FIT	From July 2012, replacing RPS. Electric power companies are obliged to purchase electricity generated from renewable energy sources on a fixed-period contract at a fixed price. Cost for purchasing is paid by electricity users in the form of a nationwide equal surcharge. Purchase price is re-examined and published in each year.	42

KOR	2012	F3	RPS	In January 2012 the Renewable Portfolio Standard (RPS) replaced previously in place feed-in tariff system in order to accelerate Korea's renewable energy deployment with a goal to create a competitive market environment for the sector. RPS programme requires 13 largest power companies (with installed power capacity larger than 500 MW) to steadily increase their renewable energy mix in total power generation in period of 2012-2024.	22
MEX	2016	F2	RPS	**Clean Energy Certificates**: The government determines the requirements for clean energy certificates on a yearly basis three years in advance of the compliance period. The first compliance period will be 2018. As of 31st of March 2015, the Clean Energy Quota for this period is set at level of 5% of total electricity consumption. Penalty for non-compliance is between USD 30-250/ MWh. The first long-term auction were be held in 2016.	43
NOR	2016	F3	GC	Same policy (Green certificates)	26
PRT	2012	F3	FIT	Renewable micro-generation Tariffs (Decree 284/2011): As of 2012, the reference tariff for renewables micro generation will be reduced from the planned EUR 360/MWh to EUR 326/MWh. Micro generation tariffs are awarded for a 15 year period, devided between the first eight years and the subsequent seven years.	44
THA	2012-13	F3	FIT (revised)	On 16 July 2013 the National Energy Policy Commission (NPS) of Thailand adopted new feed-in tariff scheme supporting rooftop and community ground-mounted solar installations. The goal of the scheme is to support installation of 1 GW of new, small-scale solar systems in Thailand by 2014.	29
USA	2016	F2	FIT, NMS, Investment subsidy, RPS	FIT was present in 3 states, FIP was present in 20 states, 30% Investment subsidies are offered by at least 14 states, 10 states have GC, 29 states have RPS, 38 states have NMS.	45

Third incentive

Country	***Year***	***Shock Form***	*Type*	***Info***	**Source**
BEL	2013	F3 (negative)	Reduction in support	2011-2013: Introduction of a fixed tariff for all PV owners. This tariff varies from 55 to 83 €/kVA installed. Tax credits (40% of investment) were cancelled by the federal authority. Installers filled their order books for almost 6 month after the 30th November 2011 so that their clients	46

				could still benefits from this tax credit. The green certificates (GC) system was revised in the 3 regions to adapt to the lowering prices of PV and the financial constraints of public services	
DEU	2012	F3 (negative)	FIT (reduction)	EEG 2009 is continued, but with decreases in tariffs: on 1 January tariffs decrease between 1.5 per cent and 24 per cent. To limit the increase of total feed-in-payments an amendment referring to PV facilites ('PV-Novelle') was agreed on end of June 2012, but effective 1 April 2012. Main components: overall target of 52 Gigawatt of PV power, an extra decrease of tariffs by 1% monthly, the introduction of a new category for roof-top facilities and the limitation of the total power of a facility to 10 Megawatt.	47
FRA					
PRT	2014	F3	FIT	Feed-in tariffs for micro and mini generation for 2013 (Portarias 430/2012 and 431 /2012): On 31st December 2012 Feed-in tariff rates for micro and mini renewable electricity generators were announced. In comparison to rates from 2012, 2013 rates are lowered by 30%. Further reductions occured for 2014 through Feed-in tariffs for micro and mini generation for 2014.	44
THA	2016	F3	RPS	The Alternative Energy Development Plan (AEDP 2015-2036) increases targets for installed alternative energy to 19.635 MW in 2036.	48

Sources for incentives:

1. http://www.tai.org.au/sites/defualt/files/PB%2021%20SHCP%20final_4.pdf
2. IEA PVPS & Australian PV Association (2011) National Survey Report Australia 2010
3. https://www.e-control.at/de/recht/bundesrecht/oekostrom-energieeffizienz/verordnungen#p_p_id_56_INSTANCE_10305A20243_
4. http://www.agentschapondernemen.be/maatregel/ecologiepremie-ep-plus
5. https://www.vlaanderen.be/nl/publicaties/detail/the-flemish-climate-policy-plan-2006-2012-the-climate-is-changing-are-you-changing-too

6. http://www.ieso.ca/en/sector-participants/feed-in-tariff-program/fit-archive
7. https://www.admin.ch/opc/it/classified-compilation/19983485/index.html
8. National Survey Report of PV Power Applications in China - 2011
9. https://en.wikipedia.org/wiki/Huanghe_Hydropower_Golmud_Solar_Park
10. http://www.erneuerbare-energien.de/EE/Navigation/DE/Recht-Politik/Das_EEG/das_eeg.html;jsessionid=75CEA3F43B6C393EA2AF774CF549AD56
11. https://www.retsinformation.dk/Forms/R0710.aspx?id=158132
12. http://www.kebmin.dk/sites/kebmin.dk/files/news/from-coal-oil-and-gas-to-green-energy/Energy%20Strategy%202050%20web.pdf
13. http://www.boe.es/buscar/pdf/2007/BOE-A-2007-10556-consolidado.pdf
14. http://www.emvi.fi/files/Feed_in_tariff_summary_6_2013.pdf
15. IEA PVPS & André Claverie, Bernard Equer, National Survey Report France - 2006
16. http://www.developpement-durable.gouv.fr/Quels-sont-les-tarifs-d-achats.html
17. https://www.gov.uk/government/collections/feed-in-tariff-statistics
18. http://wgbis.ces.iisc.ernet.in/biodiversity/sahyadri_enews/newsletter/issue45/bibliography/Solar%20energy%20in%20india%20strategies%20policies%20perspectives.pdf
19. http://www.wind-works.org/FeedLaws/Israel/renewable%20tariffs%20Israel%202009.pdf
20. https://www.gse.it/servizi-per-te/fotovoltaico/conto-energia
21. http://www.nef.or.jp/english/index.html
22. http://www.kemco.or.kr/new_eng/pg02/pg02040602.asp
23. http://www.diputados.gob.mx/LeyesBiblio/ref/lgcc.htm
24. http://seda.gov.my/go-home.php?omaneg=00010100000001010101000100001000000000000000000000&s=146
25. http://www.agentschapnl.nl/sites/default/files/bijlagen/Maak%20kennis%20met%20de%20SDE%202012.pdf
26. http://www.regjeringen.no/en/dep/oed/Subject/energy-in-norway/electricity-certificates.html?id=517462,
27. http://www.min-economia.pt/innerPage.aspx?idCat=51&idMasterCat=13&idLang=2
28. http://ec.europa.eu/energy/renewables/action_plan_en.htm
29. http://www.egat.co.th/en
30. http://www.invest.gov.tr/en-US/infocenter/news/Pages/301210-turkish-renewable-energy-law-approved.aspx
31. IEA PVPS & National Renewable Energy Laborato, National Survey Report United States of America, 2009
32. https://www.energy.vic.gov.au/renewable-energy/victorian-feed-in-tariff

33. http://www.klimafonds.gv.at/foerderungen/aktuelle-foerderungen/2013/photovoltaik-foerderaktion/
34. http://en.ndrc.gov.cn/
35. https://wirsol.com/en/wirsol-opens-largest-solar-park-in-scandinavia/
36. http://www.boe.es/boe/dias/2010/12/24/pdfs/BOE-A-2010-19757.pdf
37. http://julkaisut.valtioneuvosto.fi/handle/10024/79247
38. National Survey Report France - 2009
39. https://www.ofgem.gov.uk/publications-and-updates/renewables-obligation-ro-buy-out-price-and-mutualisation-ceilings-2018-19-ro-year
40. http://www.sciencedirect.com/science/article/pii/S2468025716300231
41. https://pua.gov.il/English/Documents/The%20Israeli%20Net%20Metering%20Scheme%20%20lessons%20learned.pdf
42. http://www.meti.go.jp/english/press/2016/0318_03.html
43. http://www.gob.mx/cenace
44. http://www.renovaveisnahora.pt/c/document_library/get_file?uuid=7c5b754a-90b2-433d-b519-a16974575d9c&groupId=13360
45. **IEA PVPS** D. Boff, D. Feldman, L. Tinker , National Survey Report of PV Power Applications in USA - 2016
46. National Survey Report of PV Power Applications in Belgium - 2013
47. https://www.iea.org/policiesandmeasures/pams/germany/name-25107-en.php?s=dHlwZT1yZSZzdGF0dXM9T2s,&return=PG5hdiBpZD0iYnJlYWRjcnVtYiI-PGEgaHJlZj0iLyI-SG9tZTwvYT4gJnJhcXVvOyA8YSBocmVmPSIvcG9saWNpZXNhbmRtZWFzdXJlcy8iPlBvbGljaWVzIGFuZCBNZWFzdXJlczwvYT4gJnJhcXVvOyA8YSBocmVmPSIvcG9saWNpZXNhbmRtZWFzdXJlcy9yZW5ld2FibGVlbmVyZ3kvIj5SZW5ld2FibGUgRW5lcmd5PC9hPjwvbmF2Pg,,
48. http://www.eppo.go.th/PDP_hearing/PDP2015_PH_RealPresentation.pdf

R – Code for the nonlinear estimation

Gauss-Newton algorithm

In order to find the optimal value for the parameters of the general Bass model we used the nls function within the R-project program which uses the Gauss-Newton algorithm as default.

The Gauss-Newton algorithm is an interactive computational method often used. The algorithm is based on approximations of the first order function *f*$(\boldsymbol{t},\boldsymbol{\theta})$ in Taylor series which lead to $\boldsymbol{\theta}_1, \boldsymbol{\theta}_2, \ldots \boldsymbol{\theta}_m$ estimates gradually closer to $\hat{\boldsymbol{\theta}}$ in regular cases (Draper and Smith, 1998).

Near the value of the real parametric vector $\boldsymbol{\theta^*}$ the following expression is true:

$$f(t_i, \boldsymbol{\theta}) \approx f(t_i, \boldsymbol{\theta}^*) + \sum_{j=1}^{p} \left[\frac{\partial f(\boldsymbol{t_i},\boldsymbol{\theta})}{\partial \theta_j}\right]_{\boldsymbol{\theta}=\boldsymbol{\theta_0}} (\theta_j - \theta_j{}^*) \qquad (A2.1)$$

The same equation can be written in vectoral form with initial value $\boldsymbol{\theta}_0$:

$$\boldsymbol{r}(\boldsymbol{\theta}) = \boldsymbol{Y} - \boldsymbol{f}(\boldsymbol{\theta}) \approx \boldsymbol{r}(\boldsymbol{\theta_0}) - \boldsymbol{F}.(\boldsymbol{\theta_0})(\boldsymbol{\theta} - \boldsymbol{\theta_0}) \qquad (A2.2)$$

for the approximation of the Jacobean $\mathbf{F.} = \mathbf{F.}(\boldsymbol{\theta}) = \left[\frac{\partial \mathbf{f}(\mathbf{t_i},\boldsymbol{\theta})}{\partial \boldsymbol{\theta}_j}\right]_{\boldsymbol{\theta}=\boldsymbol{\theta}_0}$ which plays a similar role as the X matrix in the linear least-square models.

Generally, the error sum of squares is described by the formula:

$$SS(\boldsymbol{\theta}) = \|Y - f(\boldsymbol{\theta})\|^2 \approx \|\boldsymbol{r}(\boldsymbol{\theta}^*) - \boldsymbol{F}.(\boldsymbol{\theta}^*)\boldsymbol{\beta}\|^2 \qquad (A2.3)$$

where $\boldsymbol{\beta} = \boldsymbol{\theta} - \boldsymbol{\theta}^*$.

Considering the initial value, it follows the equation:

$$SS(\boldsymbol{\theta}) = (\boldsymbol{\theta} - \boldsymbol{\theta_0})'\boldsymbol{F}.'(\boldsymbol{\theta_0})\boldsymbol{F}.(\boldsymbol{\theta_0})(\boldsymbol{\theta} - \boldsymbol{\theta_0}) - 2\boldsymbol{r}'(\boldsymbol{\theta_0})\boldsymbol{F}.(\boldsymbol{\theta_0})(\boldsymbol{\theta} - \boldsymbol{\theta_0}) + \boldsymbol{r}'(\boldsymbol{\theta_0})\boldsymbol{r}(\boldsymbol{\theta_0}) \qquad (A2.4)$$

Minimising the error sum of squares by equalling the Jacobean with respect θ to zero, a better solution is obtained[13]. The general process follows:

$$\boldsymbol{b} = \boldsymbol{\theta_{m+1}} - \boldsymbol{\theta_m} = \left(\boldsymbol{F.}'(\boldsymbol{\theta_m})\boldsymbol{F.}(\boldsymbol{\theta_m})\right)^{-1}\boldsymbol{F.}'(\boldsymbol{\theta_m})\boldsymbol{r}(\boldsymbol{\theta_m}) \qquad (A2.5)$$

where *m+1* is the maximum number of repetitions needed to stop the algorithm.

Example for Switzerland

```
plot(X$t,X$Switzerland)

####### 1.1 Generalized Bass Model #############

V=Z[1,1]  #adoptions at time 0 = also with X$Switzerland[1]

m=Z[2,1]  #minimum target

a=Z[3,1]   #shock starting point

Y_GBMCHE<-c()

t=c(0:24)

Y_GBMCHE<-YGIM(q=0.1547,c=0.907,a=17.42,A=12.5)

plot(X$Year,X$Switzerland)

plotfit(GBMCHE)

#Applying the values obtained with the Excel Optimization Procedure

preview(formula=Switzerland~ifelse(test= t<17, yes=V*m/(V+(m-V)*exp(-q*t)),
```

[13] F. is the n-dimensional normalized vector of the partial derivatives of the function $f(t,\theta_P)$ with respect to θ_P parameters.

```
                    no=    V*m/(V+(m-V)*exp(-q*(t+A/c*(1/c*(1-exp(-c*(t-a)))-(t-a)*exp(-c*(t-a))))))),

    start=c(q=0.15,c=0.907,a=17.4,A=12.5), data=X)

preview(formula=Switzerland~ifelse(test=   t<17,   yes=4.18*5350/(4.18+(5350-4.18)*exp(-q*t)),

                    no=  4.18*5350/(4.18+(5350-4.18)*exp(-q*(t+A/c*(1/c*(1-exp(-c*(t-a)))-(t-a)*exp(-c*(t-a))))))),

    start=c(q=0.15,c=0.907,a=17.4,A=12.5), data=X)



#Nonlinear optimization function

GIBMCHE=nls(formula=Switzerland~ifelse(test= t<17.4,
yes=X$Switzerland[1]*m/(X$Switzerland[1]+(m-X$Switzerland[1])*exp(-q*t)),

                    no= X$Switzerland[1]*m/(X$Switzerland[1]+(m-X$Switzerland[1])*exp(-q*(t+A/c*(1/c*(1-exp(-c*(t-a)))-(t-a)*exp(-c*(t-a))))))),

     start=c(q=0.1547,c=0.907,a=17.42,A=12.5), data=X)


GBMCHE=nls(formula=Switzerland~ifelse(test= t<17.4,
yes=4.18*5350/(4.18+(5350-4.18)*exp(-q*t)),

                    no= 4.18*5350/(4.18+(5350-4.18)*exp(-q*(t+A/c*(1/c*(1-exp(-c*(t-a)))-(t-a)*exp(-c*(t-a))))))),

     start=c(q=0.1547,c=0.907,a=17.42,A=12.5), data=X)

#parameter registration

parGBMCHE<-summary(GIMCHE)

#plotting the estimated curve

plotfit(GBMCHE, smooth=TRUE)
```

Creating the GBM cumulative estimates

```
t<-c(0:24)

Y_GBMCHE<-c()

Y_GBMCHE<-YGBM(q=summary(GBMCHE)$parameters[1,1],
c=summary(GBMCHE)$parameters[2,1],
a=summary(GBMCHE)$parameters[3,1],
A=summary(GBMCHE)$parameters[4,1])
```

Creating the annual fitting

```
S_GBMCHE<-c(0:0)

for (t in 1:25)

 {S_GBMCHE[t-1]=Y_GBMCHE[t]-Y_GBMCHE[t-1]

  t=t+1

}

#I have to add the 0 at the beginning of the period, or "NA" value

S_GBMCHE<-append(S_GBMCHE, 0,after=0)

plot(X$AnnSwitzerland)

lines(S_GBMCHE, col="green", lwd=2)
```

######## **1.2 Classic Bass model** #########

```
#Searching for initial values
```

```
preview(formula=Switzerland~m*(1-exp(-(alfa+q)*t))/(1+q/alfa*exp(-(alfa+q)*t)), start=c(alfa=0.00008,q=0.34,m=3000), data=X)

#Applying NLS estimation with the initial values found at the previous step

BSCHE=nls(formula=Switzerland~m*(1-exp(-(alfa+q)*t))/(1+q/alfa*exp(-(alfa+q)*t)), start=c(alfa=0.00008,q=0.34,m=2500), data=X)

#Estimation curve vs. true values

plotfit(BSCHE, smooth=TRUE)

parBSCHE<-summary(BSCHE)


###Creating the estimated values for each period

t<-c(0:24)

Y_BSCHE<-c()

Y_BSCHE<-
YBass(alfa=parBSCHE$parameters[1,1],q=parBSCHE$parameter[2,1],m=parBSCHE$parameter[3,1])


###Estimated annual installed capacity

S_BSCHE<-c(0:0)

for (t in 1:25)

{S_BSCHE[t-1]=Y_BSCHE[t]-Y_BSCHE[t-1]

t=t+1

}

##I have to add the 0 at the beginning of the period, or "NA" value

S_BSCHE<-append(S_BSCHE, 0,after=0)

plot(X$AnnSwitzerland)
```

```
lines(S_BSCHE, col="blue")


###Estimated growth rate
GR_BSCHE<-c()
for (t in 1:25)
{GR_BSCHE[t-1]=((Y_BSCHE[t]-Y_BSCHE[t-1])/Y_BSCHE[t-1])
t=t+1
}
GR_BSCHE<-append(GR_BSCHE, NA,after=0)
GR_BSCHE[2]<-NA
plot(X$GRSwitzerland, ylim=range(0:2.1))
lines(GR_BSCHE, col="red", lwd=2)
##I have to add the 0 at the beginning of the period, or "NA" value


########## 1.3 Residuals Bass ###########
### Computing residuals for Bass cumulative installed capacity
RES_Y_BSCHE<-Y_BSCHE-X$Switzerland
plot(RES_Y_BSCHE, main="Residuals Bass Cumulative")
abline(h=0)
###Computing the residuals for the annual installed capacity
RES_S_BSCHE<-S_BSCHE-X$AnnSwitzerland
plot(RES_S_BSCHE,main="Residuals Bass Annual")
abline(h=0)
###Computing the residuals for the growth rate
```

RES_GR_BSCHE<-GR_BSCHE-X$GRSwitzerland

plot(RES_GR_BSCHE, main="Residuals Bass Growth Rate")

abline(h=0)

########## **1.4 Forecast t=50** ############

#Forecasting until t=50

t<-c(0:50)

Y_GBMCHE<-YGBM(alfa=summary(GBMCHE)$parameters[1,1],
q=summary(GBMCHE)$parameters[2,1],
m=summary(GBMCHE)$parameters[3,1],
c=summary(GBMCHE)$parameters[4,1],
a=summary(GBMCHE)$parameters[5,1],
A=summary(GBMCHE)$parameters[6,1],
V=summary(GBMCHE)$parameters[7,1])

Y_BSCHE<-
YBass(alfa=parBSCHE$parameters[1,1],q=parBSCHE$parameter[2,1],m=parBS
CHE$parameter[3,1])

#Plotting GBM and BS with the true values

plot(X$Switzerland, xlim=range(1:50), ylim=range(1:3500), main="Forecast PV in Switzerland", ylab="Cumulative PV installed capacity (MW)", xlab="t(0) = t(1985)")

lines(Y_GBMCHE, col="purple", lwd=2)

lines(Y_BSCHE, col="orange",type="l",lwd=2)

legend(x=2,y=3000,legend=c("GBM" , "BS"), col=c("purple","orange"), lwd=2)

```
############ 1.5 GIM #############

V=Z[1,1]

m=Z[2,1]

a=Z[3,1]

# Applying the initial values found with Excel procedure

preview(formula=Switzerland~ifelse(test= t<a, yes=V*m/(V+(m-V)*exp(-q*t)),
                         no=    V*m/(V+(m-V)*exp(-q*(t+A/c*(1/c*(1-exp(-c*(t-a)))-(t-
a)*exp(-c*(t-a))))))),
      start=c(q=0.19,c=0.907,a=17.4,A=12.5), data=X)

# Nonlinear estimation

GIMCHE=nls(formula=Switzerland~ifelse(test= t<a, yes=V*m/(V+(m-V)*exp(-
q*t)),
                          no= V*m/(V+(m-V)*exp(-q*(t+A/c*(1/c*(1-exp(-c*(t-a)))-(t-
a)*exp(-c*(t-a))))))),
        start=c(q=0.19,c=0.907,a=17.4,A=12.5), data=X)


parGIMCHE<-summary(GIMCHE)

plotfit(GIMCHE, smooth=TRUE)


### Creating the GIM cumulative estimates

t<-c(0:24)

Y_GIMCHE<-c()

Y_GIMCHE<-YGIM(V=4.18,m=2000,q=summary(GIMCHE)$parameters[1,1],
c=summary(GIMCHE)$parameters[2,1],
```

```
a=summary(GIMCHE)$parameters[3,1],
A=summary(GIMCHE)$parameters[4,1])


plot(X$Switzerland,axes=FALSE,main="Cumulative SPP in Switzerland",xlab="Year", ylab="MW", mgp=c(2,2,1), font.lab=2)

lines(Y_GIMCHE, col="red")

axis(side=1,at=c(5,10,15,20,25),labels=c("1996","2001","2006","2011","2016"))

axis(side=2,at=c(0,500,1000,1500),labels=c("0","500","1000","1500"))

box()


### Creating the annual fitting

S_GIMCHE<-c(0:0)

for (t in 1:25)

{S_GIMCHE[t-1]=Y_GIMCHE[t]-Y_GIMCHE[t-1]

t=t+1

}

#I have to add the 0 at the beginning of the period, or "NA" value

S_GIMCHE<-append(S_GIMCHE, 0,after=0)


plot(X$AnnSwitzerland, axes=F, main="Annual SPP in Switzerland",xlab="Year", ylab="MW", mgp=c(2,2,1), font.lab=2)

lines(S_GIMCHE, col="green")

axis(side=1,at=c(5,10,15,20,25),labels=c("1996","2001","2006","2011","2016"))

axis(side=2,at=c(0,50,100,200,300),labels=c("0","50","100","200","300"))

box()
```

R- Code for the confidence interval

```
# Assigning the initial values

ftCHE=vector(length=25)

q_ott=as.numeric(CI[1,1])

c1_ott=as.numeric(CI[2,1])

a1_ott=as.numeric(CI[3,1])

A1_ott=as.numeric(CI[4,1])

m = as.numeric(CI[5,1])

V = as.numeric(CI[6,1])

t=c(1:25)


# Cumulative values computation for the cumulative adoption curve with the nls values


for (i in 1:25) {ftCHE[i] <-

  ifelse(test= i<a1_ott, yes=V*m/(V+(m-V)*exp(-q_ott*i)),

        no=  V*m/(V+(m-V)*exp(-q_ott*(i+A1_ott/c1_ott*(1/c1_ott*(1-exp(-c1_ott*(i-a1_ott)))-(i-a1_ott)*exp(-c1_ott*(i-a1_ott)))))))

}


# Computation of the partial derivatives

i=c(1:25)
```

```
dY_dq<-function (q,c1,a1,A1) ifelse(test= i<a1, yes= (m*i*(m-V)*V*exp(-q*i))/(((m-V)*exp(-q*i)+V)^2),
                    no= - (V*m*(m-V)*(-i-A1/c1*((1-exp(-c1*(i-a1)))/c1-(i-a1)*exp(-c1*(i-a1))))*exp(-q*(i+A1/c1*(1/c1*(1-exp(-c1*(i-a1)))-(i-a1)*exp(-c1*(i-a1))))))/((V+(m-V)*exp(-q*(i+A1/c1*(1/c1*(1-exp(-c1*(i-a1)))-(i-a1)*exp(-c1*(i-a1))))))^2) )


dY_dc1<-function (q,c1,a1,A1) ifelse(test= i<a1, yes= 0,
                    no= (V*m*(m-V)*q*exp(-q*(i+A1/c1*(1/c1*(1-exp(-c1*(i-a1)))-(i-a1)*exp(-c1*(i-a1)))))*(A1/c1*(-1/c1*(a1-i)*exp(-c1*(i-a1))-(a1-i)*(i-a1)*exp(-c1*(i-a1)) - 1/(c1^2)*(1-exp(-c1*(i-a1)))) - A1/(c1^2)*(1/c1*(1-exp(-c1*(i-a1))) - (i-a1)*exp(-c1*(i-a1)))))/((V+(m-V)*exp(-q*(i+A1/c1*(1/c1*(1-exp(-c1*(i-a1)))-(i-a1)*exp(-c1*(i-a1))))))^2) )

dY_da1<-function (q,c1,a1,A1) ifelse(test= i<a1, yes=0,
                    no=(-V*m*(m-V)*A1*q*(i-a1)*exp(-q*(i+A1/c1*(1/c1*(1-exp(-c1*(i-a1)))-(i-a1)*exp(-c1*(i-a1)))))*(-c1*(i-a1))))/((V+(m-V)*exp(-q*(i+A1/c1*(1/c1*(1-exp(-c1*(i-a1)))-(i-a1)*exp(-c1*(i-a1))))))^2) )


dY_dA1<-function (q,c1,a1,A1) ifelse(test= i<a1, yes=0,
                    no=(V*m*(m-V)*q*exp(-q*(i+A1/c1*(1/c1*(1-exp(-c1*(i-a1)))-(i-a1)*exp(-c1*(i-a1)))))*(1/c1*(1-exp(-c1*(i-a1))) - (i-a1)*exp(-c1*(i-a1))))/((V+(m-V)*exp(-q*(i+A1/c1*(1/c1*(1-exp(-c1*(i-a1)))-(i-a1)*exp(-c1*(i-a1))))))^2) )


# Creation of the Jacobean matrix

jacob<-matrix(nrow=4,ncol=length(i))

provaq<-dY_dq(q=q_ott, c1=c1_ott, a1=a1_ott, A1=A1_ott)

provac1<-dY_dc1(q=q_ott, c1=c1_ott, a1=a1_ott, A1=A1_ott)

provaa1<-dY_da1(q=q_ott, c1=c1_ott, a1=a1_ott, A1=A1_ott)
```

```
provaA1<-dY_dA1(q=q_ott, c1=c1_ott, a1=a1_ott, A1=A1_ott)

jacob<-cbind(provaq,provac1,provaa1,provaA1)


# Estimation and Taylor expansion

CHE<-as.vector(X$CHE[1:25])

z=CHE - ftCHE

stima_beta = solve ( t(jacob) %*% jacob, tol=3.031e-38 ) %*% t(jacob) %*% z

teta_ott_CHE <- matrix(c(q_ott,c1_ott,a1_ott,A1_ott),nrow=4,ncol=1)

teta_Taylor_CHE = stima_beta + teta_ott_CHE

f_Taylor_CHE = ftCHE + sum (jacob %*% stima_beta)


# Estimation of the Jacobean matrix

stima_jacob=cbind(dY_dq(q=teta_Taylor_CHE[1,1],c1=teta_Taylor_CHE[2,1],a1
=teta_Taylor_CHE[3,1],A1=teta_Taylor_CHE[4,1]),dY_dc1(q=teta_Taylor_CHE[
1,1],c1=teta_Taylor_CHE[2,1],a1=teta_Taylor_CHE[3,1],A1=teta_Taylor_CHE[4,
1]),


dY_da1(q=teta_Taylor_CHE[1,1],c1=teta_Taylor_CHE[2,1],a1=teta_Taylor_CHE
[3,1],A1=teta_Taylor_CHE[4,1]),dY_dA1(q=teta_Taylor_CHE[1,1],c1=teta_Taylo
r_CHE[2,1],a1=teta_Taylor_CHE[3,1],A1=teta_Taylor_CHE[4,1]) )

# Computation of variance/covariance matrix and of the idempotent matrix PF

C = t(stima_jacob) %*% stima_jacob

PF = stima_jacob %*% solve( t(stima_jacob) %*% stima_jacob, tol=7.7e-28) %*%
t(stima_jacob)

# Creation of the identity matrix

I25 <- diag( rep(1,times=25) )
```

```
# Estimation of the standard error

s.2 <- (t(z) %*% (I25 - PF) %*% z) / ( length(i) - 4)

C.inv = solve(C, tol=7.7e-28)

ss.2 = as.vector (s.2)

cov.mat = ss.2 * C.inv

diagonal = diag(cov.mat)

sigma.est = sqrt(diagonal)


# Computation of the confidence intervals for the parameters q, c1, a1 e A1 for
95% confidence level.

q_i95_CHE=teta_ott_CHE[1,1]-1.96*sigma.est[1]
q_s95_CHE=teta_ott_CHE[1,1]+1.96*sigma.est[1]
c1_i95_CHE=teta_ott_CHE[2,1]-1.96*sigma.est[2]
c1_s95_CHE=teta_ott_CHE[2,1]+1.96*sigma.est[2]
a1_i95_CHE=teta_ott_CHE[3,1]-1.96*sigma.est[3]
a1_s95_CHE=teta_ott_CHE[3,1]+1.96*sigma.est[3]
A1_i95_CHE=teta_ott_CHE[4,1]-1.96*sigma.est[4]
A1_s95_CHE=teta_ott_CHE[4,1]+1.96*sigma.est[4]
```

Confidence Interval results for the best fit model

The computation of the confidence intervals reveals for the countries with one shock and adequate number observations the model performs well and the confidence interval limits at 95% confidence level for the parameters are relatively close the estimated values. From this point of view, we highlight Switzerland, Sweden and Turkey. Since for Malaysia there were available only 11 observations, the parameters' estimation is not significant.

For the countries with more shocks the confidence interval computation show different results. Denmark (F3+F3) and Mexico (F2+F2) are some examples for which all the estimated parameters are significant in a model with two shocks. In other cases, such as Australia, the imitation and the persistence coefficients are significant whereas the intensity is not.

The shocks at the end of the observed periods were eliminated for the reasons already mentioned while stating the hypothesis for the choice of the shock to be inserted in the persistence versus intensity graphic: despite the clear evidence of a shock at the end of the observed period the model cannot correctly estimate the shock based on two or three observations. For this reason, we eliminated the last observations and computed the confidence intervals for the first two shocks. Here we highlight the case of USA where after the elimination of the second shock the estimation of the parameters is significant.

The results also highlight the difficulty to estimate especially the intensity parameter for the last shock in the case of models with more than one shock. Whereas for models with three shocks the difficulty is extended also to the other parameters.

				First shock				Second shock			
	Model	**q_i**	**q_s**	**c1_i**	**c1_s**	**A1 or b1_i**	**A1 or b1_s**	**c2_i**	**c2_s**	**A2_i**	**A2_s**
AUS	F3+F3	0,0812	0,2469	0,9641	0,9710	-31,5919	67,5670	0,6354	1,2958	-20,0610	24,9
AUT	F3+F3	0,2466	0,2759	-3,6111	4,8674	-5,4623	9,8355	10,4493	10,4513	-1,78E+13	1,78E+13
BEL	F1+F3+F3	0,3209	0,6191	0,6729	5,1071			2,5318	5,9082	-10,5392	53,3
CAN	F2+F3	0,1553	0,2210	0,4410	0,5456	-5,6646	25,1479				
CHE	F3	0,1394	0,1656	0,4225	0,5409	2,0158	8,9176				
CHN	F3+F3	-0,1246081	0,6917421	0,6991846	0,7960167	-99,50536	114,68	-0,2950996	1,108596	-37,93892	44,28074
DEU	F2+F2+F3	0,1641	0,6359	2,9158	3,4842	3,7821	12,6179	-1,5232	2,1232	-4,8529	6,8
DNK	F3+F3	0,0677017	0,0942078	2,980188	3,028495	839,8409	840,7354	3,234907	3,412977	47,82624	57,63318
ESP	F3+F3	-0,1224	0,4426	7,9170	8,06	1597,3	2647,03	-2,9724	5,0535	-1325,3	1339,4
FIN	F1+F3	-0,6805128	0,9399651	-44,8297	42,8297			-448,1094	458,6052	-18629,68	19132,59
FRA	F3+F3+F3	0,0572	0,2568	0,3052	1,3904	1,5642	26,80366	-14,5629	18,9287	-620,5180	731,2
GBR	F3+F3	0,1	0,5	1,7	1,8	-398,2	464,3	-0,8685	5,7264	-1071,65	1118,018
IND	F3+F3	-0,7456693	1,248579	-11,39559	13,89637	-80,13926	135,3143	-50,8005	52,57684	-5039,678	5047,471
ISR	F2+F2	-0,5676	0,8337	-3,5553	5,6764	-1585,9750	1670,8990	0,6259	0,6259	-62,2602	73,1275
ITA	F3+F2	-0,0072	0,3892	-0,5149	1,0445	-137,1393	140,2901				
JAP	F1+F3	-0,5746103	1,030916	-8,945491	11,03066			-41,95742	42,78644	-119,9961	126,3587
KOR	F3+F3	-0,2916384	0,6026775	1,414871	1,59848	-354,441	451,7089	-3,450505	5,008559	-63,7972	74,26057
MEX	F2+F2	0,0897	0,1010	0,1547	0,5976	3,0311	12,5452				
MYS	F3	-0,3448	0,9550	-174,7655	180,6805	-6732,7570	6818,7310				
NLD	F3+F3	0,2807384	0,3855867	0,3676089	0,4869809	-2,046659	-0,3048216	0,4231204	1,376425	-23,0267	32,675
NOR	F3+F3	0,04818478	0,0514478	-6733,741	6736,311	-14934,34	14958,92	-401786	401786	-280220826	280220864
PRT	F2+F3+F3	-1,8351	2,3351	-5,3971	8,3571	-50,3885	80,4885	-105,5440	128,3840	-1052,2243	1360,1243
SWE	F3	0,1414	0,1495	0,3015	0,4883	1,7165	5,1632				
THA	F3+F3+F3	-10,5693	10,7893	1,3290	2,8310	-306,2994	632,3594	-12,7731	21,0931	-442,5000	805,7200
TUR	F3	0,2869	0,2959	0,6828	0,7577	7,6981	9,9417				
USA	F3+F2	0,1853	0,1917	0,1662	0,3634	0,1044	3,0464				

Table A2- 9 Confidence interval computation of the estimated parameters for 95% confidence level.

Appendix A3 – Chapter 3

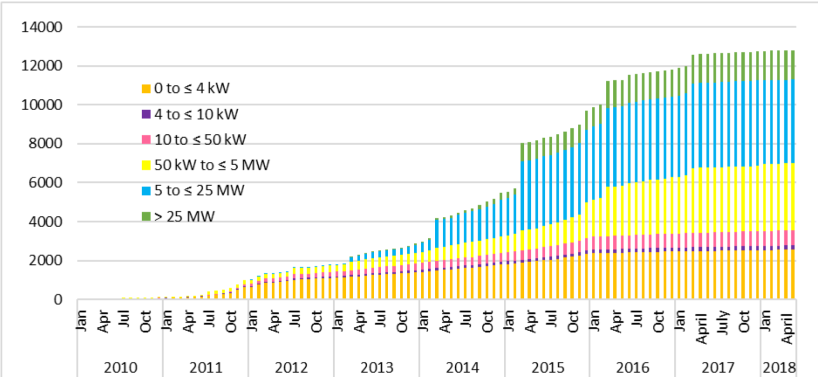


Figure A3. 1 Monthly cumulative installed capacity in MW by capacity range from January 2010 to May 2018. Data from UK Government Statistics

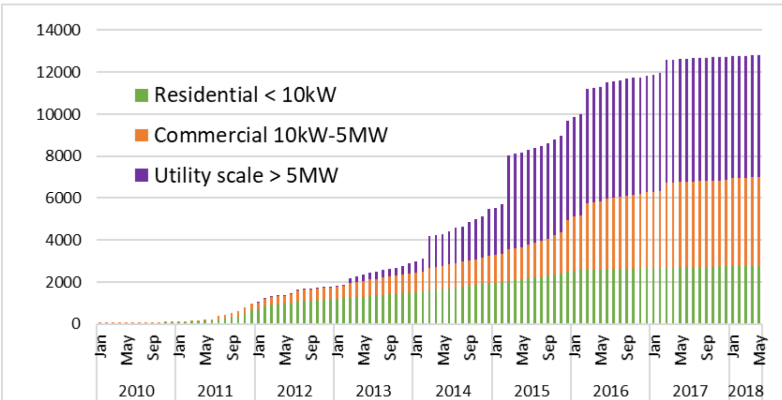


Figure A3. 2 Monthly cumulative installed capacity in MW by the three main sectors: residential (green), commercial (orange) and utility (purple) from January 2010 to May 2018. Data from [1]

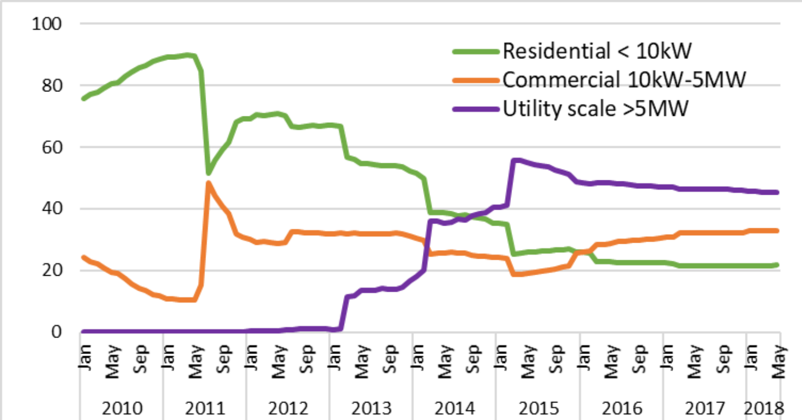


Figure A3. 4 Share in total cumulative installed capacity by sector: residential (green), commercial (orange) and utility (purple) from Januaru 2010 to May 2018. Own calculation based on data from [1]

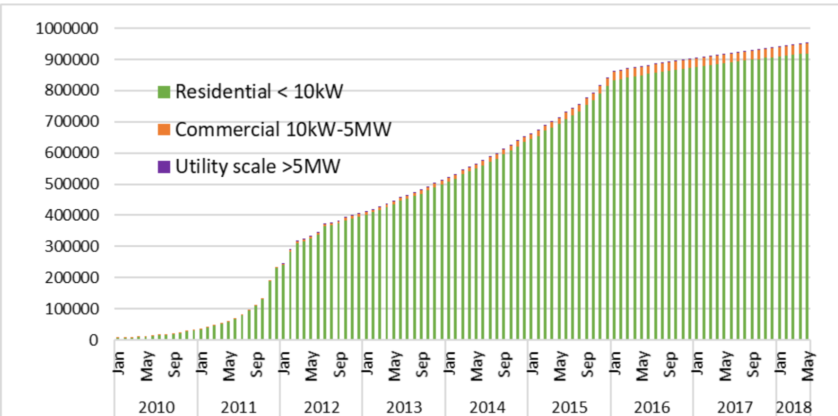


Figure A3. 3 Monthly cumulative number of installations by the three main sectors: residential (green), commercial (orange) and utility (purple), from January 2010 to May 2018. Data from [1]

Obligation period (from April to March)	Supply (%)	Buy Out Price (£/MWh)	Effective Price per Unit (p/kWh)	Supply growth rate (p.p.)
2002-2003	3	£30.00	0.09	
2003-2004	4.3	£30.51	0.13	1.3
2004-2005	4.9	£31.39	0.15	0.6
2005-2006	5.5	£32.33	0.18	0.6
2006-2007	6.7	£33.24	0.22	1.2
2007-2008	7.9	£34.30	0.29	1.2
2008-2009	9.1	£35.76	0.33	1.2
2009-2010	9.7	£37.19	0.36	0.6
2010-2011	11.1	£36.99	0.41	1.4
2011-2012	12.4	£38.69	0.48	1.3
2012-2013	15.8	£40.71	0.64	3.4
2013-2014	20.6	£42.02	0.87	4.8
2014-2015	24.4	£43.30	1.06	3.8
2015-2016	29	£44.33	1.29	4.6
2016-2017	34.8	£44.77	1.56	5.8
2017-2018	40.9	£45.58	1.86	6.1
2018-2019	46.8	£47.22	-	5.9

Table A3- 1 ROC shares and buy-out prices over the years (2002 – 2019). Data source: Ofgem

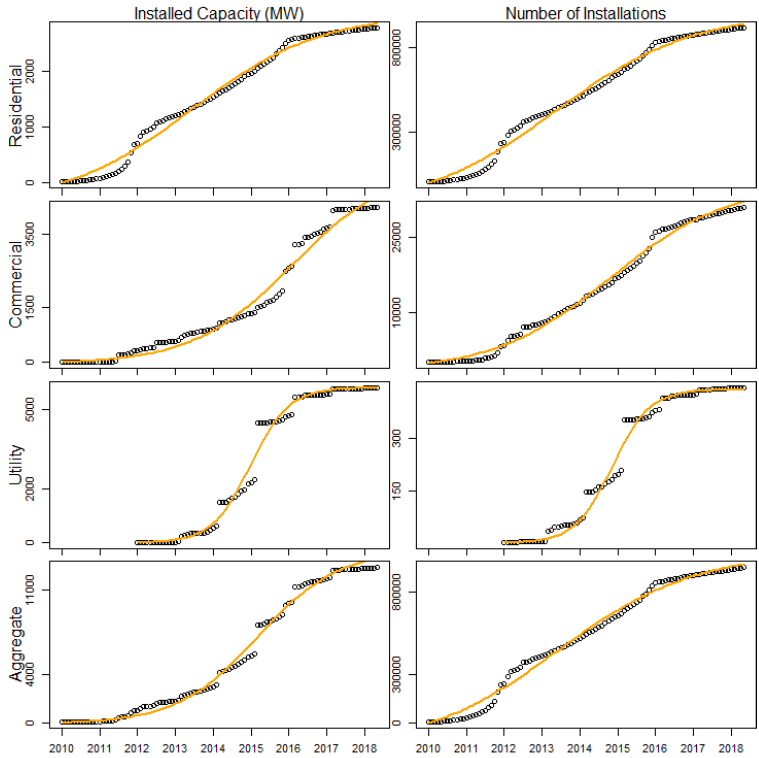


Figure A3. 5 Cumulative curves for installed capacity and number of installations by sector estimated with the "classical" Bass model

	Sector	α	q	m
Installed capacity	Residential	0.0057	0.04	3026
	Commercial	0.0006	0.06	5352
	Utility	0.0005	0.16	5817
	Aggregated	0.0006	0.08	14281
Number of installations	Residential	0.0062	0.04	1008820
	Commercial	0.0023	0.05	35385
	Utility	0.0005	0.17	443
	Aggregated	0.0061	0.04	1046952

Table A3- 2 Classical Bass model estimates (α,q,m) by sector for installed capacity and number of installations

	Installed capacity				Number of installations			
	Residential	Commercial	Utility	Aggregated	Residential	Commercial	Utility	Aggregated
Bass	0.996497979	0.991392465	0.995110261	0.996680946	0.996596149	0.997180085	0.995166035	0.996634996
1-shock	0.99728772	0.99363905	0.998438	0.9974887	0.99739	0.99886927	0.997186	0.99862814
2-shock	0.99819174	0.9986576	0.999305	0.9996593	0.998809	0.99943211	0.999099	0.9985223
3-shock	0.99995476	0.99978647	0.999402	0.99993	0.999957	0.9998421	0.9995	0.99995071
4-shock		0.9998487	0.999761	0.9999428		0.9998435	0.999904	
5-shock		0.99987272	0.999835	0.9999452		0.99984564	0.999905	
6-shock		0.99987809		0.9999459		0.99984562		
7-shock		0.99988762		0.9999459		0.99985503		
8-shock		0.99989613		0.9999464				
9-shock		0.99989628		0.999948				
10-shock		0.99989635		0.999948				
11-shock				0.9999481				
12-shock				0.999955				

Table A3- 3 R^2 values for Bass, intermediate and best fit models for each sector for installed capacity and number of installations

Table A3- 4 Confidence Intervals for the best models for the Residential, Commercial, Utility sectors and Aggregated levels

		q_inf	*q_sup*	*c1_inf*	*c1_sup*	*c2_inf*	*c2_sup*	*A2_inf*	*A2_sup*	*c3_inf*	*c3_sup*	*c4_inf*	*c4_sup*	*m_inf*	*m_sup*
Capacity	*Residential*	-0.2787	0.28484	49.8584	49.85843	0.41746	0.50593	111.1497	178.793	-1.943311	14.33474			25091.88	25091.88
	Commercial	0.032344	0.03673	3.02337	3.375809	26.6061	35.52814	X	X	1.716256	5.071872	2.099493	32.57361	3811.352	5067.352
	Utility	-0.32319	0.4119	54.6168	127.762	-161.487	228.6306	X	X	-108816.6	108971.8	-2.64E+12	2.64E+12	5440.25	6137.32
	Aggregated	0.041905	0.04469	1.53216	1.798379	12.1393	18.07084	X	X	3.734816	6.800215			11531.86	14748.71
Number of instalaltions	*Residential*	0.002622	0.0041	42.1965	42.19646	0.44606	0.455401	114.0882	114.0979	4.794527	5.007838			19768022	19768022
	Commercial	0.043305	0.04477	0.97107	1.045233	5.88235	6.175604	X	X	1.639199	1.885794			32358.96	34113.27
	Utility	-0.07881	0.17606	94.4332	126.9956	11.7849	68.42785	X	X	-5526.762	5800.337	-275798389	275798440	423.4519	472.5481
	Aggregated	-1.1854	1.19298	37.9276	37.92756	0.31547	0.579058	67.40535	137.3871	1.402034	7.72208			11621670	11621670

The computation of the confidence intervals reveal that generally the main results obtained with the GIM are significant. An interesting result is the significance of the imitation coefficient in the case of the residential sector in terms of number of installations. A good result was obtained for the commercial sector, where all the parameters are significant. However, an exception is the utility sector, for both installed capacity and number of installations. In this case the limits of the interval are far from the estimated value for all parameters. Moreover, the confidence interval analysis shows good results also for the market potential in mainly all cases.

	Installed capacity				Number of installations			
	Residential	Commercial	Utility	Aggregated	Residential	Commercial	Utility	Aggregated
1-shock vs Bass	0.226	0.261	0.681	0.243	0.233	0.599	0.418	0.592
2-shock vs 1-shock	0.333	0.789	0.555	0.864	0.544	0.498	0.680	-0.077
3-shock vs 2-shock	0.975	0.841	0.140	0.794	0.906	0.722	0.445	0.967
4-shock vs 3-shock		0.291	0.601	0.183		0.009	0.808	
5-shock vs 4-shock		0.159	0.309	0.042		0.014	0.013	
6-shock vs 5-shock		0.042		0.014		0.000		
7-shock vs 6-shock		0.078		0.000		0.061		
8-shock vs 7-shock		0.076		0.009				
9-shock vs 8-shock		0.001		0.030				
10-shock vs 9-shock		0.001		0.000				
11-shock vs 10-shock				0.002				
12-shock vs 11-shock				0.133				

Table A3- 5 Squared Multiple partial correlation coefficient (SMPCC) values for Bass, intermediate and best fit models for each sector for installed capacity and number of installations

References

Ackermann, T., Söder, L., 2002. An overview of wind energy-status 2002. Renew. Sustain. Energy Rev. 6, 67–128. https://doi.org/10.1016/S1364-0321(02)00008-4

Adam, A.D., Apaydin, G., 2016. Grid connected solar photovoltaic system as a tool for green house gas emission reduction in Turkey. Renew. Sustain. Energy Rev. 53, 1086–1091. https://doi.org/10.1016/j.rser.2015.09.023

Archer, D., Rahmstrof, S., 2010. An Introductory Guide to Climate Change.

Ardani, K., Seif, D., Davidson, C., Morris, J., Truitt, S., Torbert, R., Margolis, R., 2013. Preliminary non-hardware ('soft') cost-reduction Roadmap for residential and small commercial solar photovoltaics, 2013-2020. Conf. Rec. IEEE Photovolt. Spec. Conf. 3463–3468. https://doi.org/10.1109/PVSC.2013.6745192

Armaroli, N., Balzani, V., 2010. Energy for a Sustainable World: From the Oil Age to a Sun-Powered Future, Energy for a Sustainable World: From the Oil Age to a Sun-Powered Future. https://doi.org/10.1002/9783527633593

Avril, S., Mansilla, C., Busson, M., Lemaire, T., 2012. Photovoltaic energy policy: Financial estimation and performance comparison of the public support in five representative countries. Energy Policy 51, 244–258. https://doi.org/10.1016/j.enpol.2012.07.050

Balcombe, P., Rigby, D., Azapagic, A., 2014. Investigating the importance of motivations and barriers related to microgeneration uptake in the UK. Appl. Energy 130, 403–418. https://doi.org/10.1016/j.apenergy.2014.05.047

Balcombe, P., Rigby, D., Azapagic, A., 2013. Motivations and barriers associated with adopting microgeneration energy technologies in the UK. Renew. Sustain. Energy Rev. 22, 655–666. https://doi.org/10.1016/j.rser.2013.02.012

Balta-Ozkan, N., Yildirim, J., Connor, P.M., 2015. Regional distribution of photovoltaic deployment in the UK and its determinants: A spatial econometric approach. Energy Econ. 51, 417–429. https://doi.org/10.1016/j.eneco.2015.08.003

Bass, F.M., 1969. (Bass 1969) A new product growth for model consumer durables.pdf. Manage. Sci. 15, 215–227.

Bass, F.M., Krishnan, T. V, Jain, D.C., 1994. Why the Bass Model Fits without Decision Variables. Mark. Sci. 33, 203–223. https://doi.org/10.1287/mksc.13.3.203

Beck, F., Martinot, E., 2004. Renewable Energy Policies and Barriers. Encycl. Energy. https://doi.org/10.1016/B0-12-176480-X/00488-5

Bjørnstad, E., 2012. Diffusion of renewable heating technologies in households.

Experiences from the Norwegian Household Subsidy Programme. Energy Policy 48, 148–158. https://doi.org/10.1016/j.enpol.2012.04.078

Blanchard, Olivier J, Gali, J., 2007. The Macroeconomic Effects of Oil Shocks: Why Are the 2000s So Different From the 1970s? (No. w13368), National Bureau of Economic Research. https://doi.org/10.3386/w13368

Bollinger, B., Gillingham, K., 2012. Peer Effects in the Diffusion of Solar Photovoltaic Panels. Mark. Sci. 31, 900–912. https://doi.org/10.1287/mksc.1120.0727

Breyer, C., Birkner, C., Kersten, F., Gerlach, A., Goldschmidt, J.C., Stryi-Hipp, G., Montoro, D.F., Riede, M., 2010. Research and development investments in PV – A limiting factor for a fast PV diffusion?, in: 25th European Photovoltaic Solar Energy Conference and Exhibition / 5th World Conference on Photovoltaic Energy Conversion. Valencia, Spain, pp. 6–10.

Cancino-Solórzano, Y., Villicaña-Ortiz, E., Gutiérrez-Trashorras, A.J., Xiberta-Bernat, J., 2010. Electricity sector in Mexico: Current status. Contribution of renewable energy sources. Renew. Sustain. Energy Rev. https://doi.org/10.1016/j.rser.2009.07.022

CEBR, 2014. Solar powered growth in the UK The macroeconomic benefits for the UK of investment in solar PV 47. https://doi.org/https://doi.org/10.1016/j.enpol.2012.09.062

Celik, A.N., 2006. Present status of photovoltaic energy in Turkey and life cycle techno-economic analysis of a grid-connected photovoltaic-house. Renew. Sustain. Energy Rev. 10, 370–387. https://doi.org/10.1016/j.rser.2004.09.007

Centrone, F., Goia, A., Salinelli, E., 2007. Demographic processes in a model of innovation diffusion with dynamic market. Technol. Forecast. Soc. Change 74, 247–266. https://doi.org/10.1016/j.techfore.2006.02.006

Chen, W.M., Kim, H., Yamaguchi, H., 2014. Renewable energy in eastern Asia: Renewable energy policy review and comparative SWOT analysis for promoting renewable energy in Japan, South Korea, and Taiwan. Energy Policy 74, 319–329. https://doi.org/10.1016/j.enpol.2014.08.019

Chowdhury, S., Sumita, U., Islam, A., Bedja, I., 2014. Importance of policy for energy system transformation: Diffusion of PV technology in Japan and Germany. Energy Policy 68, 285–293. https://doi.org/10.1016/j.enpol.2014.01.023

Clark, B., York, R., 2005. Carbon Metabolism Global Capitalism, Climate Change, and the Biospheric Rift.pdf. Theory Soc. 34, 391–428. https://doi.org/10.1007/s11186-005-1993-4

Colombo, U., 2001. The club of Rome and sustainable development. Futures 33, 7–11. https://doi.org/10.1016/S0016-3287(00)00048-3 de la Tour, A., Glachant, M., Ménière, Y., 2011. Innovation and international technology transfer: The case of the Chinese photovoltaic industry. Energy Policy 39, 761–770. https://doi.org/10.1016/j.enpol.2010.10.050

de La Tour, A., Glachant, M., Ménière, Y., 2013. Predicting the costs of photovoltaic solar modules in 2020 using experience curve models. Energy 62, 341–348. https://doi.org/10.1016/j.energy.2013.09.037

Dessler, A.E., Parson, E. a., 2006. The Science and Politics of Global Climate Change: a Guide To the Debate.

Dharshing, S., 2017. Household dynamics of technology adoption: A spatial econometric analysis of residential solar photovoltaic (PV) systems in Germany. Energy Res. Soc. Sci. 23, 113–124. https://doi.org/10.1016/j.erss.2016.10.012

Dinçer, F., 2011. Overview of the photovoltaic technology status and perspective in Turkey. Renew. Sustain. Energy Rev. 15, 3768–3779. https://doi.org/10.1016/j.rser.2011.06.005

Draper, N.R., Smith, H., 1998. Applied Regression Analysis. Technometrics 47, 706. https://doi.org/10.1198/tech.2005.s303

Duan, H.B., Zhu, L., Fan, Y., 2014. A cross-country study on the relationship between diffusion of wind and photovoltaic solar technology. Technol. Forecast. Soc. Change 83, 156–169. https://doi.org/10.1016/j.techfore.2013.07.005

Dusonchet, L., Telaretti, E., 2015. Comparative economic analysis of support policies for solar PV in the most representative EU countries. Renew. Sustain. Energy Rev. 42, 986–998. https://doi.org/10.1016/j.rser.2014.10.054

Dusonchet, L., Telaretti, E., 2010. Economic analysis of different supporting policies for the production of electrical energy by solar photovoltaics in western European Union countries. Energy Policy 38, 3297–3308. https://doi.org/10.1016/j.enpol.2010.01.053

EcoFys B.V., 2012. Co-operative programme on National Survey Report of PV Power Applications in The Netherlands. Int. Energy Agency 1–53.

Faiers, A., Neame, C., 2006. Consumer attitudes towards domestic solar power systems. Energy Policy 34, 1797–1806. https://doi.org/10.1016/j.enpol.2005.01.001

Farrag, N., Gmbh, N.E., 2013. National Survey Report of PV Power Applications in Switzerland. Int. Energy Agency.

Foxon, T.J., 2010. Stimulating investment in energy materials and technologies to combat climate change: an overview of learning curve analysis and niche market support. Philos. Trans. A. Math. Phys. Eng. Sci. 368, 3469–3483. https://doi.org/10.1098/rsta.2010.0106

Fu, X., Zhang, J., 2011. Technology transfer, indigenous innovation and leapfrogging in green technology: The solar-PV industry in China and India. J. Chinese Econ. Bus. Stud. 9, 329–347. https://doi.org/10.1080/14765284.2011.618590

Gabaldón-Estevan, D., Peñalvo-López, E., Solar, D.A., 2018. The Spanish turn against renewable energy development. Sustain. 10, 1–16. https://doi.org/10.3390/su10041208

Gallager, M., Uleri, P.V., 1996. The Referendum Experience in Europe.

Glaser, A., 2011. After Fukushima: Preparing for a More Uncertain Future of Nuclear Power. Electr. J. 24, 27–35. https://doi.org/10.1016/j.tej.2011.06.003

Goel, M., 2016. Solar rooftop in India: Policies, challenges and outlook. Green Energy Environ. 1, 129–137. https://doi.org/10.1016/j.gee.2016.08.003

Guidolin, M., Guseo, R., 2016. The German energy transition: Modeling competition and substitution between nuclear power and Renewable Energy Technologies. Renew. Sustain. Energy Rev. 60, 1498–1504. https://doi.org/10.1016/j.rser.2016.03.022

Guidolin, M., Guseo, R., 2014. Modelling seasonality in innovation diffusion. Technol. Forecast. Soc. Change 86, 33–40. https://doi.org/10.1016/j.techfore.2013.08.017

Guidolin, M., Mortarino, C., 2010. Cross-country diffusion of photovoltaic systems: Modelling choices and forecasts for national adoption patterns. Technol. Forecast. Soc. Change 77, 279–296. https://doi.org/10.1016/j.techfore.2009.07.003

Guseo, R., Dalla Valle, A., Guidolin, M., 2007. World Oil Depletion Models: Price effects compared with strategic or technological interventions. Technol. Forecast. Soc. Change 74, 452–469. https://doi.org/10.1016/j.techfore.2006.01.004

Guseo, R., Guidolin, M., 2009. Modelling a dynamic market potential: A class of automata networks for diffusion of innovations. Technol. Forecast. Soc. Change 76, 806–820. https://doi.org/10.1016/j.techfore.2008.10.005

Hamilton, J.D., 2011. Historical Oil Shocks. Natl. Bur. Econ. Res. 53, 1689–1699. https://doi.org/10.1017/CBO9781107415324.004

Hamilton, J.D., 2009. Causes and Consequences of the Oil Shock of 2007-08. Brookings Pap. Econ. Act. 40, 215–283. https://doi.org/10.3386/w15002

Hammond, G.P., Harajli, H.A., Jones, C.I., Winnett, A.B., 2012. Whole systems appraisal of a UK Building Integrated Photovoltaic (BIPV) system: Energy, environmental, and economic evaluations. Energy Policy 40, 219–230. https://doi.org/10.1016/j.enpol.2011.09.048

Höök, M., Tang, X., 2013. Depletion of fossil fuels and anthropogenic climate change-A review. Energy Policy 52, 797–809. https://doi.org/10.1016/j.enpol.2012.10.046

Huijben, J.C.C.M., Podoynitsyna, K.S., Van Rijn, M.L.B., Verbong, G.P.J., 2016. A review of governmental support instruments channeling PV market growth in the Flanders region of Belgium (2006-2013). Renew. Sustain. Energy Rev. 62, 1282–1290. https://doi.org/10.1016/j.rser.2016.04.058

IEA, 2017. National Survey Report of PV Power Applications in Austria 2016.

IEA, 2016. IEA-PVPS Annual Report 2016, International Energy Agency (IEA).

IEA, I.E.A., 2013a. National Survey Report of PV Power Applications in Belgium 2012, IEA - Photovoltaics Power Systems Programme (PVPS).

IEA, I.E.A., 2013b. National Survey Report of PV Power Applications in the Netherlands 2012.

IEA, I.E.A., 2013c. National Survey Report of PV Power Applications in Denmark 2012.

IEA, I.E.A., 2009. National Survey Report of PV Power Applications in the United Kingdom, International Energy Agency Co-operative Programme on Photovoltaic Power System-Task 1.

IEA, I.E.A., 2007. National Survey Report of PV Power Applications in The Korea 2006, International Energy Agency.

IEA International Energy Agency, 2018. Photovoltaic Power System Program PVPS Annual Report 2017.

IEA PVPS, 2016. Snapshot of Global Photovoltaic Markets 1–16.

Iizuka, M., 2015. Diverse and uneven pathways towards transition to low carbon development: the case of solar PV technology in China. Innov. Dev. 5, 241–261.

International Finance Corporation, 2015. Utility-Scale Solar Photovoltaic Power Plants, World Bank Group.

IPCC, 2014. Climate Change 2014: Mitigation of Climate Change, Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. https://doi.org/10.1017/CBO9781107415416

IRENA, 2017. Renewable capacity statistics 2017.

Islam, T., 2014. Household level innovation diffusion model of photo-voltaic (PV) solar cells from stated preference data. Energy Policy 65, 340–350. https://doi.org/10.1016/j.enpol.2013.10.004

Ismail, A.M., Ramirez-Iniguez, R., Asif, M., Munir, A.B., Muhammad-Sukki, F., 2015. Progress of solar photovoltaic in ASEAN countries: A review. Renew. Sustain. Energy Rev. 48, 399–412. https://doi.org/10.1016/j.rser.2015.04.010

ITRPV, 2018. International Technology Roadmap for Photovoltaic (ITRPV) - Results 2017. Itrpv 9, 1–37.

https://doi.org/http://www.itrs.net/Links/2013ITRS/2013Chapters/2013Litho.pdf

Jacobs, D., 2012. Renewable energy policy convergence in the EU: The evolution of feed-in tariffs in Germany, Spain and France. Ashgate Publishing Limited.

Jäger-Waldau, A., 2007. Photovoltaics and renewable energies in Europe. Renew. Sustain. Energy Rev. 11, 1414–1437. https://doi.org/10.1016/j.rser.2005.11.001

Jeon, C., Lee, J., Shin, J., 2015. Optimal subsidy estimation method using system dynamics and the real option model: Photovoltaic technology case. Appl. Energy 142, 33–43. https://doi.org/10.1016/j.apenergy.2014.12.067

Johnstone, N., Haščič, I., Popp, D., 2010. Renewable energy policies and technological innovation: Evidence based on patent counts. Environ. Resour. Econ. 45, 133–155. https://doi.org/10.1007/s10640-009-9309-1

Kar, S.K., Sharma, A., Roy, B., 2016. Solar energy market developments in India. Renew. Sustain. Energy Rev. 62, 121–133. https://doi.org/10.1016/j.rser.2016.04.043

Karakaya, E., Sriwannawit, P., 2015. Barriers to the adoption of photovoltaic systems: The state of the art. Renew. Sustain. Energy Rev. 49, 60–66. https://doi.org/10.1016/j.rser.2015.04.058

Karneyeva, Y., Wüstenhagen, R., 2017. Solar feed-in tariffs in a post-grid parity world: The role of risk, investor diversity and business models. Energy Policy 106, 445–456. https://doi.org/10.1016/j.enpol.2017.04.005

Keirstead, J., 2007a. Behavioural responses to photovoltaic systems in the UK domestic sector. Energy Policy 35, 4128–4141. https://doi.org/10.1016/j.enpol.2007.02.019

Keirstead, J., 2007b. The UK domestic photovoltaics industry and the role of central government. Energy Policy 35, 2268–2280. https://doi.org/10.1016/j.enpol.2006.08.003

Kim, Y., Kim, M., Kim, W., 2013. Effect of the Fukushima nuclear disaster on global public acceptance of nuclear energy. Energy Policy 61, 822–828. https://doi.org/10.1016/j.enpol.2013.06.107

Klitkou, A., Jørgensen, B.H., 2011. The development and diffusion of renewable energy technologies in Norway and Denmark, in: Energy Systems and Technologies for the Coming Century. Roskilde: Danmarks Tekniske Universitet, Risø Nationallaboratoriet for Bæredygtig Energi. (Denmark. Forskningscenter Risoe. Risoe-R, p. 454.

Kumar Sahu, B., 2015. A study on global solar PV energy developments and policies with special focus on the top ten solar PV power producing countries. Renew. Sustain. Energy Rev. 43, 621–634. https://doi.org/10.1016/j.rser.2014.11.058

Lang, T., Gloerfeld, E., Girod, B., 2015. Don't just follow the sun - A global assessment of economic performance for residential building photovoltaics. Renew. Sustain. Energy Rev. 42, 932–951. https://doi.org/10.1016/j.rser.2014.10.077

Lee, C.Y., Huh, S.Y., 2017. Forecasting the diffusion of renewable electricity considering the impact of policy and oil prices: The case of South Korea. Appl. Energy 197, 29–39. https://doi.org/10.1016/j.apenergy.2017.03.124

Leung, D.Y.C., Yang, Y., 2012. Wind energy development and its environmental impact: A review. Renew. Sustain. Energy Rev. 16, 1031–1039. https://doi.org/10.1016/j.rser.2011.09.024

Lund, P.D., 2015. Energy policy planning near grid parity using a price-driven technology penetration model. Technol. Forecast. Soc. Change 90, 389–399. https://doi.org/10.1016/j.techfore.2014.05.004

Mahajan, V., Muller, E., 1998. When Is It Worthwhile Targeting the Majority Instead of the Innovators in a New Product Launch? J. Mark. Res. 35, 488–495. https://doi.org/10.2307/3152167

Mahajan, V., Muller, E., Bass, F.M., 1995. Diffusion of New Products : Empirical Generalizations and Managerial Uses. Mark. Sci. 14, G6–G19.

Masini, A., Frankl, P., 2003. Forecasting the diffusion of photovoltaic systems in southern Europe. Technol. Forecast. Soc. Change 70, 39–65. https://doi.org/10.1016/S0040-1625(01)00183-4

Mason, M. editor, Mor, A., 2009. Renewable Energy in the Middle East Enhancing Security through Regional Cooperation, in: Proceedings of the NATO Advanced Research Workshop on Enhancing Security in the Middle East through Regional Cooperation on Renewable Energy London, United Kingdom 16-18 January 2008. pp. 19–40.

Mayr, D., Schmidt, J., Schmid, E., 2014. The potentials of a reverse auction in allocating subsidies for cost-effective roof-top photovoltaic system deployment. Energy Policy 69, 555–565. https://doi.org/10.1016/j.enpol.2014.01.029

McCright, A.M., Dunlap, R.E., 2011. The Politicization of Climate Change and Polarization in the American Public ' S Views of Global Warming , 2001 – 2010. Sociol. Q. 52, 155–194. https://doi.org/10.1111/j.1533-8525.2011.01198.x

McCright, A.M., Dunlap, R.E., 2003. Defeating Kyoto: The Conservative Movement's Impact on U.S. Climate Change Policy. Soc. Probl. 50, 348–373. https://doi.org/10.1525/sp.2003.50.3.348

Meade, N., Islam, T., 2015. Modelling European usage of renewable energy technologies for electricity generation. Technol. Forecast. Soc. Change 90, 497–509. https://doi.org/10.1016/j.techfore.2014.03.007

Meadows, D.H., Meadows, D.H., Randers, J. and, Behrens III, W.W., 1972. The limits to growth: a report to the club of Rome.

Michaels, L., Tal, A., 2015. Convergence and conflict with the "National Interest": Why Israel abandoned its climate policy. Energy Policy 87, 480–485. https://doi.org/10.1016/j.enpol.2015.09.040

Mohr, S.H., Wang, J., Ellem, G., Ward, J., Giurco, D., 2015. Projection of world fossil fuels by country. Fuel 141, 120–135. https://doi.org/10.1016/j.fuel.2014.10.030

Moosavian, S.M., Rahim, N.A., Selvaraj, J., Solangi, K.H., 2013. Energy policy to promote photovoltaic generation. Renew. Sustain. Energy Rev. 25, 44–58. https://doi.org/10.1016/j.rser.2013.03.030

Movilla, S., Miguel, L.J., Blázquez, L.F., 2013. A system dynamics approach for the photovoltaic energy market in Spain. Energy Policy 60, 142–154. https://doi.org/10.1016/j.enpol.2013.04.072

Mundo-Hernández, J., De Celis Alonso, B., Hernández-Álvarez, J., De Celis-Carrillo, B., 2014. An overview of solar photovoltaic energy in Mexico and Germany. Renew. Sustain. Energy Rev. 31, 639–649. https://doi.org/10.1016/j.rser.2013.12.029

Nencioni, C., Manfredi, P., 2015. Energie Rinnovabili : quali prospettive dopo la chiusura degli incentivi. University of Pisa.

Nohrstedt, D., 2005. External shocks and policy change: Three Mile Island and Swedish nuclear energy policy. J. Eur. Public Policy 12, 1041–1059. https://doi.org/10.1080/13501760500270729

Olaniyan, M.J., Evans, J., 2014. The importance of engaging residential energy customers' hearts and minds. Energy Policy 69, 273–284. https://doi.org/10.1016/j.enpol.2013.12.023

Oreskes, N., 2007. The Scientific Consensus on Climate Change: How Do We Know We're Not Wrong? Clim. Chang. what it means us, our Child. our Gd. 65. https://doi.org/10.1126/science.1103618

Orioli, A., Di Gangi, A., 2017. Six-years-long effects of the Italian policies for photovoltaics on the grid parity of grid-connected photovoltaic systems installed in urban contexts. Energy 130, 55–75. https://doi.org/10.1016/j.energy.2017.04.069

Painuly, J.P., 2001. Barriers to renewable eneryg penetration; a framework for analysis. Renew. Energy 24, 73–89. https://doi.org/https://doi.org/10.1016/S0960-1481(00)00186-5

Palmer, J., Sorda, G., Madlener, R., 2015. Modeling the diffusion of residential photovoltaic systems in Italy: An agent-based simulation. Technol. Forecast. Soc. Change 99, 106–131. https://doi.org/10.1016/j.techfore.2015.06.011

Peres, R., Muller, E., Mahajan, V., 2010. Innovation diffusion and new product growth models: A critical review and research directions. Int. J. Res. Mark. 27, 91–106. https://doi.org/10.1016/j.ijresmar.2009.12.012

Polzin, F., Migendt, M., Täube, F.A., von Flotow, P., 2015. Public policy influence on renewable energy investments-A panel data study across OECD countries. Energy Policy 80, 98–111. https://doi.org/10.1016/j.enpol.2015.01.026

Popp, D., Hascic, I., Medhi, N., 2011. Technology and the diffusion of renewable energy. Energy Econ. 33, 648–662. https://doi.org/10.1016/j.eneco.2010.08.007

Pyrgou, A., Kylili, A., Fokaides, P.A., 2016. The future of the Feed-in Tariff (FiT) scheme in Europe: The case of photovoltaics. Energy Policy 95, 94–102. https://doi.org/10.1016/j.enpol.2016.04.048

Rabl, A., 1999. Discounting of long term costs: what would future generations prefer us to do?, in: Hohmeyer, O., Rennings, K. (Eds.), Man-Made Climate Changes: Economic Aspects and Policy Options. Spring Science & Business Media, pp. 111–125.

Radomes, A.A., Arango, S., 2015. Renewable energy technology diffusion: An analysis of photovoltaic-system support schemes in Medellín, Colombia. J. Clean. Prod. 92, 152–161. https://doi.org/10.1016/j.jclepro.2014.12.090

Ramirez, A., Sebastian, P.J., Gamboa, S.A., Rivera, M.A., Cuevas, O., Campos, J., 2000. A documented analysis of renewable energy related research and development in Mexico. Int. J. Hydrogen Energy 25, 267–271.

Rao, J.G., Shrivastava, S.K., 2015. A Review of Energy Scenario and Diffusion Modeling of Selected Renewable Energy Technologies in India. Int. Adv. Res. J. Sci. Eng. Technol. 2, 111–125. https://doi.org/10.17148/IARJSET.2015.2823

Ratinen, M., Lund, P., 2015. Policy inclusiveness and niche development: Examples from wind energy and photovoltaics in Denmark, Germany, Finland, and Spain. Energy Res. Soc. Sci. 6, 136–145. https://doi.org/10.1016/j.erss.2015.02.004

Ratinen, M., Lund, P., 2012. Analysing changes in electricity industries against actors and technologies: Utility to business transformations in Denmark, Germany, Finland and Spain. J. Technol. Manag. Innov. 7, 87–100. https://doi.org/10.4067/S0718-27242012000200008

Reddy, S., Painuly, J.P., 2004. Diffusion of renewable energy technologies-barriers and stakeholders' perspectives. Renew. Energy 29, 1431–1447. https://doi.org/10.1016/j.renene.2003.12.003

Robinson, S.A., Stringer, M., Rai, V., Tondon, A., 2013. GIS-Integrated Agent-Based Model of Residential Solar PV Diffusion. 32nd USAEE/IAEE North Am. Conf. July 28-31, 2013 1–19.

Ruby, T.M., 2014. Policy driven innovation-the role of energy saving obligations for energy distributors in Denmark. DRUID Acad. Conf. 2012.

Saikku, L., Tainio, P., Hildén, M., Antikainen, R., Leskinen, P., Koskela, S., 2017. Diffusion of solar electricity in the network of private actors as a strategic experiment to mitigate climate change. J. Clean. Prod. 142, 2730–2740. https://doi.org/10.1016/j.jclepro.2016.11.003

Salameh, M.G., 2004. Oil Crises , Historical Perspective. Encycl. Energy 4, 633–648. https://doi.org/http://dx.doi.org/10.1016/B0-12-176480-X/00027-9

Sawin, J., Seyboth, K., Sverrisson, F., 2017. Renewables 2017 Global Status Report.

Scarpa, R., Willis, K., 2010. Willingness-to-pay for renewable energy: Primary and discretionary choice of British households' for micro-generation technologies. Energy Econ. 32, 129–136. https://doi.org/10.1016/j.eneco.2009.06.004

Schleicher-Tappeser, R., 2012. How renewables will change electricity markets in the next five years. Energy Policy 48, 64–75. https://doi.org/10.1016/j.enpol.2012.04.042

Seber, G., Wild, C., 1989. Nonlinear Regression. Wiley, New York. https://doi.org/10.1007/978-3-8348-1981-9

Seel, J., Barbose, G.L., Wiser, R.H., 2014. An analysis of residential PV system price differences between the United States and Germany. Energy Policy 69, 216–226. https://doi.org/10.1016/j.enpol.2014.02.022

Shafiee, S., Topal, E., 2009. When will fossil fuel reserves be diminished? Energy Policy 37, 181–189. https://doi.org/10.1016/j.enpol.2008.08.016

Sherwood, L., 2010. U.S. Solar market trends, in: Interstate Renewable Energy Council, Sherwood Associates. Boulder, CO (United States).

Siegrist, M., Sütterlin, B., Keller, C., 2014. Why have some people changed their attitudes toward nuclear power after the accident in Fukushima? Energy Policy 69, 356–363. https://doi.org/10.1016/j.enpol.2014.02.026

Solangi, K.H., Islam, M.R., Saidur, R., Rahim, N.A., Fayaz, H., 2011. A review on global solar energy policy. Renew. Sustain. Energy Rev. 15, 2149–2163. https://doi.org/10.1016/j.rser.2011.01.007

Stokes, L.C., 2013. The politics of renewable energy policies: The case of feed-in tariffs in Ontario, Canada. Energy Policy 56, 490–500. https://doi.org/10.1016/j.enpol.2013.01.009

Strupeit, L., Palm, A., 2016. Overcoming barriers to renewable energy diffusion: Business models for customer-sited solar photovoltaics in Japan, Germany and the United States. J. Clean. Prod. 123, 124–136. https://doi.org/10.1016/j.jclepro.2015.06.120

Timilsina, G.R., Kurdgelashvili, L., Narbel, P.A., 2012. Solar energy: Markets, economics and policies. Renew. Sustain. Energy Rev. 16, 449–465.

https://doi.org/10.1016/j.rser.2011.08.009

Toth, F.L., Rogner, H.H., 2006. Oil and nuclear power: Past, present, and future. Energy Econ. 28, 1–25. https://doi.org/10.1016/j.eneco.2005.03.004

Van den Bulte, C., Lilien, G.L., 1997. Bias and Systematic Change in the Parameter Estimates of Macro-Level Diffusion Models. Mark. Sci. 16, 338–353. https://doi.org/10.1287/mksc.16.4.338

Vardimon, R., 2011. Assessment of the potential for distributed photovoltaic electricity production in Israel. Renew. Energy 36, 591–594. https://doi.org/10.1016/j.renene.2010.07.030

Vasseur, V., Kamp, L.M., Negro, S.O., 2013. A comparative analysis of Photovoltaic Technological Innovation Systems including international dimensions: The cases of Japan and the Netherlands. J. Clean. Prod. 48, 200–210. https://doi.org/10.1016/j.jclepro.2013.01.017

Vasseur, V., Kemp, R., 2015. The adoption of PV in the Netherlands: A statistical analysis of adoption factors. Renew. Sustain. Energy Rev. 41, 483–494. https://doi.org/10.1016/j.rser.2014.08.020

Vasseur, V., Kemp, R., 2011. The role of policy in the evolution of technological. Int. J. Technol. Policy 11, 307–327.

Weibel, D., 2011. The Swiss Feed-in Tariff System 1–22.

Wittneben, B.B.F., 2012. The impact of the Fukushima nuclear accident on European energy policy. Environ. Sci. Policy 15, 1–3. https://doi.org/10.1016/j.envsci.2011.09.002

Yamada, H., Ikki, O., 2017. National survey report of PV power applications in Japan 2016 1–42.

Yamaguchi, Y., Akai, K., Shen, J., Fujimura, N., Shimoda, Y., Saijo, T., 2013. Prediction of photovoltaic and solar water heater diffusion and evaluation of promotion policies on the basis of consumers' choices. Appl. Energy 102, 1148–1159. https://doi.org/10.1016/j.apenergy.2012.06.037

Yang, R.J., Zou, P.X.W., 2016. Building integrated photovoltaics (BIPV): Costs, benefits, risks, barriers and improvement strategy. Int. J. Constr. Manag. 16, 39–53. https://doi.org/10.1080/15623599.2015.1117709

Yoon, J.H., Sim, K. ho, 2015. Why is South Korea's renewable energy policy failing? A qualitative evaluation. Energy Policy 86, 369–379. https://doi.org/10.1016/j.enpol.2015.07.020

Yu, H.J.J., Popiolek, N., Geoffron, P., 2016. Solar photovoltaic energy policy and globalization: a multiperspective approach with case studies of Germany, Japan, and China. Prog. Photovoltaics Res. Appl. 24, 458–476. https://doi.org/10.1002/pip.2560

Zhang, Y., Song, J., Hamori, S., 2011. Impact of subsidy policies on diffusion of photovoltaic power generation. Energy Policy 39, 1958–1964. https://doi.org/10.1016/j.enpol.2011.01.021

Zhao, Y., Tang, K.K., Wang, L., 2013. Do renewable electricity policies promote renewable electricity generation? Evidence from panel data. Energy Policy 62, 887–897. https://doi.org/10.1016/j.enpol.2013.07.072

Zhi, Q., Sun, H., Li, Y., Xu, Y., Su, J., 2014. China's solar photovoltaic policy: An analysis based on policy instruments. Appl. Energy 129, 308–319. https://doi.org/10.1016/j.apenergy.2014.05.014

Sitography Chapter 1

1. https://www.technologyreview.com/s/603649/india-now-has-the-worlds-worst-air-pollution/

2. https://www.solarinsure.com/largest-solar-power-plants

3. https://www.technologyreview.com/s/607920/switzerland-votes-to-phase-out-nuclear-power/

4. RD&D from IEA Data Services: http://wds.iea.org/WDS/TableViewer/dimView.aspx

5. http://futures.tradingcharts.com/historical/QM/2008/0/continuous.html

6. https://uk.reuters.com/article/us-germany-nuclear/german-government-wants-nuclear-exit-by-2022-at-latest-idUKTRE74Q2P120110530

7. https://www.ft.com/content/f0918c6c-3e26-11e7-9d56-25f963e998b2

8. http://unfccc.int/kyoto_protocol/items/2830.php

9. https://ec.europa.eu/clima/policies/strategies/2020_en

10. https://www.independent.co.uk/environment/france-petrol-diesel-ban-vehicles-cars-2040-a7826831.html

11. https://www.alternet.org/environment/india-unveils-global-solar-alliance-120-countries-paris-climate-summit

12. https://www.nytimes.com/2017/11/02/climate/trump-coal-cop23-bonn.html

13. http://www.cansia.ca/uploads/7/2/5/1/72513707/cansia_roadmap_2020_final.pdf

14. http://www.iea-pvps.org/?id=93

15. https://www.seia.org/initiatives/solar-investment-tax-credit-itc

16. www.bundesnetzagentur.de

17. https://www.teias.gov.tr/sites/default/files/2018-01/Kguc2017.pdf

18. https://www.gov.uk/government/statistics/solar-photovoltaics-deployment

19. https://www.enerdata.net/publications/daily-energy-news/japan-will-cut-feed-tariffs-solar-plants-2018.html?utm_source=Enerdata&utm_campaign=afbf59ba95-Email_Daily_Energy_News_02_2018&utm_medium=email&utm_term=0_838b1c9d18-afbf59ba95-124371697

20. https://www.iea.org/policiesandmeasures/pams/korea/name-22121-en.php

21. https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000032452174&categorieLien=id

22. http://www.ris.bka.gv.at/Dokumente/Erv/ERV_2011_1_75/ERV_2011_1_75.pdf

23. https://www.iea.org/policiesandmeasures/pams/austria/

24. https://www.e-control.at/documents/20903/26585/OekostromVO+2012.pdf/b5670553-46cb-4516-8341-e3a30ca70465

25. https://www.klimafonds.gv.at/funding-programmes/current-funding-programmes/2013-en-US/photovoltaik-foerderaktion-en-US/

26. https://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/snpsht/2017/02-02lrgslrfrms-eng.html

27. http://www.ieso.ca/en/sector-participants/feed-in-tariff-program/fit-archive

28. http://www.statnett.no/Global/Dokumenter/Kraftsystemet/Elsertifikater/English%20unofficial%20translation%20of%20Norwegian%20elcertificate%20act.pdf

29. www.iea.org/policiesandmeasures/pams/portugal

30. http://www.greenrhinoenergy.com/solar/radiation/empiricalevidence.php

31. http://energyinformative.org/net-metering-feed-in-tariffs-difference

Sitography Chapter 3

1. https://www.gov.uk/government/statistics/solar-pv-deployment-december-2017
2. https://www.bre.co.uk/filelibrary/nsc/Documents%20Library/Not%20for%20Profits/KTN_Report_Solar-PV-roadmap-to-2020_1113.pdf, page 11
3. https://www.theecoexperts.co.uk/sites/default/files/filemanager/cost-of-solar-2017-graph
4. https://www.solarpowerportal.co.uk/news/solar_made_to_wait_for_future_direction_as_clean_growth_strategy_defers_pv
5. https://www.ofgem.gov.uk/environmental-programmes/ro/about-ro/ro-closure
6. https://www.theguardian.com/environment/2012/jan/25/solar-subsidies-government-loses-court-appeal
7. https://www.ofgem.gov.uk/publications-and-updates/renewables-obligation-ro-buy-out-price-and-mutualisation-ceilings-2018-19-ro-year
8. https://www.gov.uk/government/news/new-feed-in-tariff-levels-for-large-scale-solar-and-anaerobic-digestion-announcecd-today
9. https://www.solarpowerportal.co.uk/blogs/inside_clay_hill_the_uks_first_subsidy_free_solar_farm
10. https://www.energylivenews.com/2017/11/29/feed-in-tariff-scheme-to-close-in-april-2019/
11. https://www.parliament.uk/documents/post/pn164.pdf
12. www.legislation.gov.uk
13. Reform of the Renewables Obligation, May 2007, National Archives gov.uk http://webarchive.nationalarchives.gov.uk/+/http:/www.berr.gov.uk/files/file39497.pdf
14. Government response to the consultation on proposals for the levels of banded support under the Renewables Obligation for the period 2013-17 and the Renewables Obligation Order 2012 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/42852/5936-renewables-obligation-consultation-the-government.pdf
15. http://www.legislation.gov.uk/ukpga/2013/32/contents/enacted
16. GOV.uk – https://www.gov.uk/government/publications/contracts-for-difference/contract-for-difference
17. https://www.pv-magazine.com/2016/11/09/uk-solar-still-being-blocked-in-next-cfd-auction_100026847/
18. https://www.solarpowerportal.co.uk/news/let_solar_back_into_cfds_energy_uk_urges_government