# ANALYSIS OF ECONOMIC IMPACTS OF THE FEED-IN TARIFF SCHEME FOR PHOTOVOLTAIC TECHNOLOGY IN ITALY

by

Daniele Poponi

A dissertation submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Energy and Environmental Policy

Summer 2018

# ANALYSIS OF ECONOMIC IMPACTS OF THE FEED-IN TARIFF SCHEME FOR PHOTOVOLTAIC TECHNOLOGY IN ITALY

by

Daniele Poponi

Approved: ________________________________________________
Ismat Shah, Ph.D.
Director of the Energy and Environmental Policy Program

Approved: ________________________________________________
Babatunde A. Ogunnaike, Ph.D.
Dean of the College of Engineering

Approved: ________________________________________________
Douglas J. Doren, Ph.D.
Interim Vice Provost for the Office of Graduate and Professional Education

I certify that I have read this dissertation and that in my opinion it meets the academic and professional standard required by the University as a dissertation for the degree of Doctor of Philosophy.

Signed: ________________________________________

Lado Kurdgelashvili, Ph.D.
Professor in charge of dissertation

I certify that I have read this dissertation and that in my opinion it meets the academic and professional standard required by the University as a dissertation for the degree of Doctor of Philosophy.

Signed: ________________________________________

Lawrence Agbemabiese, Ph.D.
Member of dissertation committee

I certify that I have read this dissertation and that in my opinion it meets the academic and professional standard required by the University as a dissertation for the degree of Doctor of Philosophy.

Signed: ________________________________________

William Latham, Ph.D.
Member of dissertation committee

I certify that I have read this dissertation and that in my opinion it meets the academic and professional standard required by the University as a dissertation for the degree of Doctor of Philosophy.

Signed: ________________________________________

Riccardo Basosi, Ph.D.
Member of dissertation committee

# ACKNOWLEDGMENTS

I would like to express my deep gratitude to my thesis chair, Professor Lado Kurdgelashvili, with whom I was able to develop the concept for this thesis and, most importantly, to rebuild quantitative analytical skills after being away from academia and analytical work for almost ten years. It has been a real pleasure to work with him.

I am grateful to all the Thesis Committee Members for their valuable suggestions that helped shape this work. A special vote of thanks goes to Professor William Latham, whose “Econometrics” course and “Energy Economics” seminars were really instrumental for expanding the horizon of my academic research. I am sincerely grateful to Professor Lawrence Agbemabiese and Professor Riccardo Basosi for serving as committee members. I really enjoyed interacting with them and receiving their advice throughout my academic career. My special thanks also go to Professor Young-Doo Wang for his academic advice and valuable suggestions.

I would like to express my sincere gratitude to Professor John Byrne for the academic advice he provided over the course of my academic career at the University of Delaware. His courses were amongst the most valuable, intellectually enriching experiences of my life.

I deeply thank all of my fellow PhD students with whom I enjoyed sharing this part of my life. They are too many to name, but I would like to thank here Hana Kim, Hun Park, Andrea Ruotolo, and Kenneth Zame.

I am also grateful to Ms. Denver Beattie for helping me edit this dissertation, and to Paola Babucci of Unicredit, who made this project possible.

Finally, my gratitude goes to my friends Fabio Minciarelli and Gianmarco Pantella, and to my parents for their continued support throughout my academic life.

# TABLE OF CONTENTS

# LIST OF TABLES

## LIST OF FIGURES

# LIST OF ACRONYMS

| | |
|---|---|
| CAGR | Compound Average Growth Rate |
| CET | Clean-energy Technology |
| C&I | Construction and Installation |
| CS | Counterfactual Scenario |
| EE | Energy Efficiency |
| EIA | Economic Impact Analysis |
| EPC | Engineering, Procurement, Construction |
| ES | Energy Storage |
| EUR | Euro |
| FIT | Feed-in Tariff |
| FTE | Full-time Equivalent |
| GDP | Gross Domestic Product |
| GSE | Gestore dei Servizi Energetici |
| IEA | International Energy Agency |
| IRENA | International Renewable Energy Agency |
| I-O | Input-Output |
| LCOE | Levelized Cost of Electricity |
| MFLD | Multifactorial Learning Curves |
| MSE | Ministero dello Sviluppo Economico (Ministry for Economic Development) |
| O&M | Operation and Maintenance |
| NACE | European Classification of Economic Activities |

| | |
|---|---|
| PV | Photovoltaic(s) |
| RE | Renewable Energy |
| RES | Renewable Energy Sources |
| RET | Renewable-Energy Technology |
| RS | Reference Scenario |
| USD | United States Dollar |

# ABSTRACT

With 22 TWh of electricity generated in 2016, solar photovoltaic (PV) systems contribute to meet more than 8% of Italian electricity demand, the third-highest share in the world. Between 2006 and 2016, domestic PV capacity underwent a massive scale-up, increasing from 37 to 19,300 MW. More than 90% of domestic PV installations over the same period were supported by the feed-in tariff program *Conto Energia*.

While the Conto Energia program was undoubtedly impactful in terms of spurring domestic PV demand, the question of whether it was a cost-effective program remained largely unanswered at the end of its implementation cycle. In 2016, annual feed-in tariff payments for PV systems totaled approximately EUR 6 billion, equivalent to about 0.4% of the Italian GDP. The estimated total cost of this incentive scheme, throughout its full lifetime from 2006 to 2038, is about EUR 130 billion. Given the scale of this financial burden, the possibility that Italy could have achieved the same energy sustainability goals, but at lower subsidization costs and with higher economic impacts, warrants serious investigation. The rationale for this analysis is not only to conduct a posthumous assessment of sunken costs, but also to provide Italian energy policymakers with useful methodological insights as they prepare to design new policies to achieve the objectives set forth in the National Energy Strategy published in 2017.

The methodological framework used in the present study is based on the integration of three main methodologies: learning curves, energy scenarios, and input-

output tables. The economic impact analysis was carried out within the frame of two scenarios spanning the time period 2010-35. The reference scenario incorporates historical PV deployment under the Conto Energia program between 2010 and 2016. The counterfactual scenario assumes lower PV deployment between 2010 and 2020, but higher energy-efficiency investments, so that the impact on reducing natural gas demand and carbon emissions by 2020 is the same as in the reference scenario. Both scenarios achieve the National Energy Strategy objective for PV generation by 2030.

Projections for PV system prices and their components for the two scenarios were developed based on the historical relationship between prices and market, as expressed by the learning-curve equation. Between 2002 and 2016, PV-system prices in Italy observed a learning rate of 15%. A large part of the PV-system price reduction can be explained by the reduction in module and inverter prices, two components that are subject to global learning and economies of scale effects. However, local learning effects also had a non-negligible impact on reducing PV system prices and in the scenarios, and it is assumed that they will continue to do so.

Between 2010 and 2020, estimated subsidies paid to support PV deployment under the Conto Energia program amount to EUR 73 billion in the reference scenario. In the counterfactual scenario, estimated subsidies paid to support PV deployment and the additional investments in energy-efficiency projects total about EUR 17 billion. This suggests that a “wait and see” strategy, postponing support to PV deployment in order to benefit from global learning effects and at the same time “free up” financial resources to accelerate energy efficiency, would have probably had a significant effect on reducing overall clean-energy subsidization costs in Italy between 2010 and 2016.

The Input-Output methodology was used to estimate the gross output and employment effects of the two scenarios. The calculation of output multipliers did not show significant differences between the two scenarios in the three sectors analyzed (PV Installation, PV Operation and Maintenance, and Energy Efficiency), while the difference between employment multipliers was marked. The much higher employment multiplier of the additional energy-efficiency investments in the counterfactual scenario makes this scenario more efficient in terms of employment mobilization. Averaging impacts in the three sectors, the employment multiplier for the counterfactual scenario is about 15% higher than in the reference scenario.

Finally, the overall cost-effectiveness of the two scenarios was assessed by dividing employment impacts by estimated subsidies. The twofold strategy underlying the counterfactual scenario – to dilute support for PV technology over time and to accelerate energy-efficiency investments – results in a ratio of employment impacts to subsidies more than three times higher than in the reference scenario. This finding suggests that at least part of the incentives disbursed to support PV deployment under the Conto Energia program could have had a significantly more efficient impact in terms of creating employment, while still having the same effect on contributing to energy-sustainability objectives. It can be concluded that the Conto Energia program had and still has a significant “opportunity cost” on the Italian economy.

# Chapter 1

# INTRODUCTION

## 1.1 Problem Statement

By the end of 2016, the installed photovoltaic (PV) capacity in Italy totaled 19.2 GW[1], generating about 22 TWh of electricity (GSE, 2017b). Over 2016, Italy held the third highest share (8.4%) of PV generation of total electricity demand in the world[2] , and the highest among G20 countries, also ranking fifth in the world for installed cumulative capacity after People's Republic of China, Germany, Japan, and the United States (IEA-PVPS, 2017). PV generation and cumulative installed capacity in Italy accounted respectively for about 9% of global PV electricity generation (285 TWh) and 8% of global PV cumulative capacity (228 GW) in 2015 (IEA-PVPS, 2017)[3].

---

[1] Electric power units that refer to photovoltaic systems are usually denoted by the "p" subscript, e.g., $KW_p$, $MW_p$, $GW_p$ (Gigawatt-peak). This convention reflects the fact that the power output of a PV module (the main component of a PV system) is a function of solar irradiance and temperature, with the rated power of a PV module achieved with standard test conditions (STC) of 1000 $W/m^2$ and 25°C. In the remainder of this thesis, the "p" subscript will be omitted, and the power units used for PV systems should always be intended as power obtained at STC.

[2] The two countries with the highest shares of PV generation on total electricity demand in the world in 2015 were Honduras and Kiribati (IEA-PVPS, 2017).

[3] As a term of comparison, Italian electricity consumption is only equivalent to about 1.4% of global electricity demand (IEA, 2017).

These significant achievements in domestic PV deployment were the result of support schemes introduced by the Italian Government, and in particular the feed-in tariff (FIT) program called *Conto Energia*, which provided financial support for PV installations from 2006 to mid-2013[4]. As a result of the Conto Energia program, domestic PV cumulative capacity increased from 25 MW (0.025 GW) at the end of 2005 to about 16.4 GW at the end of 2012 (an increase by a factor of 650). With Conto Energia, annual installations grew from 6.5 MW (0.0065 GW) in 2006 to 3.64 GW in 2012, with a compound annual growth rate (CAGR) of 120%. Over the same 2005-12 time frame, global PV cumulative capacity grew by a factor of 23 (from 4.2 GW to about 99 GW), whereas global annual installations grew by a CAGR of 53% (from 1.4 GW in 2005 to about 29 GW in 2012).

This pace of growth in domestic installations made the Italian PV market one of the main drivers of global PV demand. In 2011, Italy had the highest annual installations in the world (9.4 GW), while the Italian market accounted for about 17% of cumulative global PV demand between 2006 and 2012.

This sustained market deployment was accompanied by a significant reduction in PV system prices, particularly from 2008 onwards. As a result, electricity generated from distributed PV systems[5] achieved grid parity[6] in the residential and commercial

---

[4] The Conto Energia program ended in June 2013, but a residual quota of plants admitted to the fifth FIT scheme was installed from July 2013 to 2016. See section 2.5.

[5] The category "distributed PV systems" is defined by the IEA-PVPS as systems "installed to provide power to a grid-connected customer or directly to the electricity grid (specifically where that part of the electricity grid is configured to supply power to a number of customers rather than to provide a bulk transport function". The other category of grid-connected PV systems defined by the IEA-PVPS is "centralized PV

sectors in southern Italy as early as 2013 (Politecnico di Milano, 2014), whereas utility-scale systems achieved market parity[7] in 2017 (Qualenergia.it, 2017).

While the success of Conto Energia in terms of supporting domestic PV market deployment is indisputable, the costs and benefits of this FIT scheme, on the other hand, have been subject to debate (see, e.g., Alesina and Giavazzi, 2013).

The benefits of PV or, more broadly, renewable-energy (RE) deployment that are usually considered in cost-benefit analyses are: (a) economic impacts (output, value added, and jobs created); (b) avoided emissions of carbon dioxide, other greenhouse gases (e.g., $NO_2$), and air pollutants ($SO_x$, $PM_{10}$, etc.) as a result of the "crowding out" of conventional electricity generation from fossil fuels; (c) improved energy security due to avoided imports of natural gas; and (d) in the case of renewables generating electricity, peak reductions in wholesale electricity prices that are reflected in lower final electricity prices (IRENA, 2018).

---

power systems" which are defined as "PV power systems performing the function of a centralized power station" (Castello et al., 2015: 211).

[6] *Grid parity* for electricity generated from PV systems can be defined in different ways. The conventional definition is "the moment when PV can produce electricity at a price below the price of electricity" (IEA-PVP, 2016: 61). A "conservative" application of this definition would only consider the equivalence between the LCOE of PV systems and the variable component of the end-user price of electricity. The grid parity definition used in the cited study from the Politecnico di Milano is based on the equivalence between the actual rate of return of an investment in a PV system (given current PV system prices) and a target rate of return (e.g., 4% for residential systems). Grid parity achieved in Italy in 2013 was measured according to the second approach (Politecnico di Milano, 2014).

[7] *Market parity* for utility-scale PV systems is defined here as the ability to sell PV electricity in the wholesale electricity market and compete with other generation sources to an extent that the PV plant investment is economically viable without any need of policy support.

An additional impact of a more qualitative nature that can be added to the above-mentioned benefits is the *policy compliance benefit*, namely the higher likelihood of achieving commitments undertaken within international energy and climate policy frameworks as a result of the incentive-driven deployment of renewable energy. For example, Italy was committed to the Kyoto Protocol target of reducing greenhouse gas GHG emissions by 6.5% during the target period 2008-12, and the PV deployment that took place after 2006 contributed significantly to the reduction of carbon emissions in the electricity sector by displacing natural gas consumption. The PV capacity installed under Conto Energia was also a significant factor that contributed to putting the Italian energy system on track to achieve the 2020 target (17% of gross internal consumption from RE sources by 2020) of the European Union (EU) Renewable Energy Directive 2009/28/CE (GSE, 2017a). In fact, by 2017, the 2020 objective of the Directive was achieved in advance, in part due to the increase in PV capacity between 2010 and 2013.

As far as its costs are concerned, at the end of 2016, FIT payments to owners of PV systems installed under Conto Energia were estimated to be about 6 billion Euros (EUR) (GSE, 2017a), equivalent to about 0.4% of Italian GDP. FIT Payments for PV systems installed under Conto Energia will end in 2038[8], when the cumulative costs of Conto Energia will reach an estimated EUR 130 billion[9].

---

[8] FIT payments were originally guaranteed for the first 20 years of operation of the PV systems. The FIT scheme was retroactively modified by the Italian government in 2014, and as a result of one specific provision of this policy change, FIT payments for PV systems larger than 200 kW were extended to 24 years. The last FIT payments are expected to occur in 2038 (GSE, 2017).

[9] Estimate from the author. Unless otherwise specified, monetary figures in this chapter are in nominal terms.

The salient issue on Conto Energia is therefore whether or not the benefits from the incentive program have been large enough to justify its costs to final energy users, who pay for the incentives through a levy in their electricity bill. As of early 2018, this question remains largely unanswered. In particular, with the exception of a single study (Cai et al., 2016), there is a distinct lack of scholarly, peer-reviewed analyses looking ex post at the economic impacts of Conto Energia, carrying out such analysis through the whole life cycle of the incentive program (until 2038), and finally, comparing its impacts with a counterfactual scenario that can present policymakers with useful insights.

Ultimately, notwithstanding the wide range of potential benefits related to PV diffusion, the limited contribution from peer-reviewed literature on fundamental aspects like economic impacts has constrained the policy debate on what the future of PV technology in Italy could be to meet ambitious long-term decarbonization goals.

## 1.2 Rationale for Research

Seeing as the Conto Energia program was discontinued in June 2013, from the point of view of Italian policymakers and the overall domestic economy, the costs related to the implementation of this FIT scheme can now be considered "sunk costs"[10]. Hence, at this stage, any "posthumous" economic-impact analysis (EIA) of Conto Energia might be conceived as having limited value to decision makers. In fact,

---

[10] In microeconomic theory, a *sunk cost* is a cost "that has already been paid, or must be paid, regardless of any future action considered". In theory, "sunk costs should not be considered when making decisions" (Hall and Lieberman, 2012: 8).

from July 2013, the diffusion of PV technology in Italy has been supported by other measures, such as tax deductions for residential systems and net metering, and currently, no plans have been announced to reintroduce FITs for supporting PV electricity generation in Italy.

However, an assessment of the economic impacts, such as employment generated by PV deployment spurred by Conto Energia, both seen in the past and expected in future years, can bring scholarly insights to the scientific community and, most importantly, provide operational added value for policymakers. Research on the economic impacts of PV deployment under Conto Energia, both historically and over the years to come, can be of value to policymakers insofar as it can contribute to the design of future energy policies. In the new, recently published Italian National Energy Strategy (NES) (MSE, 2017), national policymakers (the Ministry of Economic Development and the Ministry of the Environment) have set strategies to achieve RE generation and energy efficiency (EE) targets for 2030 in compliance with the relevant European Directives. The objective for solar PV set in the NES is a generation of about 70 TWh in 2030, which would likely require an installed PV capacity of approximately 57 GW[11]. The ministries will need to implement specific energy and climate policy measures to achieve the 2030 targets in the frame of the so-called National Energy and Climate Plans.

In general, the rationale for conducting academic research on past and future economic impacts of PV and, broadly speaking, clean-energy[12] technology (CET)

---

[11] Assuming a “PV yield” of 1,225 kWh/kW (see Chapter 4).

[12] In the context of this thesis, *clean energy* is defined to include RE and energy efficiency.

diffusion in Italy is to advance scholarly knowledge on the methodological approaches that can be used to conduct ex ante-economic assessments of alternative energy policies aimed at pursuing a specific energy sustainability[13] goal. For example, a targeted share of energy from renewable sources by a given future date can be achieved with different mixes of renewable electricity sources, renewable heat sources, biofuels, and energy efficiency. Energy efficiency can be a critical component of such a policy mix, since it would reduce the magnitude of energy demand and thus "amplify" the contribution of absolute increases in renewable generation to achieve a targeted RE share on energy consumption. In a similar way, objectives to reduce carbon emissions from the energy sector can be achieved through a least-cost low-carbon mix by using so-called *marginal abatement curves* (Nauclér & Enkvist, 2009). Therefore, ex ante-analyses can, in theory, help identify clean-energy policy mixes that can bring maximum net benefits or economic impacts to the whole economy.

While previous analyses undoubtedly provided insights to advance knowledge on the impacts of Conto Energia and incentive-driven RE deployment in Italy in general (e.g., GSE, 2016b; Cai et al, 2016), there are still areas of research that deserve more granular investigation. One such area is the analysis of trade-offs in allocating financial resources to support the deployment of different clean energy options, for example, between renewable energy and energy efficiency, as mentioned above.

---

[13] *Energy sustainability* can be defined as the combination of three different dimensions: (a) environmental sustainability of energy extraction, conversion, and use (e.g. reduced greenhouse gas emissions and air pollution); (b) energy security; and (c) energy access and affordability.

Another area that deserves academic research is the application of multi-methodological frameworks that include learning-rate, cash flow, and economic impact analyses to construct scenarios projecting the diffusion of RE technology, and specifically PV in Italy. New knowledge that can emerge from this analysis also has the potential to inform future energy policy design by providing novel data on metrics, such as domestic learning rates, employment factors, output and employment multipliers, and other indicators in the frame of alternative energy scenarios. It can also help define priorities for public energy research, development, and demonstration (RD&D) funding, which Italy has committed to double in the context of the Mission Innovation initiative (Mission Innovation, 2017).

## 1.3 Research Questions

The main research question for which the present analysis will aim to provide answers regards estimating, in the frame of a *reference scenario*, the magnitude of economic impacts generated by historical PV deployment (to a large extent spurred by Conto Energia) during the years 2010-16 and projected through to 2020. To provide these answers, economic-impact analysis will estimate the output and employment generated in the economic sectors in which PV-system demand positively impacted production, directly or indirectly.

In order to provide a benchmark for comparison, the economic impacts of this reference scenario will then be compared with those of a *counterfactual scenario* based on different policy choices. The objective will be that of estimating the extent to which economic impacts might have been different, had Italian policymakers opted for a different strategy to support PV deployment.

The analysis will additionally aim to answer research questions relating to longer-term, future PV deployment in Italy (e.g., up to 2030 and beyond). There are two reasons for extending the analysis well beyond the historical time frame of 2010-16.

First, as mentioned in the previous section, payments for the FITs will cease in 2038, and the size of the annual financial incentives paid (and to be paid) is significant relative to the size of the Italian economy. Payments made to PV-system owners in 2016, financed through a levy on electricity prices, amounted to about EUR 6 billion (roughly 0.4% of the Italian GDP). Therefore, Conto Energia also has an *opportunity cost* in terms of an alternative, hypothetical use of the financial resources used for the FIT payments. For instance, to achieve the same reductions in both emissions and fossil fuel demand as was achieved with the historical PV installations under Conto Energia, at least a part of these resources might have been used instead to support EE projects (such alternative use will be described in detail in the counterfactual scenario).

Second, between 2006 and 2013, in parallel with the PV deployment spurred by Conto Energia, significant price reductions of PV systems took place in the domestic PV market. A deeper understanding of the factors that have been driving prices down since the very first phase of PV market commercialization, both on the global scale and in Italy, can provide greater methodological strength in constructing projections on investments in new PV systems or in operation and maintenance (O&M) expenditures for future years.

If these reductions were also the result of learning effects in the so-called *soft costs* (e.g. planning, permitting, and installation) and not only in the main components, like PV modules and inverters (the price reductions of which are the results of global market dynamics), then Conto Energia could also be credited with these *learning-effect benefits*. It could be counterargued that such domestic learning effects might have occurred even in the hypothetical case of delayed PV deployment, had access to FIT incentives been made available at a later stage or spread over a time period longer than the eight years (2006-13) of Conto Energia. However, the relatively fast FIT-driven deployment during Conto Energia had the ultimate effect of dragging back PV grid parity in a few market niches (see chapter 4). Without the significant market growth under Conto Energia, grid parity might have been reached later and the achievement of future energy sustainability objectives like those of the National Energy Strategy by 2030 could have been more challenging for policymakers.

In this regard, the two most relevant research questions related to learning dynamics and market competitiveness that will be addressed are: (a) to what extent the different PV system components[14] have contributed to the observed price reduction trend in Italy, and (b) what have been the driving factors of the price reductions for each PV system component. A more specific question is whether the increase in the domestic capacity spurred by the incentives has induced relevant learning effects in the soft-cost components of PV systems and, if so, what the contribution of this factor was toward the overall cost reduction of PV systems observed in Italy. Once the driving factors behind the observed price-reduction trend are understood, then future

---

[14] The main physical components of a PV system are PV module(s), inverter(s), support structures, and other electrical equipment (e.g., cables). The cost of a PV system includes also the so-called “soft-costs” related to the installation of the system (e.g., the profit margin of the company, the costs of the installation work, permits, etc.).

PV system prices in the Italian market can be projected assuming specific market-growth paths.

The scenario assessment extending to 2035 will complement the EIA from 2010 to 2020, with the objective of estimating any significant opportunity costs of energy-policy choices made in the past with respect to incentivizing PV commercialization. In order to address this broader question, scenarios will be based on projections on PV installations, PV system prices, and clean-energy investments alternative to PV. The research questions guiding the analysis are summarized in Figure 1.1.

### 1.4 Research Methodologies and Scenarios

The *economic impacts* and costs of policies supporting PV commercialization and, broadly speaking, RE diffusion, can be evaluated within the frame of so-called *Economic Impact Analysis*. Economic impacts can be defined as “effects on the level of economic activity in a given area” (Weisbrod & Weisbrod, 1997: 1) resulting from an economic event (including a change in policy). Economic impacts can be viewed in terms of (1) business output (or sales volume), (2) value added (or gross regional product), (3) wealth (including property values), (4) personal income (including wages), (5) jobs, and (6) welfare. Economic impact analyses can be assessed either after the economic event has occurred (ex post-impact analysis, looking at historical data), or before the economic event is expected to occur (ex ante-impact analysis), to cover the full time-frame where the policy is assessed to produce impacts (Weisbrod & Weisbrod, 1997)[15].

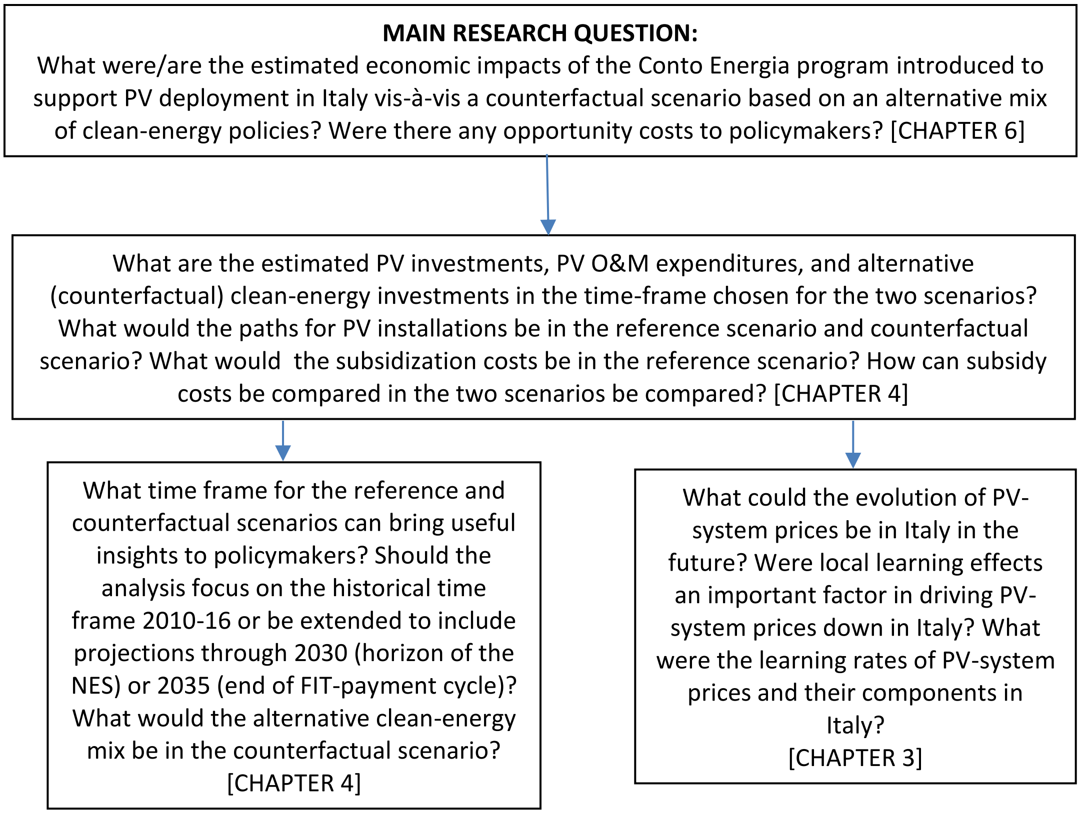


Figure 1.1 Logical Framework of Research Questions

---

[15] Measurement of welfare effects can be carried out through welfare functions (e.g., equivalent variation functions) or through alternative indicators to GDP, such as the Index of Sustainable Economic Welfare (ISEW; Daly and Cobb, 1989). Such indicators often include the effect on the well-being of citizens of reduced environmental pollution.

EIAs usually estimate economic impacts in the frame of two scenarios, the (a) reference or baseline scenario, which assumes the economic event under analysis actually occurs, and (b) counterfactual or alternative scenario, built on the assumption that the economic event does not occur. The four main methodological approaches used in literature for the economic impact analysis of energy policies or simply policy-driven deployment of a specific energy technology have been (1) employment coefficients, (2) input-output (I-O) models, (3) full economic models and (4) integrated modeling approaches combining two or all three of previous approaches (Breitschopf, Nathani, & Resch, 2013).

Policies supporting RE deployment (the above-mentioned economic event) that are the subject of economic impact analysis can consist of different measures, be these market creations (e.g., renewable portfolio standards combined with green certificates), capital subsidies, feed-in tariffs, or market regulation (e.g. net-metering standards), among others. Financial incentives (e.g. capital subsidies and feed-in tariffs) are usually paid through an increase in taxation of consumers and companies. Market creation or regulation measures can result into higher energy generation costs on the part of producers, which can be passed on to final consumers.

All these policies supporting RE deployment can produce both positive and negative economic impacts, and these impacts are further differentiated into gross and net effects. Gross positive economic impacts consist of a (estimated) positive variation of GDP and employment due to the (a) new production in the RE sector (so-called *direct effects*, consisting of the installation of RE systems) and linked industries (so-called *indirect effects*, consisting of the production of all the components of RE systems) spurred by the incentives, and (b) increased final consumption from the newly employed labor force (defined as *induced effects*). Conversely, gross negative economic impacts consist of a negative variation of GDP and employment due to (a) reduced production in the incumbent energy sectors (direct effects) and linked industries (indirect effects) "crowded out" by RE deployment, which will also determine a (b) reduction in consumption as a result of job losses in these incumbent industries where production is reduced (induced effects). There can be different degrees of complexity in estimating the induced effects, be these a simple "endogenization" of the net increase in labor force (if any), resulting in higher consumption, or an estimation of the so-called income and substitution effects (Nicholson, 1998) generated by increased taxation to pay for financial incentives or increased final energy costs. If impact analysis is also aimed at quantifying welfare effects, these could "capture" both environmental benefits (such as reduced pollution due to the avoided consumption of fossil-fuels) and energy security benefits resulting from reduced imports of oil and natural gas into a specific *welfare function* embedded in a macroeconomic model. The analytical output of the impact analysis will be the *net effects*, measured as the difference between the gross positive impacts and the gross negative impacts.

An economic impact analysis of policy-supported PV deployment in Italy should ideally capture all the aforementioned effects generated by industries directly impacted by PV deployment (e.g., manufacturing of PV-system components, construction and installation of PV systems, along with their operation and maintenance). However, for the sake of maximizing methodological solidity with respect to the data available and models accessible, it was opted to focus the analysis by estimating gross (direct and indirect) output and employment effects whilst not including the analysis of the induced or welfare effects. In fact, the literature review suggested that comprehensive analyses of the economic impacts of policy-driven deployment of a single RE technology at the national level that also include an estimation of the price and substitution effects are uncommon, as these are usually carried out for broad technology families (e.g. renewable energy, energy efficiency, biofuels). In practical terms, this means that EIAs of the deployment of a specific RE technology have usually made use of I-O models, which usually do not estimate the price effects that are instead captured by full economic models (e.g. Computable General Equilibrium Models or Macro-econometric models).

The major caveats of I-O models, namely that they usually do not incorporate the price and substitution effects that are generated, for example, by an increase in taxation to pay for the RE incentives, might not be relevant in those cases where the "no-policy" counterfactual scenario has no significant analytical value. This can be the case, for instance, when the policies for which the impacts are estimated are the result of previous international commitments, leaving policymakers only with room to look for optimized, least-cost ways to achieve targets (e.g., reduction of $CO_2$ emissions or increase in the share of renewable energy in primary energy supply). In light of the above considerations, the present analysis of the economic impacts of Conto Energia will be carried out using the I-O methodology in the frame of a multi-methodological framework that also includes the development of scenarios and the use of learning curves[16].

---

[16] A schematic of the methodological framework is shown in Figure 1.2.

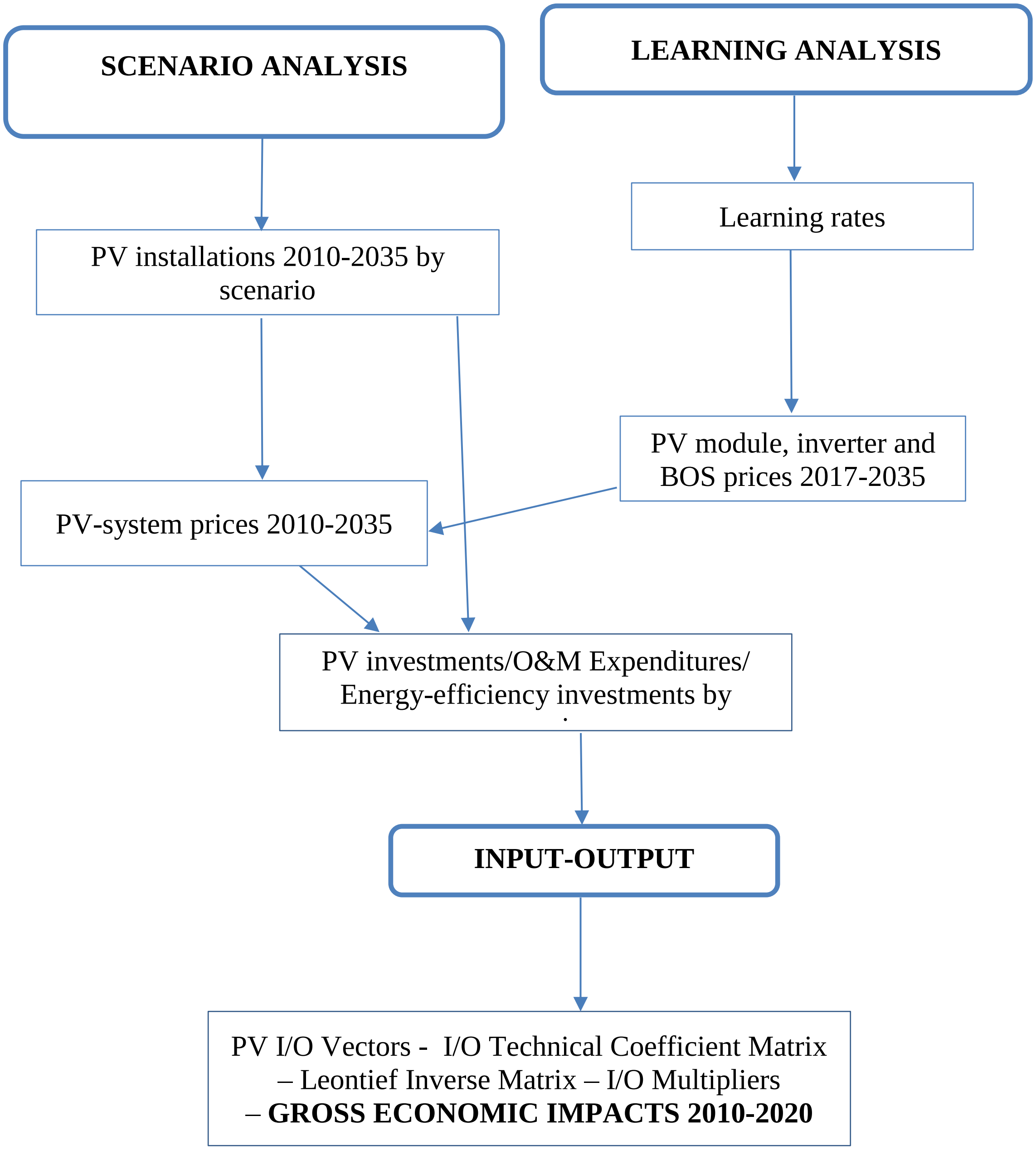


Figure 1.2 Modeling Framework

In the preliminary research phase of the research, a review was conducted of the most relevant literature concerning the application of learning analyses, I-O models, and integrated methodological approaches. This review focused on an analysis of past and present models used, and was aimed at discerning critical aspects that could determine the effectiveness of a specific modeling framework versus alternative ones.

As already mentioned, the analysis will be aimed at estimating the gross economic impacts between 2010 and 2020 of two different scenarios, combining ex post- and ex ante-analysis: (1) a reference scenario that is based on historical data between 2010 and 2016; and projections to 2020; (2) a counterfactual scenario, characterized by delayed support for PV technology, where installed capacity by 2016 is lower than the reference scenario but where there is additional support for energy efficiency so as to achieve the same reductions in natural gas demand between 2010 and 2020, as in the reference scenario. Furthermore, scenario projections are extended to 2035 to assess the long-term opportunity costs of the PV-deployment path initiated by Conto Energia that are embedded in the reference scenario, as well as the potential subsidy savings of the counterfactual scenario. Both scenarios are assumed to reach the PV objective of the National Energy Strategy by 2030.

The price reduction trend of PV systems in Italy and their main components was analyzed so as to derive the *Learning Rate,* a metric that quantifies the percentage reduction of cost and price for each doubling of installed (or production) capacity. Experience curves were then used to project prices of key PV-system components in Italy between 2017 and 2035.

With projections on components of PV system prices from the experience-curve analysis and PV annual installations exogenously determined in the scenario analysis, annual investments in PV capacity and O&M expenditures are estimated for both the reference and counterfactual scenarios. A grid-parity analysis was also carried out to understand at which level of PV system prices the domestic PV market would be self-sustaining. With data on PV investments defined in the frame of the two scenarios, the analysis sets out to answer the main research question, that is, what the economic impacts of these two pathways are over the 2010-20 time frame.

The scenario results are “fed” as inputs into the I-O model in order to estimate the gross economic impacts (direct and indirect output and employment effects). The I-O analysis consisted in the construction of the vector of the Italian PV industry (installation and O&M), the technical coefficient matrix, the Leontief matrix, the output and employment multipliers, and the calculation of the economic impacts.

The analysis concludes with a qualitative policy assessment that includes policy recommendations.

## 1.5 Data Collection and Literature Reviews

The main sources of data for the analysis were reports published by private and governmental entities as well as online databases. The reports that provided the most important data included the *National Survey Report* of the International Energy Agency (IEA) Photovoltaic Power Systems’ (PVPS) Programme (IEA-PVPS) (Castello et al., 2003-2015; Tilli et al., 206-207), the *Trends in PV Applications Report* from (IEA-PVPS, 2016; 2017), the *Rapporto Statistico Solare Fotovoltaico* from the government-owned entity Gestore dei Servizi Energetici (GSE, 2009-2016), and the

*Solar Energy Report* of the Energy&Strategy Group (Politecnico di Milano, 2014). The I-O table was obtained from the online database of the Italian National Statistics Agency (ISTAT, 2015).

Literature reviews were conducted with the objective of providing the most up-to-date knowledge on the methodologies used for and issues related to the application of the experience curve and I-O methodologies to RE technologies, with a focus on solar PV. The most important sources reviewed are detailed specifically in each of the chapters. Literature reviews were also aimed at complementing the main data sources in terms of extracting data useful for the analysis, such the price share of the different PV system components, the operation and maintenance costs, and all the data needed to construct the I-O vectors for PV technology in Italy.

The most relevant sources reviewed on the economic impact analysis of PV deployment or, more broadly, on the deployment of all renewable energy in Italy and Europe, are based on the I-O methodology, either before the peak-phase (2009-12) of Conto Energia (CNES, 2007; Barbarella, Liberatore, & Galli, 2009; D'Orazio, 2009) or after its end (GSE, 2016b; Cai et al., 2016). The EmployRES study (e.g., Ragwitz et al., 2009) and the work carried out for the IEA's Renewable Energy Technology Deployment (RETD) Implementing Agreement (Breitschopf, Nathani, & Resch, 2013) provided important methodological insights and guidelines for the construction of the I-O vectors for PV technology in Italy. The book *Input-Output Analysis* by Miller and Blair (2009) provided the broad conceptual framework for the I-O analysis.

## 1.6 Organization of Chapters

After analyzing the current status of PV technology in Italy and the most relevant elements of the policy and institutional framework, Chapter 1 provides an introduction to the research problem. This research problem is identified as a lack of understanding the economic impacts of the Italian feed-in tariff program that supported PV technology until 2013 (with an extension for specific categories of PV systems until 2016) and of which the financial effects will continue beyond 2030. The several, complex research questions that need to be answered to address this research problem require the adoption of a multi-methodological framework that includes experience curves, grid-parity assessment, and an input-output framework.

Chapter 2 analyzes the Italian PV market and policy support schemes as they evolved from the very early phases of PV deployment (early 1990s) to the current phase, as a transition to a fully self-sustaining market unravels. The single support measure that provided an effective boost to the domestic PV market was the feed-in tariff program Conto Energia, which was implemented in five phases from 2006 to 2013. After the Conto Energia program was discontinued, the domestic PV market experienced a marked contraction, though the existing schemes (tax deductions for residential systems, net-metering, and the *Sistemi Efficienti di Utenza*) were able to support the market to achieve annual installations in the 300 to 400 MW range. Moving forward, the policy framework will need to ensure a smooth transition to full commercial viability of PV without any incentive.

Chapter 3 sets to analyze PV-system prices in the Italian market with the objective of elaborating 2017-35 projections, as input for the scenario analysis. The chapter first assesses the historical price-reduction trend of the different PV system components observed in Italy between 2002 and 2016, building on granular data collection. The experience curve methodology is subsequently used to estimate the Learning Rate of PV systems in Italy over the same time period, looking also at each of the main PV-system components (modules, inverters, installation costs, and other elements). The role of local learning effects in the installation phase was subject to particular scrutiny, in order to also understand the extent to which this factor could play a role in future price reductions. Projections on PV-system components through 2035 are then elaborated, assuming a range of market-growth rates.

The scenarios framing the economic impact analysis of PV deployment spurred by Conto Energia are discussed in Chapter 4. Projections are first elaborated for PV installations, from which the soft-cost component (installation costs) of PV system prices in each scenario are derived. Projections on PV-system prices are then calculated by summing estimated prices for modules, inverters, and BOS (subject to global learning effects) and for soft costs (subject to local learning effects). Next, investments for construction and installation of PV systems and O&M expenditures of PV capacity are derived for the two scenarios. Energy efficiency investments in the counterfactual scenario are also estimated, from available literature. The extent of government subsidies needed for investments in the two scenarios are calculated by estimating the *subsidy-equivalent* of the FIT payments, the degree of *subsidization* of energy-efficiency investments, and the commercial break-even point for PV technology, after which incentives are not needed to ensure a commercially viable market.

Chapter 5 discusses the theoretical framework for the economic impact analysis. Economic impacts (both positive and negative) are realized through a complex interaction of economic mechanisms that are first categorized into direct, indirect, and induced effects. A literature review was conducted to analyze the specific models used in various academic and professional works estimating the impacts of energy technology diffusion. From among all the available models, the input-output modeling framework was judged as the one most suitable for carrying out the present impact analysis.

The economic impact analysis of the reference and counterfactual scenario is discussed in Chapter 6. All the methodological steps are described in detail, beginning with the data collection necessary to construct the input-output vectors for the Italian PV sector. The two PV I-O vectors (one for investments for the installation of PV systems and the other for operation and maintenance on existing PV systems), a 12-sector transaction matrix and the related coefficient matrix with 12 sectors were constructed. Gross output and employment effects were estimated for the two scenarios for the time frame 2010-2020.

Chapter 7 concludes the analysis, summarizing the results and linking these with recommendations for Italian public decision makers.

## 1.7 Summary

Notwithstanding the significant contribution of PV technology to the Italian electricity sector, there is a lack of empirical research on the economic impacts of the main driver of PV market deployment in the past years, namely the Conto Energia FIT program. Novel analysis that addresses this research gap can help policymakers design more effective and efficient energy policies, where the economic returns of public financial resources used to incentivize sustainable energy can be properly assessed. A multi-methodological approach is used to answer several research questions related to estimating the economic impacts of Conto Energia throughout the whole life cycle of the program. The methodological framework adopted consists of experience curves, scenario analysis, and the input-output methodology.

# Chapter 2

# THE EVOLUTION OF THE ITALIAN PV MARKET AND PV SUPPORT POLICIES FROM 1992 TO 2016

## 2.1 The Evolution of the Italian PV Market from 1992 to 2016

Cumulative PV capacity in Italy at the end of 1992[17] was only 0.78 MW, most of which was used for off-grid applications (Castello, Tilli, & Guastella, 2015). After twenty-four years of incentive-driven deployment, by the end of 2016, PV cumulative capacity in Italy reached about 19,300 MW, with a generation of 22.1 TWh (GSE, 2017) – meeting more than 7% of Italian electricity demand. From 1993 to 2016, photovoltaics successfully transitioned from being a small niche market to becoming the fourth source of electricity generation in Italy (after natural gas, hydro, and coal)[18]. The market deployment of PV technology in Italy has been supported by different incentive schemes that have spanned over an almost thirty-year period (1988-2017). The specific measures taken and their relative effectiveness has varied significantly over time since the first support scheme was introduced in the late 1980s. Arguably,

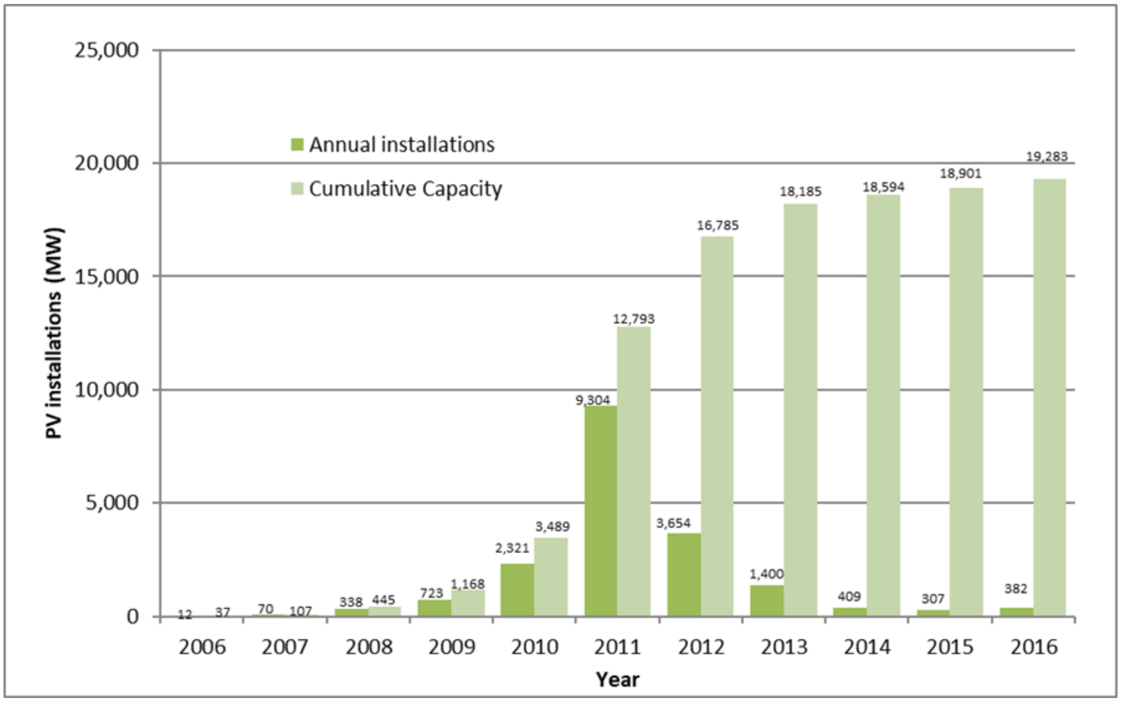
---

[17] 1992 is the first year for which data on PV installations are reported by the National Survey of the International Energy Agency – Photovoltaic Power Systems Programme (IEA-PVPS).

[18] Data used in this chapter are drawn from the Annual Reports (Surveys) of the IEA-PVPS program (Castello, Tilli & Guastella, 2015), the annual Solar Photovoltaics Statistical Reports of Gestore dei Servizi Energetici (GSE) (2008-2017b), The Solar Energy Report, and the Renewable Energy Report of the Politecnico di Milano (2009-2017).

the attitude of policymakers towards PV technology has also been influenced by several factors, such as the successful implementation of PV incentive programs in Germany and Japan, the greater public interest in distributed renewable technologies, and the cost-reduction trend observed in the market over time.

The pattern of PV market growth in Italy can be divided into four major stages. The first period, from 1993 to 2001, is characterized by linear growth with cumulative capacity increasing from 0.78 MW in 1992 to 8.35 MW in 2001. The second phase, beginning in 2002, is denoted by an increase in annual installations spurred by the introduction of a capital subsidy program, the *Diecimila Tetti Fotovoltaici* ("10,000 Photovoltaic Roofs") program. In the five years between 2002 and 2006, cumulative capacity grew from 10 to 37 MW, a much higher increase in absolute levels than what occurred during the ten years previous, from 1992 to 2001. The introduction of the Conto Energia feed-in tariff (FIT) program in 2006 marks the beginning of the third phase. From 2007 to 2011, the domestic PV market grew exponentially, with cumulative capacity increasing from 37 MW at the end of 2006 to about 12,800 MW at the end of 2011 (Figure 2.1). Annual installations grew from a volume of 70 MW in 2007 to a record 9,300 MW in 2011. In 2012-13, however, for the first time in twenty years, annual PV installations exhibited a decreasing trend, with 3,400 MW of installed power in 2012 and 1,618 MW in 2013. This market contraction was caused by a marked decrease in FITs and their eventual phase-out in July 2013. The fourth phase, which can be defined as the post-FIT phase, begins in mid-2013 and can be considered as a transition from a (previously) strongly incentivized market (Conto Energia FITs often provided returns higher than 15% to owners of PV systems) to one with moderate policy support (e.g., capital subsidies for residential PV systems and a net billing scheme) in order to accompany PV technology to market viability without support measures. Between 2014 and 2016, PV annual installations returned to the 2008 levels, hovering around the 300 to 400 MW range.



Data sources: Castello et al. (2002-2015) ; GSE (2009-2017).

Figure 2.1 PV Annual Installations and Cumulative Capacity, 2007-2014

## 2.2 Historical Trends in the Different PV Market Niches and Applications

Understanding how PV technology was deployed in different segments or niches of the Italian market can provide useful data and insights for the first analytical steps in the methodological framework, such as the examination of the reduction trend in PV system prices over time.

Of the 19.3 GW of grid-connected cumulative PV capacity in Italy operating at the end of 2016, almost 40% of installations were *distributed* [19] (up to 200 kW of rated power), while the remaining 60% was made of *centralized* systems (above 200 kW of rated power). The shares of these two market segments on PV annual installations varied significantly over time. At the onset of the implementation of the FIT program in 2006, these shares were 82% and 18% for distributed and centralized systems, respectively.

While in 2009 distributed PV systems and centralized systems had equal shares in annual installations, the share of distributed PV gradually decreased to about 30% in 2011. Between 2010 and 2012, centralized power systems had more than half of the market share, with a peak of about 70% of annual PV installations in 2011. This trend of decreasing market shares for distributed PV systems was reversed in 2012, and from 2013, the latter increased their share markedly, reaching 83% of annual installations in 2016 (Table 2.1), when the shares of PV cumulative capacity were about 60% and 40% for centralized and distributed PV systems, respectively.

---

[19] The category *distributed PV systems* is defined by the IEA-PVPS as grid-connected systems “installed to provide power to a grid-connected customer or directly to the electricity grid specifically where that part of the electricity grid is configured to supply power to a number of customers rather than to provide a bulk transport function“. The other category of grid-connected PV systems defined by the IEA-PVPS is *centralized PV power systems*, which are defined as “PV power systems performing the function of a centralized power station” (Castello et al., 2015: 211). This thesis will use a simplified definition based on rated-power ranges as specified in the text.

From these trends, it can be inferred that during the first part of the aforementioned market phase (from 2007 to 2011), that is, during the first three schemes of the Conto Energia program, the policy framework was particularly attractive (in relative terms) for centralized power systems. From 2012 onwards, on the other hand, the policy framework privileged distributed PV systems.

Table 2.1 Annual Installations and Cumulative Capacity of Distribute and Centralized Grid-connected Photovoltaic Systems

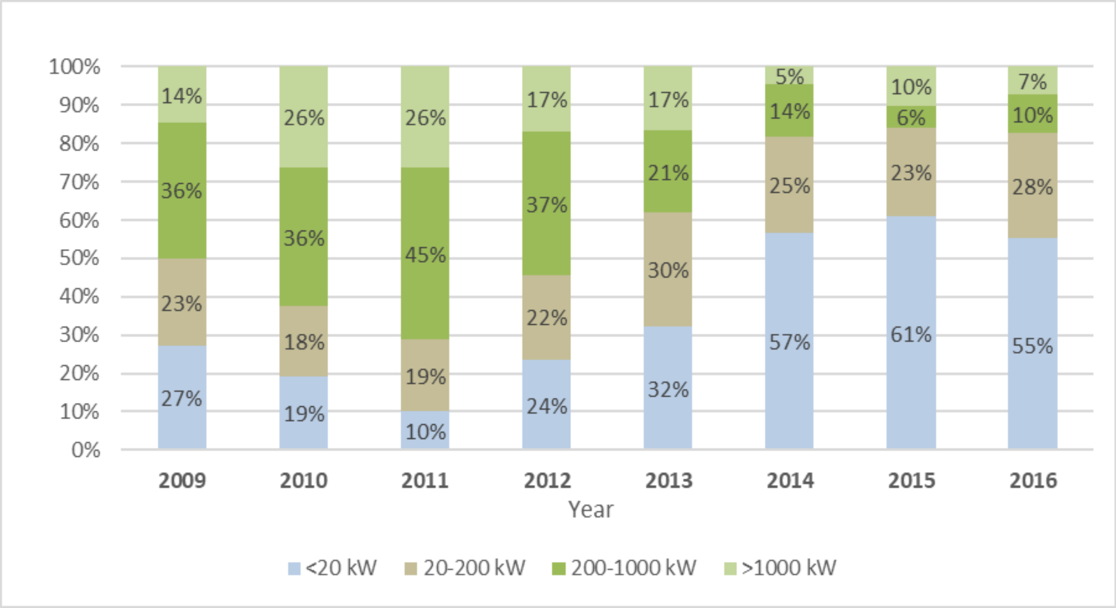
| Year | **Annual Installations** | | | **Cumulative Capacity** | | |
|---|---|---|---|---|---|---|
| | Total PV (MW) | Distributed PV(a) (%) | Centralised PV(b) (%) | Total PV (MW) | Distributed PV(a) (%) | Centralised PV(b) (%) |
| 2002 | 2 | 100% | 0% | 10 | 35% | 65% |
| 2003 | 4 | 100% | 0% | 14 | 53% | 47% |
| 2004 | 4 | 100% | 0% | 19 | 64% | 36% |
| 2005 | 7 | 100% | 0% | 25 | 73% | 27% |
| 2006 | 12 | 100% | 0% | 37 | 82% | 18% |
| 2007 | 70 | 69% | 31% | 107 | 78% | 22% |
| 2008 | 338 | 62% | 38% | 445 | 66% | 34% |
| 2009 | 723 | 50% | 50% | 1,168 | 55% | 45% |
| 2010 | 2,321 | 38% | 62% | 3,489 | 43% | 57% |
| 2011 | 9,304 | 29% | 71% | 12,793 | 33% | 67% |
| 2012 | 3,646 | 46% | 54% | 16,439 | 36% | 64% |
| 2013 | 1,746 | 62% | 38% | 18,185 | 38% | 62% |
| 2014 | 424 | 82% | 18% | 18,609 | 39% | 61% |
| 2015 | 307 | 84% | 16% | 18,916 | 40% | 60% |
| 2016 | 382 | 83% | 17% | 19,299 | 41% | 59% |

Note: (a) ‘Distributed PV’ refers to PV systems up to 200 kW of rated power; (b) ‘Centralized PV’ refers to PV systems above kW of rated power.

Data sources: Castello et al., 2002-2015; GSE, 2009-2017; Politecnico di Milano, 2008-2014; author’s estimates.

Looking at a more granular categorization of PV systems: residential PV systems (1-20 kW) had the highest share of annual installations (55%) in 2016, followed by commercial (20-200 kW – 28% of the market), industrial (200-1000 kW –

10%), and utility-scale (above 1000 kW – 7%) systems (Figure 2.2). The sector with the highest share of cumulative PV capacity in 2016 was industrial systems (38%), while residential, commercial, and utility-scale systems had about 20% of installed capacity each (GSE, 2010-17).



Data sources: Castello et al., 2002-2015; GSE, 2009-2017.

Figure 2.2 Annual PV Installations by System Size, 2009-2016

Another common categorization of PV applications is that distinguishing between building-applied (BAPV), building-integrated (BIPV), and ground-mounted PV systems[20]. At the end of 2016, there were about 11.4 GW of BAPV systems and

---

[20] *BAPV systems* are defined by the IEA-PVPS program as PV systems on rooftops installed as a retrofit on the building envelope (IEA-PVPS, 2016; Castello et al.,

7.9 GW of ground-mounted systems installed[21]. The shares of these two applications on the PV market varied markedly over time (Table 2.2).

Table 2.2 PV Capacity in Italy by Market Segment: Ground-mounted and BAPV Systems, 2002-2016

| Year | **Annual Installations** | | | **Cumulative Capacity** | | |
|---|---|---|---|---|---|---|
| | Total PV (MW) | Ground-mounted PV (%) | BAPV[(a)] (%) | Total PV (MW) | Ground-mounted PV (%) | BAPV[(a)] (%) |
| 2002 | 2 | 0% | 100% | 10 | 65% | 35% |
| 2003 | 4 | 0% | 100% | 14 | 47% | 53% |
| 2004 | 4 | 0% | 100% | 19 | 36% | 64% |
| 2005 | 7 | 0% | 100% | 25 | 27% | 73% |
| 2006 | 12 | 0% | 100% | 37 | 18% | 82% |
| 2007 | 70 | 7% | 93% | 107 | 11% | 89% |
| 2008 | 338 | 27% | 73% | 445 | 23% | 77% |
| 2009 | 723 | 50% | 50% | 1,168 | 40% | 60% |
| 2010 | 2,321 | 41% | 59% | 3,489 | 41% | 59% |
| 2011 | 9,304 | 50% | 50% | 12,793 | 48% | 52% |
| 2012 | 3,646 | 22% | 78% | 16,439 | 42% | 58% |
| 2013 | 1,746 | 28% | 72% | 18,185 | 41% | 59% |
| 2014 | 424 | 8% | 92% | 18,609 | 40% | 60% |
| 2015 | 307 | 3% | 97% | 18,916 | 40% | 60% |
| 2016 | 382 | 2% | 98% | 19,299 | 39% | 61% |

Note: (a) See footnote [21] for definition of BAPV systems

Data sources: Castello et al., 2002-2015; GSE, 2009-2017; Politecnico di Milano, 2008-2014; author's estimates.

---

2015). *BIPV systems* are defined by the same IEA-PVPS program as "PV modules doubling [sic] as construction products, which are integrated in the building envelope as part of the building structure, replacing conventional building materials and contributing to the aesthetic quality of the building as an architectural component" (IEA-PVPS, 2017:36). For the sake of simplicity, in the remainder of this thesis, the term *BAPV* will be used to refer to both BAPV and BIPV systems as defined by the IEA-PVPS program.

[21] Estimate from the author based on different sources (Castello et al, 2015; GSE, 2016; Politecnico di Milano, 2014).

Between 1993 and 2001 (first market phase), more than 80% of PV capacity was installed in the niche of ground-mounted PV systems[22]. Between 2002 and 2006 (second market phase), BAPV made up the bulk of annual PV installations. From 2007 to 2013 (third market phase), both market segments experienced exponential growth in absolute terms. Annual installations of ground-mounted systems grew at much higher pace than BAPV systems until 2011 (when annual installations of the former were about 4,600 MW and made up 50% of the market), but then reduced to less than one-third of the market in 2013. During the fourth phase (second half 2013 to end of 2016), the market reduction was more marked for ground-mounted installations, which had a decrease in volume to less than 10 MW in 2016.

## 2.3 The Early Phases of PV Technology Deployment in Italy

The deployment of PV technology in Italy began in the late 1980s, with the realization of several demonstration projects for both grid-connected PV (rooftop and ground-mounted applications) and stand-alone systems. The National Energy Plan of 1988 had an objective of 25 MW of PV installations by 1995. While this target was not achieved, Italy was nonetheless the top ranked country in Europe for cumulative installed capacity during the first half of the 1990s (IEA-PVPS, 2002).

---

[22] The IEA-PVPS defines "Centralized PV Power Systems" as a "power production system performing the function of a centralized power stations. The power supplied by such a system is not associated with a particular electricity customer, and the system is not located to specifically perform functions on the electricity grid other than the supply of bulk power. Typically ground mounted and functioning independently of any nearby development." (Castello et al., 2015: 21).

An FIT scheme was introduced for centralized PV power stations as early as 1992. Furthermore, the Italian Government was also committed to supporting the deployment of PV technology through research, development, and demonstration (RD&D) activities. These policies had an important effect on the domestic PV industrial system, with Italy being among the global leaders in industrial production of PV modules until the mid-1990s.

In 1996, however, the national PV program was discontinued and Italy lost its leadership in PV (Ferrazza et al., 2002). This decrease in research funding and inadequacy of support measures caused a significant slow-down in the domestic market, and for rooftop PV systems in particular. While between 1992 and 1996 cumulative domestic PV capacity had almost doubled, increasing from 8.5 MW to 16 MW, the increase between 1997 and 2001 was of a modest 3 MW, with cumulative capacity at the end of 2001 totaling 20 MW (Castello et al., 2015). As a result, Italy lost the status as technology and market leader that it had, until then, shared with Germany, Japan, and the United States (US).

## 2.4 The *10,000 PV Roof* National Program

The national program *10,000 PV Roofs*, a capital-subsidy scheme for small PV systems, was introduced by the Ministries of Environment and Industry in 2001 (Castello et al., 2002). Under this program, capital subsidies were made available to individuals, private companies, and public entities for rooftop PV systems ranging in size from 1 to 20 kW and connected to the low-voltage electric grid. The subsidy was calculated as a percentage of the capital investment, initially set at 75% (and later decreased to 65%). This program lasted about four years (2001-04) and was articulated in three different sub-programs: (1) a national program for public entities; (2) a national program for PV systems with high architectural value; and (3) regional programs for private and public entities.

The 10,000 PV Roofs program was characterized by two distinct financing cycles. The first phase was concluded during the first months of 2002 and saw the installation of 2,000 PV systems for about 11 MW. The second phase started in 2002 and was concluded in 2005. As a result of this capital subsidy program, PV capacity installed in Italy increased from 22 MW at the end of 2002 to 37.5 MW at the end of 2005. However, the management of the program at the local level by the Regions was characterized by significant bottlenecks, in particular the lengthiness of the approval and financing process, which reflected a general lack of technical capacity by local authorities.

## 2.5 The Conto Energia Feed-in Tariff Program (2006-2013)

After the encouraging results of the capital-subsidy program and the positive outcome of the FIT program in Germany, in 2005, an FIT program (Conto Energia) was also launched in Italy. This first Conto Energia scheme was followed by four different revisionary schemes over the 2007-13 period.

The first FIT scheme was introduced in July 2005 (with substantial revisions made in February 2006) and was in effect until late 2006. Tariffs were diversified based on size (ranging from a minimum of 1 kW and classified in different segments) and type of systems (ground-mounted vs. BAPV), and were also fixed for 20 years (but with FITs for new plants set to decrease by 5% each year). Tariffs under this first Conto Energia scheme varied from 0.445 EUR/kWh for PV systems up to 20 kW (but only for the PV electricity produced used for self-consumption by the PV-system owner) to 0.46 EUR/kWh for PV systems with rated power from 50 to 100 kW (regardless of whether the PV electricity generated was used for self-consumption or fed into the grid). The decree that introduced this first FIT scheme had an objective of 300 MW of PV capacity by 2015 and a cap of 100 MW of the same PV capacity to be supported with FITs.

This first FIT scheme rapidly had a positive impact on PV diffusion, given that the total cap of cumulative capacity (100 MW) was reached only 9 days from the publication of the decree. In total, the first Conto Energia scheme supported the installation of 163 MW.

The second Conto Energia scheme was introduced in February 2007 and was characterized by a simplification of procedures and a reduction of tariffs. Another major difference was that tariffs for PV systems between 1 and 20 kW were granted not only to self-consumed electricity, as in the previous scheme, but now to all PV electricity generated (regardless of whether self-consumed or fed into the grid). PV systems eligible for the twenty-year tariffs were classified into three categories: integrated, partially integrated, and non-integrated.

The maximum capacity to be supported with this scheme was set at 1,200 MW, with a goal for cumulative capacity of 3,000 MW by 2016. The second Conto Energia was slated to be phased out in December 2010, but new legislation introduced in August 2010 (the so-called Salva Alcoa Decree) also granted the tariffs to PV plants installed before the end of 2010 but connected to the grid during the first half of 2011. The total capacity supported by the second Conto Energia amounted to about 6,800 MW. Under this second scheme, the Italian PV market shifted from a “niche” dimension (with 70 MW installed in 2007) to much larger volumes (2,300 MW in 2010).

Due to the marked reduction in PV system costs and the significant increase in domestic demand (+1100% in annual installations in 2009 with respect to 2007 levels), in August 2010, policymakers revised the incentive program with the third Conto Energia scheme, which was approved after a five-month legislative vacuum. The main changes introduced were a simplified classification of plants, the introduction of new capacity caps for specific categories of plants, and a general reduction of tariffs. PV systems were classified into three categories: (1) “solar PV plants” (with tariffs differentiated between two subcategories: (a) “plants on buildings”; and (b) "other plants", the latter subcategory including ground-mounted systems); (2) “integrated plants with innovative characteristics” (aimed at substituting the architectural elements of a building); and (3) “concentrating PV plants”[23].

The FITs, which were diversified for these categories and for different capacity intervals, were granted for twenty years for all electricity generated (regardless of whether self-consumed or fed into the grid), but were subject to a 2% annual decrease. The tariffs varied in relation to the size of the PV systems and were also scheduled to decrease along three different implementation phases. For example, in the first implementation phase (January – April 2011), tariffs for BIPV plants ranged from 0.40 to 0.333 EUR/kWh whereas for ground-mounted plants, the interval was from to

---

[23] Tariffs for technologically innovative plants were to be introduced with a subsequent implementation decree, which was never issued because of the approval of the fourth Conto Energia FIT scheme that further reformulated the classification of plants.

0.362 to 0.297 EUR/kWh. In addition to FITs, PV plant owners could also opt for net metering (only for plants up to 200 kW) or for selling the electricity not self-consumed (either to GSE, the electricity market, or to wholesalers). Furthermore, several premium tariffs were also introduced for special cases such as, for example, a 10% increase for PV plants replacing roofs with asbestos. The capacity that could be supported by the incentives was capped according to the different categories, ranging from 200 MW for PV concentrating plants to 3,000 MW for BIPV systems and other plants. The 2020 objective was set at 8000 MW of PV installed capacity. This third scheme was in force for only five months (January – May 2011) and supported the installation of 1,535 MW.

The continued drop in module prices coupled with the sustained growth of installations, particularly ground-mounted plants at utility-scale (above 1 MW), raised concerns about the financial sustainability of the program and the excessive use of agricultural land. Consequently, in May 2011, a fourth FIT scheme was introduced with the aim of achieving a more balanced composition of PV capacity, with a higher share of small, BAPV plants with respect to large, ground-mounted plants. The PV capacity target was revised to 16 GW by 2016. The major features of the fourth Conto Energia scheme were: (1) a further simplification of the classification of plants; (2) a further decrease in tariffs; and (3) a revision of the cap on capacity to be supported by incentives combined with a cap on the total cost of incentives. Tariffs were reduced for all types of plants, with an average decrease in the order of 24.5% for BIPV and 25.5% for other plants. The scheduled reductions for tariffs were established on a monthly basis for plants installed in 2011, and on a semester basis from 2012. The combined cap on the financial cost of the incentive scheme and on the maximum capacity of big plants to be supported by the incentives was established on a semester basis. For example, for the period June 2011 – December 2012, the cost limit was set at EUR 580 million, and the capacity target at 2,690 MW. The capacity cap was translated into a limited access to incentives through the creation of a register for big plants. Applications for inclusion in the register were ranked according to different criteria, such as whether the PV plants were already operating at the date of the submission of the application, whether construction works were already completed, the date of permits, the size of the plants, and the date of submission of the application. Following the same approach as the third scheme, the fourth Conto Energia scheme also included premium tariffs for BIPV plants with innovative characteristics and for concentrating PV plants. The provision of these premium tariffs reflected policymakers' intent to support the pre-competitive research of national companies in market niches considered to still be in the development stage. Another new feature of the fourth FIT scheme was the provision of a premium 10% increase in tariffs for those PV systems for which at least 60% of the cost could be tracked to components produced within the European Union (EU). However, the cumbersome and contradictory implementing measures of this specific provision in the context of falling costs of cells and modules made this premium tariff virtually ineffective in supporting EU production. Overall, the fourth FIT scheme supported the installation of 7,600 MW of PV systems.

The fifth and last phase of the Conto Energia program was introduced in July 2012. The most important changes to the previous scheme were: (1) a further reduction in the FITs (see Table 2.3); (2) the obligation for all PV systems with a capacity higher than 12 kW to compete for the incentives through a ranking system in the frame of a specific national register (the threshold for the previous scheme was set at 200 kW for BIPV systems and 1 MW for ground-mounted systems); (3) the setting of a financial cap of EUR 6.7 billion per year as the maximum annual cost for the FIT scheme (for plants installed throughout of the five phases); (4) the partitioning of the tariff in two components: (a) a "comprehensive tariff" for the PV electricity that was fed into the grid; and (b) a "self-consumption bonus" tariff for PV electricity that was consumed on-site (see Table 2.3); and (5) the incompatibility between the FIT scheme and other forms of market support such as net metering and *ritiro dedicato* (a simplified purchase agreement of electricity generated by PV systems, alternative to FITs) (Politecnico di Milano, 2013: 87-88). The ranking of PV systems in the national register was based on different criteria such as the (certified) energy efficiency of the building (in case of building-integrated systems), the possibility of replacing asbestos in old roofs, the use of components manufactured within the EU, the installation on special sites (brownfields, depleted mines, etc.), the integration of PV systems (with capacity lower than 200 kW) with a production activity, and other building-integration criteria (e.g. greenhouses).

Table 2.3 Feed-in Tariffs of the Fifth Conto Energia between January and May 2013

| | **Building-applied PV systems** | | **Other PV systems** | |
|---|---|---|---|---|
| Capacity tier (kW) | Comprehensive tariff (Euro/kWh) | Self-consumption bonus (Euro/kWh) | Comprehensive tariff (Euro/kWh) | Self-consumption bonus Euro/kWh) |
| 1 -3 | 0.182 | 0.1 | 0.176 | 0.094 |
| 3 - 20 | 0.171 | 0.089 | 0.165 | 0.083 |
| 20 - 200 | 0.157 | 0.075 | 0.151 | 0.069 |
| 200 - 1,000 | 0.13 | 0.048 | 0.124 | 0.042 |
| 1,000 - 5,000 | 0.118 | 0.036 | 0.113 | 0.031 |
| > 5,000 | 0.112 | 0.03 | 0.106 | 0.024 |

Data source: GSE, 2014a

The main effect of the reduced tariffs and extension of the capacity range with the obligation of registration procedure was that of driving the market towards installations of a lower size relative to the fourth Conto Energia scheme.

The financial cap of EUR 6.7 billion set by the Italian Government for the annual cost of the Conto Energia program was reached in July 2013. Hence, from the second half of 2013, FITs were no longer available to support PV installations except in specific categories, which benefited from the incentives of the fifth Conto Energia until September 2016[24].

In 2014, the Italian Government issued a legislative decree[25] (*Spalma Incentivi*) that introduced retroactive changes to the FITs for plants with rated power higher than 200 kW, effective from 1 January 2015. Owners of PV plants had to choose from among three options: (1) a reduction of the tariff (between 17 and 25%) coupled with an extension of the entitlement period to 24 years (vs. the initial 20 years); (2) a reduction of the tariff (between 10% and 26%) in a first phase followed by an increase (of the same absolute percentage of the initial decrease) in a second phase, with the total duration of 20 years remaining unchanged; and (3) a reduction of the incentive for the remainder of the entitlement period in the order of 6% for plants up to 500 kW of rated power, 7% for plants from 500 kW to 900 kW, and 8% above 900 kW (Politecnico di Milano, 2015).

---

[24] Two of these categories were: (a) public-sector entities, which had access to the incentive until 2015; and (b) owners of new PV systems located in specific provinces hit by earthquakes (GSE, 2017a).

[25] Legislative Decree n. 91/2014.

Table 2.4 summarizes the results of the five schemes of the Conto Energia program, which between 2006 and 2013 supported the installation of 550,587 PV systems with a capacity of 17,734 MW (more than 90% of PV capacity in operation at the end of 2016). More than 80% of the capacity installed was supported by the second and fourth schemes.

Table 2.4 Summary of Results of the Five Conto Energia Schemes

| **FIT Scheme** | **Years active** | **PV Capacity supported** | |
|---|---|---|---|
| | | **MW** | **(%)** |
| First Conto Energia | 2006-2009[a] | 163 | 0.92% |
| Second Conto Energia | 2007-2011 | 6,840 | 38.57% |
| Third Conto Energia | 2011 | 1,555 | 8.77% |
| Fourth Conto Energia[a] | 2011-2013 | 7,772 | 43.82% |
| Fifth Conto Energia | 2012-2016[b] | 1,404 | 7.92% |
| Total | | 17,734 | 100.00% |

Note: (a) the first and fourth scheme had “tails”, for which PV plants under specific conditions could still be installed with tariffs of the latter schemes event if the following FIT scheme (hence the second and the fifth) were already operational (therefore benefiting from higher tariffs); (b) From July 2013 to 2016, the available incentive scheme was extended for selected applications – see footnote [25].

Data source: GSE, 2017a

Overall, the Conto Energia program was not a stable policy framework, with as many as five schemes in eight years of implementation, the third of which lasting only five months, and even including a legislative vacuum lasting five months. Furthermore, the retroactive changes introduced in 2014 to reduce the financial costs of the program added further perception of policy instability on the part of installers.

## 2.6 The Post Conto Energia Policy Framework

After Conto Energia was discontinued in 2013, individuals and private companies could still have access to other forms of incentives available for the installation of PV systems. The main policy measures that supported PV installations between July 2013 and the end of 2016 were: (1) tax deductions; (2) net billing; and (3) “Sistemi Efficienti di Utenza”  (see section 2.6.3). Outside of the category of policy measures that have either directly provided for financial incentives (e.g. tax deductions) or reduced the “weight” of system charges (e.g., net-billing or SEUs) to distributed PV producers, there are also other measures or enabling regulatory and market frameworks supporting PV market diffusion in Italy. At the time of this writing (December 2017), the market deployment of PV technology is also being supported through a “command-and-control” approach, requiring new residential buildings to install at least 1 kW of PV capacity on roofs (Castello, Tilli, & Guastella, 2015)[26]. Owners of commercial and industrial PV systems can also enter into power purchase agreements (PPAs), the so-called “linee dirette” (direct lines), with industrial customers. These linee dirette are expected to bring significant growth to the Italian PV market between 2018 and 2019 (Bellini, 2017).

---

[26] PV projects could also qualify for the emission of "White Certificates", which are tradable certificates issued by GSE to subjects that implement qualifying energy efficiency measures or that install qualifying renewable energy systems (Codegoni, 2014). At the time of writing, however, there is no data available that quantify PV capacity installed through projects entitling to white certificates. "Sistemi di Distribuzione Chiusi" (SDC) are another measure expected to support PV residential installations, but its application is still limited to niche areas. SDCs are private electric grids that allow the exchange of electricity, including that produced from distributed renewable systems, among prosumers (Qualenergia, 2015a; Redazione di Qualenergia, 2017a).

### 2.6.1 Tax Deductions

Expenses incurred by individuals for the installation of a PV system on existing buildings are considered “interventions finalized to improve energy efficiency” by recent Italian Budget Laws and, as such, a portion of these can be deducted from personal income taxes. The possibility of deducting expenses for PV system installation was also available during the period of implementation of the Conto Energia program, however the two incentives could not be cumulated and individuals largely opted for the Conto Energia FITs. The current tax deduction rate is set at 50% of the installation cost. This deduction is not available for PV systems installed on residential buildings already under construction before the introduction of this provision, or for commercial and industrial buildings (regardless of whether pre-existing or under construction).

### 2.6.2 Net Billing

The market diffusion of PV technology in Italy has also been supported by the option made available to PV-system owners in specific capacity tiers to exchange electricity with the distribution grid, under specific conditions that can qualify as a form of incentive and which are referred to by the IEA-PVPS as either *net metering* or *net billing*.

In a net-metering scheme, the PV electricity fed into the distribution grid is remunerated at a value equal to the full retail price (including system costs and charges)[27]. PV-system owners are remunerated for the total value of the PV-electricity

---

[27] Additional incentives (Belgium) or additional taxes (Arizona, US) might be added to a net-metering scheme (IEA-PVPS, 2017).

fed into the grid through a compensation that offsets (reduces) electricity costs, and this is usually carried out by the distribution utility. This compensation – which can be defined as an energy compensation of electricity flows – can take place during a period of time that could range from a few months to even years. In a net-billing scheme, there is no full energy compensation of electricity flows, but there can be different prices attributed to self-consumed and produced electricity, coupled with additional features (e.g. the export-price guarantee in Italy) (IEA-PVPS, 2016:41).

Broadly speaking, both the net metering and net billing schemes can be defined as incentives, as the electricity generated by a PV system that is fed into the grid is remunerated (usually by the distribution utility) at a price higher than wholesale electricity prices. The costs of these schemes can either be borne by utilities (e.g. in a few US states) or by the Government (e.g. in Italy). These two schemes can be an important prerequisite to increasing the financial attractiveness of investing in a PV system, as on average, not more than 30% of the electricity generated by a residential PV system is self-consumed (unless an energy storage system is available) (Jäger-Waldau, 2016).

The provisions related to net metering and net billing in Italy (referred to as *Scambio sul Posto*) have changed significantly over time, with the first relevant legislation introduced from the Authority for Energy and Natural Gas (AEEG) as early as in 2000 and the last modifications implemented in 2012[28].

The economic compensation to the PV-system owner took place annually and was calculated on the basis of the physical difference between the electricity

---

[28] "Delibera" n. 224/2000 and n. 570/2012, respectively.

consumed from the grid and the electricity fed into that same grid. Electricity distribution utilities were legally obliged to carry out the compensation in electricity bills and to bear implementation costs.

The net-metering system was revised into a first net-billing scheme that was in place from January 2009 to December 2013. Under this scheme, the value of PV electricity fed into the grid was not remunerated as equal to the full retail price, but was calculated on the basis of a complex formula that took into account different factors, the most important of which was the wholesale price of electricity in the specific market region. The underlying assumption of this method of calculation was that the value of PV electricity fed into the grid should vary with supply and demand dynamics in the electricity market rather than being aligned with the full retail price, which also includes system charges. As a result, only when regional wholesale prices of electricity were extremely high was the value of the net-metered electricity equivalent to the retail electricity price. Another major difference with respect to the previous system was that compensation was paid not by the distribution utility but rather by GSE (Politecnico di Milano, 2013).

The legislative provisions on net metering introduced in December 2012 (and still in place at the time of this writing) further modified the calculation method of the Scambio sul Posto. The two major changes introduced by this scheme were: (1) a different methodology for “pricing” electricity consumed; and (2) a cap on the compensation component for system charges (*onere servizi*) for plants with rated power higher than 20 kW. According to simulations conducted by the Politecnico di Milano in 2013, the modifications introduced resulted ceteris paribus only in slightly lower economic benefits to residential PV system owners, whereas there were no negative impacts on commercial PV systems with respect to the previous net-billing system (Politecnico di Milano, 2013).

Overall, the impact of the revisions to the net-metering and net-billing systems introduced from 2008 onwards was that of gradually increasing the gap between the retail price of electricity and the economic value assigned to the PV electricity fed into the grid. As a result, PV-system owners had the incentive to maximize the quantity of self-consumed PV electricity. Since the December 2013 revisions were implemented, the sizing of PV systems has been more “constrained” and there has been no premium placed on PV systems that were oversized with respect to the consumption needs of PV-system owners. A more recent effect of net-billing legislation has been that of incentivizing the market uptake of dispatchable PV systems (PV systems with energy storage), which, however, still need a significant capital subsidy for the energy-storage component to ensure market viability (Politecnico di Milano, 2017).

### 2.6.3 Sistemi Efficienti di Utenza

*Sistemi Efficienti di Utenza*[29](SEU) can be broadly defined as a network or system of distributed electricity generation and consumption. The characteristics of an SEU are defined by legislative decrees 115/08 and 56/2010 as “a system where one or more renewable energy or high-efficiency cogeneration power plants with nominal capacity not higher than 20 MW, installed on the same site, that can be owned by an

---

[29] *Sistemi Efficienti di Utenza* can be literally translated as “Efficient-User Systems”. The IEA-PVPS Annual Report maintains the original Italian name in the paragraph describing Italian policies (IEA-PVPS, 2016).

individual or a company other than the final user of the electricity generated, are directly connected – through a private grid without the obligation of granting access to third parties – to the consumption units of one final customer (individual or legal entity). The power plant can be realized within the premises of the final customer or made fully available to the latter" (Politecnico di Milano, 2013: 107).

An SEU can hypothetically consist of a small-to medium enterprise (SME) installing a PV system on the roof of its building and entering into a power purchase agreement (PPA) with another SME located in the same industrial district. The PV-system owner will first use the electricity generated to meet its own demand and then sell the excess electricity to the entity with which it has entered into a PPA. The PV electricity will obviously have to be sold to the final customer at a lower price than the variable component of retail price of electricity from the distribution utility. In fact, the price competitiveness of electricity sold under an SEU is supported by an exemption to distribution and transmission charges, which, assuming a connection to the distribution grid at 150 kW, added about 0.04 EUR/kWh to the retail price of electricity on top of a "net" price of 0.15 EUR/kWh in 2013 (Politecnico di Milano, 2013: 110).

### 2.6.4 Effects of the Post FIT Framework on PV Deployment

As mentioned, after the discontinuation of the Conto Energia FIT program in July 2013, the volume of annual PV installations decreased significantly to levels roughly between 300 and 400 MW. While the absolute reduction relative to market levels experienced in 2010-12 was significant, the Italian PV market between 2014 and 2016 repositioned itself at roughly the same volumes observed in 2008, during the third year of implementation of Conto Energia.

Overall, as a result of the positive impacts of the tax deductions and the net billing scheme, the post-FIT incentive framework has been successful in supporting the market of systems up to 200 kW. For systems above 200 kW, the SEUs and lastly, the *Sistemi di Distribuzione Chiusi* (SDC) did not help to enhance significant volumes in industrial applications, due to legislation establishing a very narrow scope of application for their implementation (Politecnico di Milano, 2016).

As far as utility-scale plants (above 1 MW) are concerned, installations in the three-year frame 2014-16 were less than 10% of the market, and mostly related to the "tail" of the fifth Conto Energia scheme. These included plants installed in geographical areas hit by the earthquakes in 2015 and 2016, for which the possibility of access to the FITs was granted as part of recovery policies.

In the broader frame of the PV transition to full-market viability without incentives, the Italian PV market can be included among the early-movers globally. In 2017, so-called *market-parity* was achieved in Central Italy, where a 1 MW PV plant was installed without the support of any incentive scheme, and installers expect it will achieve targeted returns entirely through the wholesale of electricity (Qualenergia.it, 2017).

## 2.7 Summary

In the early 1990s, Italy was among the global technology and market leaders in the PV sector. The momentum gained with the first incentive and R&D programs, however, was gradually lost, with modest or no growth in PV installations throughout the rest of the decade. At the beginning of the 2000s, Italy was well behind the PV market leaders (Japan, Germany), both in terms of domestic market and industrial capacity.

Support was stepped up in 2002, with the introduction of a national capital-subsidy program, which effectively provided the conditions for higher growth in the market. Cumulative PV capacity doubled from 2002 to 2006, when it reached 37 MW. The capital subsidy program gave new impetus to the domestic PV market but annual installations were still below the 10 MW volume. Consensus was reached within the policy-making community that domestic PV market deployment had to step up its pace to reach more ambitious deployment objectives. Therefore, the Italian government decided to follow the path of Germany and Spain with the introduction of an FIT program (Conto Energia).

The Conto Energia program boosted the Italian PV market from 12 MW in 2006 to about 3,600 MW of annual installations in 2012 (with a peak of about 9,500 MW in 2011). The rapid growth in the market was fostered by as many as five different FIT schemes, which progressively reduced tariffs and introduced different provisions related to the typology of PV systems eligible for incentives, capacity caps, etc. Under the Conto Energia program, PV technology market successfully transitioned from serving a small niche of applications to becoming the fourth largest source of electricity generation in Italy.

In July 2013, Conto Energia was discontinued and since then, PV deployment in Italy has been mostly supported by three support measures: tax deductions, net billing, and *Sistemi Efficienti di Utenza*. The combination of these three measures, in addition to the regulatory obligation to install PV in new buildings, helped maintain market volumes in the 300 to 400 MW-range between 2014 and 2016. Tax deductions and net billing were particularly effective in supporting the market for residential and commercial PV systems. In 2017, market parity was achieved for utility-scale applications in Central Italy.

## Chapter 3

# PV SYSTEM PRICES AND LEARNING EFFECTS

### 3.1 Introduction

Economic impact analyses (EIA) of clean-energy technology deployment need to incorporate[30] the *cost data* of those energy technologies whose diffusion might give rise to economic impacts of interest to policymakers. More specifically, unit cost data (e.g., USD/kW of PV installed capacity) and projected market demand are needed to estimate the investment costs necessary to deploy a specific clean-energy technology[31]. These investment costs, along with the operation and maintenance of running capacity, produce variations on employment and economic output that can be assessed by economic impact analyses. These costs may be found in historical data or may need to be estimated from available data specifically to construct ex-post counterfactual scenarios or analyze scenarios that can project a given technology's future diffusion[32]. Cost data are usually not disclosed by companies producing

---

[30] Cost data of energy technologies are treated as exogenous parameters (inputs) in the various models that can be used to carry out EIAs, but might also be endogenous if the EIA is carried out through application of a computable general equilibrium (CGE) model (see chapter 5).

[31] The values of these investments, which are often referred to as *deployment* or *market-diffusion* investments, are obtained by multiplying installed capacity (e.g., in power units such as MW or GW) by cost per unit of capacity.

[32] *Scenarios* can be broadly defined as possible pathways of energy systems (at global, regional, national, and local levels) based on sets of assumptions (see chapter 4 for a full definition). The term *projection* is used in the frame of the energy scenarios

components for clean-energy technology systems (e.g., turbines for power plants, modules for PV power plants) or by those active in the installation segment of the market. In fact, the difference between price and cost, often referred to as a *mark-up*, is a commercially sensitive parameter. For this reason, cost values of energy technologies are, for the most part, estimated from price data which, for renewable energy technologies, are made available to the public in reports published by international organizations (e.g., the International Energy Agency of the International Renewable Energy Agency) or research institutes (e.g., US the National Renewable Energy Laboratory).

Prices of PV systems[33] vary significantly across geographical areas and market niches. Values reported to the International Energy Agency's Photovoltaic Power Systems (IEA-PVPS) program in 2016 for residential systems ranged from 1.05 USD/W in the People's Republic of China (lowest value) to 2.93 in the United States (average value) and 3.13 USD/W in Switzerland (highest value). Average prices reported to the IEA-PVPS program for ground-mounted systems ranged from 1.30 USD/W in China to 1.49 USD/W in the US to 2.93 USD/W in Japan. PV-system prices in Italy in 2016 ranged from about 1.10 USD/W for ground-mounted plants to 1.34-1.73 USD/W for residential systems[34] (IEA-PVPS, 2017).

---

analyzed herein to denote all estimated future values of a given metric (e.g., capacity, prices, investments). The meaning of projection should not be confused with *forecast* (see also chapter 4).

[33] Unless specified differently, all metrics related to PV systems refer to grid-connected systems.

[34] The IEA-PVPS program carries out annual surveys of PV power applications and markets in the program's 29 member countries.

PV technology has experienced a rapid decline in prices since the mid-2000s. As a term of comparison: the lowest residential PV system price in 2005 among IEA-PVPS reporting countries was 5.5 USD/W in Denmark. In 2016, the lowest price reported for residential PV systems in Denmark was 1.18 USD/kW. Indeed, over the 2002-16 period, PV system prices for residential systems in Italy decreased by about 80%[35] (Castello et al, 2002; Tilli et al., 2016).

## 3.2 Evolution of PV-System Prices and Their Components in Italy

Developing projections on PV-system prices to be used in scenario analysis requires, first and foremost, the collection and analysis of historical data using a breakdown of the main PV components. Historical data on PV system prices should ideally be disaggregated by their four main components, namely: (1) module, (2) inverter, (3) balance-of-system (BOS[36] - e.g., mounting system, DC cabling, transformer, infrastructure, and grid-connection), and (4) project engineering and installation (the latter are often referred to as *soft costs*).

The breaking down of the price into these four components allows for an investigation of the role that different factors (e.g., economies of scale, learning by doing, technological innovation, etc.) have had in determining cost reductions for each component. Once there is enough data to characterize the historical cost-reduction

---

[35] From an estimated 8.65 USD/W in 2005 to 2.23 USD/W in 2014 (the latter calculated as average between the lower and upper-bound figures provided by IEA-PVPS (2016).

[36] The IEA-PVPS program carries out annual surveys of PV power applications and markets in the program’s 29 member countries.

path according to a set of parameters (e.g., the progress ratio – see section 3.3), then these parameters can be used in scenario analysis to project future price values.

Data collection activities on PV system prices and their cost distribution in Italy have been carried out through a review of the technical literature available. Data on PV system prices in Italy began to be systematically reported in 2002 in the IEA-PVPS report *National Survey Reports of PV Power Applications in Italy* (Castello et al., 2003 – 2014; Tilli et al, 2017). Price data reported on IEA-PVPS national surveys is disaggregated either by capacity range (e.g., 1-3 kW, 3-20 kW, 20-100 kW, etc.) or by market niche (distributed versus centralized power systems). Data on PV system prices from 2008 to 2016, including a breakdown into the different components, were also reported by the Energy & Strategy group of the Politecnico di Milano (Politecnico di Milano 2009-2017)[37]. Altogether, these two sources have allowed for the construction of a database of prices for PV systems in Italy with a breakdown of the four aforementioned components from 2002 to 2016. The results of this data collection and subsequent elaboration are shown in Table 3.1.

In Table 3.1, both the terms *price* and *cost* are used to refer to PV systems and their components. The term *price* is used for (a) PV systems, (b) modules, and (c) inverters, as these elements can be purchased as stand-alone products from producers, distributors, or system integrators (installers). Conversely, the term *cost* is used for (d) BOS components, and for (e) soft costs (project engineering, installation, permitting,

---

[37] The breakdown into the different components of PV system price data was included in the reports published by the Politecnico di Milano only from 2010 to 2013, and in 2016. Before 2010, modules and structures were often aggregated into one price component, and the same applied to inverter and other electrical equipment.

etc.), as these elements are categories used strictly for definitional purposes in order to aggregate several elements, some of which are intangible (e.g., overhead costs of the installers that are part of the project engineering and installation component).

Table 3.1 Prices and Costs of PV Systems and Major Components in Italy, 2002-2016

| Year | PV system nominal average price (Eur2016/kW) | PV module average price(a) (Eur2016/kW) | Inverter average price(a) (Eur2016/kW) | BOS average cost (Eur2016/kW) | Project eng. and installation (soft costs) average cost (Eur2016/kW) |
|---|---|---|---|---|---|
| 2002 | 9,154 | 4,239 | 1,098 | 1,465 | 2,352 |
| 2003 | 8,732 | 3,919 | 1,048 | 1,397 | 2,368 |
| 2004 | 8,358 | 4,106 | 1,003 | 1,337 | 1,912 |
| 2005 | 8,060 | 4,070 | 967 | 1,290 | 1,733 |
| 2006 | 7,077 | 3,903 | 714 | 1,132 | 1,328 |
| 2007 | 6,874 | 4,130 | 540 | 1,027 | 1,177 |
| 2008 | 5,799 | 3,654 | 504 | 702 | 939 |
| 2009 | 4,094 | 2,200 | 433 | 534 | 926 |
| 2010 | 3,653 | 1,742 | 378 | 511 | 1,022 |
| 2011 | 2,380 | 1,076 | 332 | 464 | 507 |
| 2012 | 2,031 | 777 | 278 | 430 | 547 |
| 2013 | 1,761 | 690 | 217 | 351 | 503 |
| 2014 | 1,781 | 703 | 210 | 344 | 524 |
| 2015 | 1,754 | 700 | 200 | 333 | 521 |
| 2016 | 1,385 | 684 | 193 | 323 | 186 |
| % Variation 2002-2016 | -85% | -84% | -82% | -78% | -92% |

Note: (a) Prices of modules and inverters include a wholesale trade margin estimated as a share of PV system costs. The wholesale trade margin share is assumed to decrease from 7% in 2002 to 3% in 2016.

Data Sources: Castello et al., 2002-2015; GSE, 2009-2017; Politecnico di Milano, 2008-2014; author’s estimates.

Average prices (reported in constant EUR(2016)/kWp) of PV systems in Italy between 2006 and 2016 had a reduction of 80% (and of 85% from 2002), which is the aggregate result of reductions for each of the four aforementioned components. Price reductions for each of the four components were 86% for soft costs, 82% for modules, 73% for inverters, and 72% for the BOS[38]. The reduction in the prices of PV modules amounts to about 57% of the total PV-system price reduction between 2006 and 2016, followed by soft costs (20%), BOS (14%), and inverter prices (9%).

The shares of the different components on total PV-system price did not see significant variations between the values reported in 2006 and in 2016 (see Figure 3.1). The largest variations were those of PV modules (from 59% in 2006 to 49% in 2016) and soft costs (from 19% to 14%). The share of the BOS cost increased from 16% to 23%, whereas that of the inverter price increased from 10% to 14%. However, the share of PV modules on total PV-system prices varied significantly over the period observed, increasing up to 63% in 2008 and then continuously decreasing to current values from 2009.

The cost of silicon is often cited as one of the factors behind the price rise of PV modules between 2004 and 2007 (Trappey et al., 2016), which translated into an increased share of PV modules on total PV-system prices in Italy.

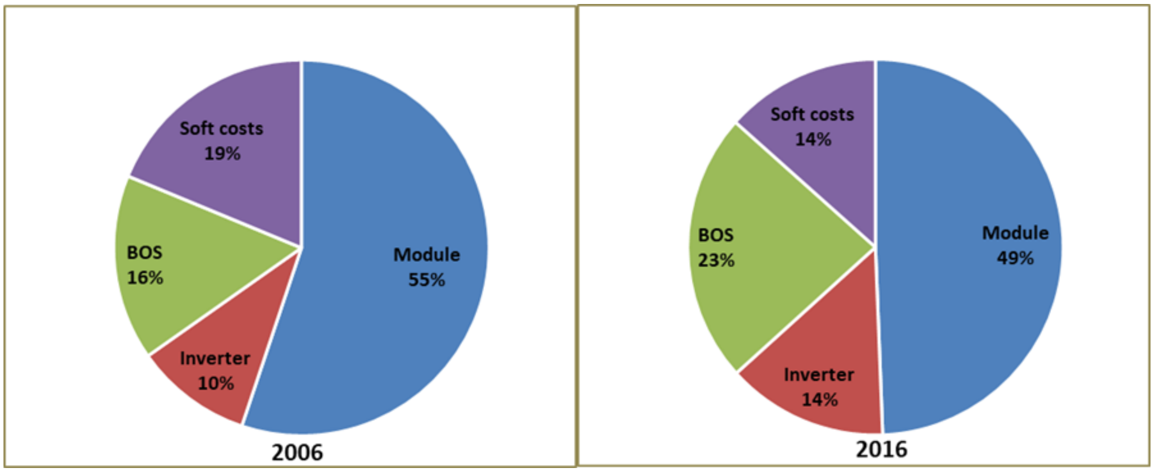
## 3.3 The Learning Process

The objective of this section, and the remainder of this chapter, is to analyze the price reduction of PV systems in Italy at the most granular level of methodological scrutiny possible through the application of *experience curve methodology* and to

---

[38] For the purpose of this specific analysis, prices in real terms are needed to quantify the effects of the different cost-reduction drivers net of inflation, which will be required to estimate the learning parameters in the following section.

examine the learning dynamics of PV systems and their components in the Italian market.



Data sources: Castello et al., 2003-14; Politecnico di Milano, 2009-17; Tilli et al., 2017.

Figure 3.1 Distribution of PV System Cost by Component in Italy, 2006 vs. 2016

*Technological innovation* or *technological progress* is considered one of the most important driving factors of economic growth (Solow, 1957). Arrow (1962) argued that technological innovation is an endogenous factor of economic growth. That growth is, to a significant extent, determined by a *learning* or *learning-by-doing* process, which is, in turn, driven by different factors, such as the acquired skills of the labor force or better organization of labor at production facilities.

In its most basic definition, *learning* is defined as a process whereby the human capital participating in a production process "learns" from experience, reducing the time or quantity of other inputs required to produce a unit of the final product. The learning process may relate to the production process (e.g., innovations in the production line of a given product) or to product changes (e.g., better design, standardization of different variants of a product). As a result of accumulated learning in the production process, production costs will (according to theory) be characterized by a decreasing trend. In fact, one of the variables used in learning analysis is the level of cumulative production achieved since the beginning of production ($t = 0$). For example, as cumulative production increases, the technical personnel in charge of the operation of a production plant will increase their knowledge of the production process. New experience is likely to result in improved operation of the production process, reduced production stops, and optimized output. Machinery used in the production process is also subject to a learning process. For example, through the repeated use of machinery, it may be possible to achieve a higher efficiency of operation, or the same machinery can be replaced by more advanced equipment which incorporates more innovative technologies (Isoard and Soria, 2001).

The expectation of a high likelihood of learning effects in a production process might provide producers with a rationale to fix prices of new products at a level low enough to accelerate the growth of sales and cumulative production in order to, in turn, generate that expected learning at a faster pace. This strategy allows producers to gain a comparative technological advantage on competitors and achieve a dominant position in the market (Isoard & Soria, 2001). In other words, the learning process can create entry barriers in a market by providing competitive cost advantages to those producers who entered the market in the early phases of product diffusion.

While economies of scale[39] and learning effects are two different cost-reduction factors, in practice, it is often difficult to separate the net effect that either of these factors have in reducing production costs. In fact, the great majority of the learning curves for renewable energy technologies published in literature are single-factor learning curves, and even analyses on multi-factorial learning curves (MFLC) do not separate the effects of learning-by-doing from economies of scale in determining cost-reductions (Isoard and Soria, 2001; Nemet, 2006; Byrne and Kurdgelashvili, 2011). The complex interrelationship between economies of scale and technological learning promotes a continuous evolution of the socio-economic and technological environment, where innovation is generated and a process of technology diffusion takes place. Learning effects and economies of scale can reinforce each other in determining a decrease of production costs. For example, if an increase in output is characterized by economies of scale, cumulative production is likely to grow at a faster pace, triggering additional learning effects. However, if there are so-called *diseconomies of scale* (Grubler, 2010), the impact of learning effects may not be sufficient to effect a reduction in costs.

Due to the combined effect of the various factors involved, which can vary significantly over a time frame that is short-run, the learning process can be better analyzed over long periods of time. As a result, several doublings of cumulative production are considered necessary to discern a specific trend. Furthermore, learning effects can be sought at the micro-scale (e.g., in the context of an enterprise attempting

---

[39] *Economies of scale* are intended here in the conventional microeconomic meaning of “cost advantages” that arise when the average production (unit) cost decreases with increasing output.

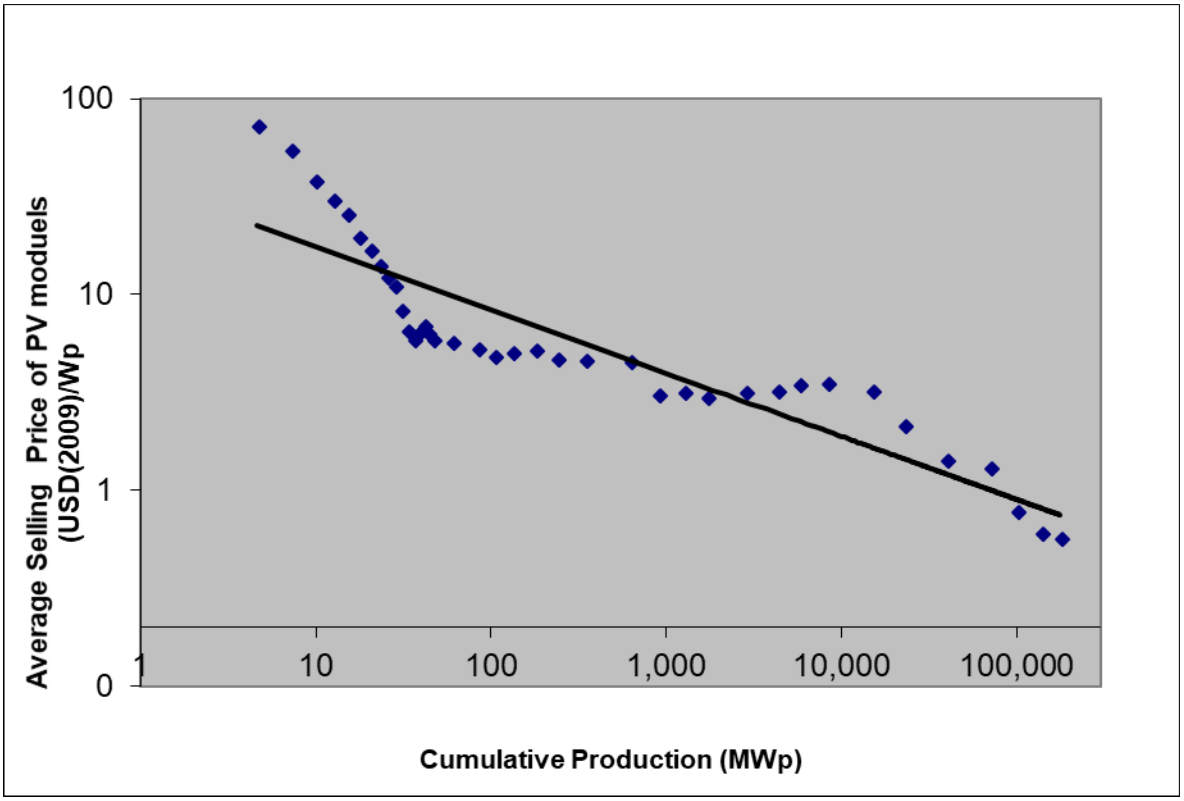
to increase its competitiveness) or at a broader scale through a country's economic, technological, and industrial policies.

## 3.4 The Learning Curve

*Learning curves* depict the relationship between the reduction in total production costs of a given product (including capital, marketing, R&D, labor, etc.) and the increase in cumulative production. The learning curve concept can be considered a widely accepted methodology within economic theory and technology diffusion analysis (Isoard and Soria, 2001).

Figure 3.2 is an example of a learning curve of photovoltaic modules during the period 1976-2014, where the y-axis displays price (logarithmic scale), the x-axis shows cumulative production (logarithmic scale), and the learning curve is depicted as a trendline based on a power function.

Learning curves were used initially for the analysis of production processes characterized by a significant contribution of the labor factor of production, whereby the skills and experience of the labor force are fundamental dimensions of the production process (particularly in industries using production lines). In fact, among the different kinds of industries, the highest learning rates were seen in manufacturing industries where production is based on standardized processes or procedures and characterized by a high intensity of human capital. In a later phase, learning curve analysis was extended to all kinds of industries. It was found that a higher intensity of non-human capital in an industry correlates with a lower learning rate (Isoard and Soria, 2001).



Data sources: Maycock, 2002; Mints, 2012; Feldman et al., 2015

Figure 3.2 Learning Curve of PV modules, 1976-2014

The basis of the learning curve or experience curve methodology is the equation

$$C_t = C_0 * X_t^{-E} \tag{3.1}$$

In this equation, $C_t$ is the unit production cost of the technology or product at time ‘t’, C0 is the unit production cost at time 0 (the constant of the equation), $X_t$ is cumulative unit production at time ‘t’, and E is the experience index (IEA, 2000). An alternative equation used in the literature is

$$C_t = C_0 \left(\frac{Q_t}{Q_0}\right)^b \tag{3.2}$$

In this equation, $Q_t$ is cumulative production. Since $X_t$ in (1) is cumulative production expressed in terms of physical units produced at time 0 (a value that might be higher than unity), the two expressions are algebraically equivalent for $X_t = (Q_t/Q_0)$ and $b = -E$. The experience-curve equation allows the estimation of the constant percentage of decline in cost at each doubling in cumulative production. Thus, the so-called *Learning Rate* (LR) obtained from the experience index is as follows:

$$\mathrm{LR} = 1 - 2^{-\mathrm{E}} \tag{3.3}$$

An alternative and specular metric to the learning rate is the Progress Ratio (PR):

$$\mathrm{PR} = 2^{-\mathrm{E}} \tag{3.4}$$

The experience index "E" can be derived from (3.1) as follows

$$E = \frac{\ln C_0 - \ln C_t}{\ln \mathrm{Xt}} \tag{3.5}$$

Obviously, the reduction in costs of a given technology depicted by the learning curve can be determined by several factors, of which learning-by-doing is only one[40]. Other cost-reduction factors discussed in the literature are economies of scale, *learning-by-searching*, input price reductions, and supply-side subsidies reducing production costs (Nemet, 2006; Sagar and Van der Zwaan, 2008; Byrne and Kurdgelashvili, 2011; Yu et al., 2011; Trappey et al., 2016; Mauleón, 2016).

---

[40] The effect of different factors other than learning-by-doing in explaining cost reductions might highlight the "incongruence" of the definition of learning curve as such.

## 3.5 Literature Reviews on Experience Curves Applied to Photovoltaic Modules

The learning-curve concept has been extensively applied both to analyze the historical cost-reduction process of PV modules (and to a lesser extent, of PV systems, inverters, and other PV-system cost components) as well as to elaborate projections on prices.

The first reported study on the use of learning curves for PV technology was published in 1975 by Maycok and Wakenfield, who analyzed the pre-mass commercialization trend in the cost of PV modules, estimating a LR of 20% between 1965 and 1973 (Harmon, 2000). Williams and Terzian (1993) estimated a LR of 18% for PV modules between 1976 and 1992. Harmon (2000), reported an estimate of a 20% LR between 1968 and 1998.

Poponi (2004) analyzed technology diffusion paths for PV systems based on estimates on the historical LR for PV modules over the period 1975-2001, and on calculated break-even price levels for different market applications. He concluded that photovoltaics could have entered the market niche of building-integrated applications (residential PV systems) without incentives in the first years of the 2010s, assuming a continunation of the historical LR of 20% and an average annual global market growth rate of at least 15%.

Nemet (2006) looked at the role of a wide range of factors affecting the cost reduction process of PV technology. Between 1975 and 2001, module efficiency, plant size, and silicon costs were the three most important factors in driving down the prices of PV modules, and he concluded that learning-by-doing had only a weak statistical relationship with these three factors.

Neij (2008) discusses an analytical framework for the analysis of future cost reductions of new energy technologies for electricity generation (including photovoltaics). The methodological elements of this integrated framework are experience curves, bottom-up analysis of sources of cost reductions, and judgmental expert assessments.

Ferioli et al. (2009) developed a model in which technology cost is determined by two components: one that exhibits learning, and another characterized by constant cost over time. The theoretical justification for this model was that some cost components, such as those that require a high input of raw materials (e.g. steel support structures in PV systems) or labor, might not exhibit cost reductions over time.

Bhandari and Stadler (2009) use experience curves to project PV module costs until the year 2060. PV electricity generation costs are calculated for Germany for both the wholesale and retail electricity markets, and grid-parity years are estimated.

Byrne and Kurdgelashvili (2011) modeled PV technology diffusion in the US in the frame of a scenario extending to the year 2050 using experience curves and logistic curves. The experience curve was developed for PV systems in the US over the period 1998-2005, with an estimated LR of 13.8%. A two-factor learning curve was developed to also assess the impacts of research and development (R&D) activities with estimation of the learning-by-innovating index, complementing the learning-by-doing one.

Yu et al (2011) used regression analysis to investigate the statistical relationship between unit costs of PV modules and the following factors: learning by doing, economies of scale, silicon prices, and silver prices. Results of the analysis indicate that all these factors are statistically significant. Yu et al. also described the methodology used to create a multi-factor learning curve and projected PV-system prices in the frame of two scenarios.

Trappey et al (2016) developed a *hierarchical learning curve model* to estimate the effects of several factors (including the cost of raw materials) affecting the price of PV systems in Taiwan. They conclude that the reduction in PV system prices correlates not only to the increase in cumulative capacity in the Taiwanese domestic market, but also to the cost of silicon in international markets.

Mauleon (2016) analyzed the PV cost reduction trend with an econometric estimation of PV learning rates through different static and dynamic specifications. Two additional variables considered, on top of installed capacity, were the price of silicon and the price of energy (as input into the PV-module manufacturing process). Two of the main findings of Mauleon are that the estimated learning rate increases significantly by moving the base year over time and that the omission of the price of silicon from the specification also yields a higher LR. Mauleon concludes that the so-called *Total Learning Rate* (net of the effect of the price of silicon on PV system prices) might be as high as 25% (with a 95% likelihood), as opposed to the values around 20% reported in other literature.

### 3.6 Learning Curves as a Methodology for Projecting Market Diffusion of Energy Technologies

Assessments on the evolution of future costs of energy technologies are of significant relevance to policymakers, who need to evaluate the effects of their energy-policy strategies in terms of both possible changes in the structure of supply and demand within the national energy system and the associated economic impacts. Though learning curves cannot be considered a forecasting tool, they can be used to develop projections on costs (or prices) of energy technologies in the frame of energy scenarios.

The most common approach for projecting costs of energy technologies is that of merely assuming a continuation of the historical learning rate. This approach could, however, be seen as too deterministic, since it assumes that all the variables (e.g., learning-by-doing, economies of scale, learning-by-innovating) that drove technology costs down over the historical period analyzed will simply continue to act with the same intensity, extending the historical LR value into the future. Such an approach could be considered risky, because as market deployment unfolds, technology becomes more mature and price reduction could slow down.

The uncertainty related to the effects that different elements have on future energy technology costs is usually factored in through variant scenarios or sensitivity analyses. For example, projections can also be based on LR values that are different from the historical one, to account for either an acceleration or deceleration in cost reductions.

## 3.7 Learning Analysis for PV Systems

Analyses on the learning process for PV systems carried out in literature have, for the most part, focused on modules, while a relatively lower amount of research has been devoted to the other components. PV modules began to be commercialized outside the first niche market of space applications during the 1970s, with the first significant production volumes reported in 1975 (Maycock, 2002). The average selling price (ASP) of PV modules has decreased from 30 USD/kWp in 1975 to 0.80 USD/kWp in 2016 (Maycock, 2002; Jager-Waldau, 2016). This price reduction path has not been linear; for example, there was a slight increase between 2004 and 2007, whereas only a marginal decrease in prices was observed from 2013 (Mints, 2012; Jager-Waldau, 2016). Annual shipments of PV modules have increased from 2 MW in 1976 to 76,000 MW in 2016 (Maycock, 2002; IEA-PVPS, 2017). Jager-Waldau (2016) estimated a 20% LR of PV modules between 1976 and 2016, which would mean that prices of PV modules have been reducing – on average – by 20% at each doubling of cumulative capacity.

An additional element to consider is that estimates of cost reductions reported for PV modules and inverters are often the results of weighted averages between technologies that may actually have significant differences. This is the case for crystalline and thin-film modules, for which separate LRs are often reported in the literature (Candelise et al. 2013). For example, in developing global market scenarios for PV technology, the European Photovoltaic Industry Association (EPIA, 2011) assumes an LR of 20% for thin-film modules in 2020, while, on the other hand, the LR for crystalline modules is projected to be 5% that same year. As far as inverters are concerned, the EPIA reported a significant difference between the realized price reductions of small-scale and large centralized inverters in the PV industry since the 1980s-1990s, with a 20% LR for small-scale and 10% for large inverters, respectively (EPIA, 2011: 13).

The learning-by-doing process that contributed to driving down prices of PV modules can be defined as *global* in its geographical dimension, since module production has been carried out by companies operating globally, that is, with production facilities in more than one country (e.g., First Solar). PV-module production has likely benefited from an exchange of scientific and technological information and know-how transfer at the international level (Bhandari and Stadler, 2009). The same consideration applies to inverters, though there is less data available on prices for these components.

The analysis of peer-reviewed literature indicated that there is still a limited understanding of the complexity and heterogeneity of the cost reduction factors and learning effects for BOS-related components of PV systems. This is due to a lack of empirical analysis. The learning of the BOS component of PV systems is more complex to analyze because of the various sub-systems and factors that make up its cost, such as DC cables, transformers, mounting system, etc.

It can be argued that cost reductions of BOS elements are also the result of a global learning process, as the international manufacturing environment for these components is not significantly different from that of modules. Obviously, the weight of specific cost reduction factors is likely to vary for components of different technological complexity such as, for instance, that of transformers and mounting structures. Cost reductions for electrical equipment, for example, are likely to be the result of both economies of scale and learning effects in the manufacturing process. In the case of steel support structures, for which the manufacturing process is relatively “low-tech”, cost reductions are likely to be the result of economies of scale with no or very limited learning effects relative to PV modules and inverters. Furthermore, the cost of BOS components per unit of power also depends on the efficiency of modules and of the overall system: the higher the system and module efficiency, the lower the requirement for structural components (EPIA, 2011).

Soft costs of PV systems are also quite heterogeneous, as they include costs of labor (e.g., the man/hours to install the system), planning, and permitting, as well as the profit margins of system integrators. Learning effects in the project engineering and installation component are related to the improved experience of planners and installers. Increasing cumulative experience in the design, integration, and installation of PV systems can result in improved system integration and a reduction in the number of BOS parts (Bhandari and Stadler, 2009). In this case, the learning process is almost exclusively a local process, save for the possibility that the know-how of designers and installers is transferred to third countries through international capacity-building activities or the operation of system-integrating companies operating in different national markets (e.g., Enel Green Power).

The reduction in soft costs per unit of capacity over time can be related to learning effects (e.g., more experienced installers) as well as to the reduction of margins of system integrators due to a more competitive environment, typical of more mature markets. Generally speaking, there is a lack of empirical analysis related to the soft-cost component of PV systems (project engineering, installation, permitting, and licensing costs). For instance, the higher PV system prices in the US with respect to more mature European markets (Germany) can be explained by differences in soft costs, such as those due to higher costs for licensing and permitting (IEA-PVPS, 2016; Barbose et al., 2013).

## 3.8 The Role of Input Prices and RD&D on PV-system Costs

There are additional elements to factor in when discussing the cost-reduction process of PV systems. The price of physical inputs like silicon, steel, energy, or that of labor costs could be so large that they compensate the effects of learning-by-doing and economies of scale. In their study on the Taiwanese PV sector, Trappey et al

(2016) concluded that reductions in silicon prices have significantly contributed to decreasing PV system prices in Taiwan (Trappey et al., 2016). Additional factors that contributed toward the driving down of prices between 2009 and 2012 was the oversupply in production capacity observed over the last few years, and the market entry of players from emerging economies, and China in particular, whose cell and module producers had relatively lower labor costs than did incumbents such as Germany and Japan. In fact, these changes drove several players out of the market (Mints, 2012; IEA-PVPS, 2013; ISE, 2013).

Mauleon (2016) carried out an econometric estimation of the effects of introducing silicon and energy prices in the learning-rate equation for PV modules over the period of 1990-2013. He found that the overall impact of introducing the price of silicon and energy into the learning-rate equation across different models is that of reducing the estimated value for the learning rate.

Byrne and Kurdgelashvili (2011) developed a two-factor learning curve to assess the impact of R&D on PV-system prices in the US market between 1998 and 2005. The two-factor learning curve is used to estimate the (net) learning-by-doing and learning-by-searching parameters, the latter representing cost-reductions associated with R&D expenditures. Once the impact of R&D is factored, it was found that the "total" learning-rate for PV systems is reduced from 13.8% to 13.1%.

### 3.9 Learning Rate Estimation for PV systems in Italy

The calculation of the LR of PV systems in Italy is based on equations (3.1-3.4). Cumulative-capacity values from 2002 to 2016 were divided by capacity in year 2002 (Q0 in equation [3.2]), so that the latter (about 4 MW) is set equal to 1. This procedure allows for the calculation of the number of doublings that took place in the period 2002-16. Global PV capacity values were used to calculate the LR of modules and inverters, whereas domestic PV capacity data was used to estimate the LR for BOS costs. The following step is the transformation of nominal price data into constant price data with the Consumer-Price Index for Italy, where the 2016 value is set equal to 100. Finally, the experience index "E", the LR for PV systems, and each of the four major price components were calculated, and the results are shown in Table 3.2.

The LR of PV system prices in Italy during the 2002-16 period is 16%, meaning that an (average) price reduction of 18% took place at each doubling of domestic cumulative capacity. As mentioned above, this price reduction is likely the result of different factors, including learning-by-doing, learning-by-innovating, and the reduction or raw-material costs.

Table 3.2 Experience Indexes and Learning Rates for Key Components of PV Systems in Italy, 2002-2016

| Year | Domestic PV cumulative capacity $Q_t$ (MW) | Global PV cumulative capacity $Q_{tGLOBAL}$ (MW) | Global PV cumulative unit capacity $X_t = Q_t/Q_0$ | Domestic PV cumulative unit capacity $X_t = Q_t/Q_0$ | PV system average price (Eur2016/kW) | PV module average price (Eur2016/kW) | Inverter average cost (Eur2016/kW) | Soft Costs (Eur2016/kW) |
|---|---|---|---|---|---|---|---|---|
| 2002 | 10.34 | 1,244 | 1.00 | 1.00 | 9,154 | 4,239 | 1,098 | 2,352 |
| 2016 | 19,283 | 302,736 | 243 | 1,865 | 1,385 | 683.90 | 193 | 186 |
| | | | | Experience index 'E' | 0.2508 | 0.3320 | 0.3168 | 0.3371 |
| | | | | Progress ratio | 0.8404 | 0.7944 | 0.8028 | 0.7916 |
| | | | | Learning Rate | **0.1596** | **0.2056** | **0.1972** | **0.2084** |

Note: Progress ratios of PV modules and inverters were calculated using global capacity values.

Source: Author's analysis.

The LR of modules based on estimated prices in the domestic market is 20.5%, which aligns with what by Jager-Waldau estimated with global average selling prices (2016). The LR for inverters is 20%, which is slightly higher than the value (18.9%) estimated by the Fraunhofer Institute based on prices in the German market, though this only includes utility-scale inverters. The LR of the BOS is 17%, though this cost category combines at least five different elements (mounting system, DC cabling, infrastructure, transformer, and grid connection), and hence the "aggregate" LR is not of significant analytical added value  (for this reason, the LR for the BOS is not reported in Table 3.2). Finally, the LR for soft costs (project engineering and installation) is 21%.

## 3.10 Analysis of Factors for BOS Price and Soft Costs Reductions Observed in Italy

Seeing as the global PV market (annual installations) grew from a scale of 500 MW in 2002 to about 75,000 MW in 2016, global learning, economies of scale, learning-by-innovating, and lower input-costs (e.g. for silicon and silver) can be recognized as the most important factors in driving price reductions for modules and inverters globally and in Italy. As mentioned, lower BOS costs may also be the result of economies of scale and lower input costs (e.g., steel). In addition, cost reductions and/or performance improvements in other hardware components are likely to have played a role. For example, increases in module efficiency reduce the area needed for installing a PV-system with a given capacity, and are therefore reflected in diminished requirements in terms of support structures and cabling.

Investigating the trend of decreasing unit cost for soft costs is analytically challenging. In fact, there is a lack of empirical analysis of what factors determined the decreases observed in soft costs in Italy and to what extent they did so. Local learning effects (Bhandari and Standler, 2009) are one possible explanation. However, there are two other factors to consider. First, system integrators may have applied a fixed percentage “mark-up” to hardware costs to cover installation costs and their profit margin. As hardware costs went down in absolute levels, soft costs per unit of capacity would have also decreased, had the latter been calculated as a percentage of the sum of all remaining costs (e.g., 30% of the sum of the costs of modules, inverters, and the BOS). Second, a reduction in profit margins (in percentage terms) due to higher market competition may have also been a factor at play. If these two processes cannot explain for the entire cost-reduction trend for soft costs, learning effects on the part of installers may also be considered as having played a role.

An in-depth analysis of the factors that drove the reductions of soft costs in Italy is necessary in order to evaluate the probability of their impacts in the future, so that the accuracy or likelihood of PV system price projections can be increased. Zuccaro (2013) indicated that a learning process in soft cost components did occur and that this involved both the personnel in charge of the installations and the managers making the project quotations to prospective customers. With greater experience in managing the installation of PV systems, management of PV companies active in the installation segment were better able to estimate the amount of time required for the installation. This aspect, in conjunction with the market entry of more competitors, was considered by Zuccaro to be a significant factor for the reduction of soft costs in Italy.

## 3.11 The Weight of the Italian PV Market on International Learning and Economies of Scale Dynamics

An additional element worthy of investigation in assessing the real influence domestic factors have had in driving PV system prices down is the share of the Italian market on PV installations globally. As shown in Table 3.3, the global share of the Italian PV market reached a peak in 2011 with 31% of global market, and hovered around or slightly above 10% in 2009, 2010, and 2012. For almost all of the other years, this share had been lower than 4% and returned, in 2015, to be below 1%, which was the level Italy had in 2006 at the onset of Conto Energia.

Table 3.3 Share of Italy on Global PV Market, 2006-2016

| Year | Annual Installations Italy MW | World MW | Share of Italy on World % |
|---|---|---|---|
| 2006 | 12 | 1,447 | 0.83% |
| 2007 | 70 | 2,514 | 2.78% |
| 2008 | 338 | 6,569 | 5.14% |
| 2009 | 781 | 7,949 | 9.82% |
| 2010 | 2,328 | 16,811 | 13.85% |
| 2011 | 9,539 | 30,353 | 31.43% |
| 2012 | 3,654 | 28,988 | 12.61% |
| 2013 | 1,400 | 38,284 | 3.66% |
| 2014 | 409 | 39,932 | 1.02% |
| 2015 | 307 | 50,655 | 0.61% |
| 2016 | 382 | 75,000 | 0.51% |
| Cum. 2006-2016 | 19,220 | 298,502 | 6.44% |

Data sources: IEA-PVPS, 2017; Castello et al., 2006-2014; GSE, 2015-2016.

Overall, over the 11-year period from 2006 to 2016, Italy’s share of cumulative global PV demand is about 6%. So with the notable exception of 2011, the Italian domestic market had limited impact in pushing PV demand globally. Hence, it can be deduced that the price reduction observed in Italy for all manufactured PV-system components traded globally (modules, inverters, and other BOS components) can be largely attributed to exogenous market dynamics (e.g., the global supply glut in PV modules observed in 2010-12 as a result of the entry into production of new factories in China).

### 3.12 Scenario Development for PV-system Prices

The most relevant question regarding scenario analysis that incorporates projections on PV system prices is: how likely is it that the historical cost-reduction path can be maintained over the long term? Assuming that the historical price-reduction trend will continue, industry experts might see projections on PV system prices as unlikely. As a result, experience-curve projections should ideally be one part of an integrated framework that also includes bottom-up engineering assessment (Niej, 2008; Candelise et al. 2013).

The IEA's Technology Roadmap for Solar Photovoltaic Energy (IEA, 2014c) includes estimates on "expected prices" of PV modules and PV systems to 2050. The Roadmap's analysis is based on the "High-Ren Scenario" of the *Energy Technology Perspectives 2014* report (IEA, 2014b), in which PV cumulative capacity between 2013 and 2030 is projected to grow at an average growth rate of about 16% globally and 5.5% in Europe. Prices of PV modules, based on the historical learning curve, are expected to fall to between USD 0.3/W and USD 0.4/W by 2035. Turnkey prices of PV power plants are estimated to reach, on average, USD 1/W by 2030, but plants in the most favorable conditions (e.g., high solar radiation, relatively low cost of capital) would already reach this mark by 2020, according to the IEA's PV roadmap. Rooftop

PV systems are projected to reach about USD 1.3/W by 2030. In the baseline scenario of the latest IEA's *Energy Technology Perspectives* (ETP) report (IEA, 2017), the PV market is projected to grow with a CAGR of 12% at global level between 2014 and 2030.

The report *Current and Future Cost of Photovoltaics* from the German research institute Fraunhofer ISE (2015) discusses several long-term scenarios for market development and system prices of utility-scale PV systems. The three scenarios used in the analysis for the time frame 2015-50 have CAGRs for annual installations of 5%, 7.5%, and 10%, respectively. The growth rates are not projected as constant during the 2015-50 time frame, but an S-curve model is used to elaborate more realistic market-penetration paths with different phases of market growth. As a result, growth rates between 2015 and 2030 are higher than CAGR for the whole projection time frame (2015-50); for example, the estimated CAGR for the period 2021-25 for the central scenario is about 14% (versus a 7.5% average CAGR between 2015 and 2050)[41]. As far as prices are concerned, the methodology used by Fraunhofer for constructing projections on PV systems is based on experience-curve analysis for PV modules and inverters and on expert-based assessments for all other cost components. Investment cost of ground-mounted, solar PV power plants is projected to reach an average of 640 EUR(2014)/kWp in Germany in 2030.

---

[41] The complete dataset by year on growth rates and annual installations derived from the S-curve model is not included in the report from the Fraunhofer institute. The CAGR between 2015-30 is therefore estimated from annual-installations values shown in figure 65 of the report (Fraunhofer-ISE, 2017).

A comparison of the latest projections on PV capacity the IEA and those of the Fraunhofer Institute indicates shows that the 12% CAGR used in the IEA's ETP2017 for the period 2014-30 closely aligns with the one estimated from the central scenario of the Fraunhofer Institute over the time-frame 2015-30.

## 3.13 Projections on PV System Prices in Italy to 2030

The methodology applied to project PV-system prices that will feed into the comprehensive scenario analysis is based on the approach followed by Fraunhofer-ISE in the aforementioned study *Current and Future Costs of Photovoltaics* (Fraunhofer-ISE, 2017). Prices of PV modules and inverters available in the Italian market in the period 2017-35 are assumed to continue their reduction trajectory along their respective learning curves, with estimated LR values of 20% for modules (Jager-Waldau, 2016) and 19% for inverters (based on price data reported in the Italian market). The global PV market is assumed to grow with the following CAGRs: 18% between 2017 and 2020; 14 % between 2022 and 2026; 7% between 2027 and 2030; and 1.5% between 2031 and 2035 (the CAGR for the period 2017-2035 is about 7.5%). This growth path approximates that of a S-curve, so that global cumulative PV capacity values by 2030 (3,100 GW) and 2035 (4,700 GW) align with those of the central scenario of the Fraunhofer report.

Price projections for the BOS are based on Fraunhofer's cost-component analysis relying on expert-based technical assessments (Fraunhofer-ISE, 2017). The rationale for not using learning-curve analysis for BOS components has to do with the fact that these components are less influenced by global learning effects than are module and inverters. Furthermore, long-term historical price data might not be available to justify the use of learning curves. The approach followed to elaborate projections on BOS cost in Italy consisted in interpolating the average percentage cost-reductions for all BOS-components projected in the Fraunhofer study from 2015 to 2050, and also correcting for the different baselines (2015 vs. 2016 in the present study). The resulting weighted average of the projected percentage reduction in costs for the sum of all BOS components is about 20%.

The methodology applied to construct PV-system price scenarios departs from the one developed by Fraunhofer for soft costs, which is also based on expert-based assessment. As mentioned, Zuccaro (2013) suggested that local learning effects did play a role in reducing soft costs. A complete data series from 2002 to 2016 is available for Italy to estimate the local learning rate for this component, which is about 15%. The methodological approach for all cost components is summarized in Table 3.4.

The results of the projections analysis are shown in Table 3.5, detailing the annual values for all the cost components having prices that are a function of the global market, namely modules, inverters, and other BOS components. Annual PV installations reach about 360 GW at global level by 2035, when cumulative capacity would exceed 5,600 TW. With values of annual installations and cumulative capacity estimated applying the assumptions on growth rates, the cumulative unit capacity (fourth column in Table 3.5) is simply obtained by division, and from the latter it was possible to estimate future price values for each component ($C_t$ in equation 3.2) with the historical experience indexes.

Table 3.4 Summary of Methodological Approach Followed to Project PV System Prices through 2035

| **PV-system Cost Component** | **Approach used to project systems costs** | **Learning rates** | **Estimated % Cost reduction by 2035 from expert-based assessments** |
|---|---|---|---|
| Module | Learning-curve analysis | 21% | - |
| Inverter | Learning-curve analysis | 20% | - |
| Other BOS components | Expert-based assessments in literature | N.A. | -22% |
| Planning and Installation | Learning-curve analysis | 21% | - |

Source: Author's elaboration

Prices of PV modules in the Italian domestic market are projected to reach about 280 EUR/kW in 2035 (about 310 USD/kW), a value that is consistent with the expected price range reported in the latest IEA's Solar Photovoltaics PV Technology Roadmap (IEA, 2014a). By this date, prices of inverters would reach about 80 EUR/kW, whereas BOS costs would total about 260 EUR/kW. Projections on the soft-cost component are not reported in the table (and hence projections on the total PV-system costs are not reported either), as these would depend on the evolution of the domestic PV market, which will be discussed in the next section.

Table 3.5 Price Projections of PV-system Components Subject to Global Learning Effects, 2016-2035.

| Year | Global PV annual installations (MW) | Global PV cumulative capacity (MW) | Cumulative unit capacity | (1) PV module price Eur2016/kW | (2) Inverter price Eur2016/kW | (3) Balance of System (BOS) price Eur2016/kW | Total (1)+(2)+(3) Eur2016/kW |
|---|---|---|---|---|---|---|---|
| 2016 | 75,000 | 302,736 | 1 | 684 | 193 | 323 | 1,199 |
| 2017 | 88,500 | 391,236 | 1 | 628 | 178 | 318 | 1,124 |
| 2018 | 104,430 | 495,666 | 2 | 581 | 165 | 314 | 1,059 |
| 2019 | 123,227 | 618,893 | 2 | 539 | 154 | 309 | 1,002 |
| 2020 | 145,408 | 764,301 | 3 | 503 | 144 | 305 | 951 |
| 2021 | 159,949 | 924,250 | 3 | 472 | 135 | 300 | 907 |
| 2022 | 175,944 | 1,100,194 | 4 | 446 | 128 | 296 | 869 |
| 2023 | 193,538 | 1,293,733 | 4 | 422 | 122 | 291 | 835 |
| 2024 | 212,892 | 1,506,625 | 5 | 401 | 116 | 287 | 804 |
| 2025 | 234,182 | 1,740,807 | 6 | 383 | 111 | 282 | 775 |
| 2026 | 245,891 | 1,986,698 | 7 | 366 | 106 | 278 | 750 |
| 2027 | 258,185 | 2,244,883 | 7 | 352 | 102 | 273 | 727 |
| 2028 | 271,094 | 2,515,977 | 8 | 339 | 98 | 269 | 706 |
| 2029 | 284,649 | 2,800,626 | 9 | 327 | 95 | 264 | 686 |
| 2030 | 298,882 | 3,099,508 | 10 | 316 | 92 | 260 | 668 |
| 2031 | 303,365 | 3,402,873 | 11 | 306 | 90 | 260 | 655 |
| 2032 | 307,915 | 3,710,788 | 12 | 298 | 87 | 260 | 644 |
| 2033 | 312,534 | 4,023,322 | 13 | 290 | 85 | 260 | 634 |
| 2034 | 317,222 | 4,340,544 | 14 | 282 | 83 | 260 | 625 |
| 2035 | 321,980 | 4,662,525 | 15 | 276 | 81 | 260 | 616 |

Source: Author's elaboration

## 3.14 Uncertainty in Developing Price Projections

A major element of uncertainty in developing scenario projections is the rate of technological change. As mentioned, so-called *baseline* projections are usually built on the assumption of a continuation of historical, single-factor learning rates. However, there are two caveats that should be taken into account when using this approach to develop price projections of clean-energy technologies.

First, as aforementioned, single-factor learning rates also incorporate the effects of factors that are not strictly related to technological innovation and economies of scale of the technology, such as changes in input prices (e.g., silicon feedstock) or reductions in the mark up of producers. For example, the IEA (2015) discusses an accelerated price reduction trend for PV modules based on a 23% learning rate, which is estimated with data from 1976 to 2003. As price data from 2012 to 2014 is consistent with an extrapolation of the 1976-2003 learning curve, the IEA concluded in 2015 that PV module prices between 2003 and 2011 might have been lower had there been an adequate supply of silicon feedstock.

Second, even if the data available would make it possible to develop multi-factor learning curves, and hence to have coefficients that would only account for "net" learning-by-doing and learning-by-innovating processes (excluding scale economies and change in input prices), it is extremely unlikely that these coefficients would remain constant over time. Technology innovation is an inherently uncertain process, and it is extremely challenging to determine a statistically solid relationship between inputs (e.g., RD&D investments) and outputs related to innovation performance (e.g., cost reductions, technical improvements) (Sagar & van der Zwaan, 2006). In addition to the linear improvements of existing technologies, there is always the possibility that transformational innovations emerge, radically changing energy markets, as happened in the so-called shale-gas revolution. Obviously, it is not possible to predict technology breakthroughs, but one could at least monitor the evolution of the innovation frontier for a specific technology and gauge the extent to which changes in the historical cost reduction trend are likely or not. For example, perovskite PV cells are currently considered a candidate for a possible acceleration in the reduction process of PV modules (The Economist, 2018).

In order to account for the inherently uncertain nature of technological innovation, a variant scenario is developed where prices of PV modules from 2016 to

2035 are described by a 25% LR versus the 20% value used in the baseline analysis (shown in Table 3.5). This *breakthrough energy scenario* (BET) with an accelerated learning path leads to a 20% difference in the price of PV modules by 2035 (220 USD[2016]/kW versus 276 USD[2016]/kW) if the same market growth rates of the reference case are assumed. However, a minimum degree of elasticity of market to prices should also be factored in, as lower prices would lead to an acceleration in market diffusion. If the CAGR from 2017 to 2035 underlining the BET scenario is increased to 8.6% (from the 7.6% in the baseline case), average PV modules would further decrease to 212 USD(2016)/kW by 2035. For a country like Italy that is importing almost 100% of its PV-cell demand, a reduction in prices of PV modules (necessarily underlined by a reduction in PV cells) would be beneficial, due to reduced import bills and, overall, to lower investment costs to reach the PV capacity target of the National Energy Strategy by 2030.

## 3.15 Summary

PV-system prices in Italy observed an 81% reduction between 2006 and 2016 in parallel with the significant increase in volumes of the domestic and global market. Reductions in the price of PV modules and soft costs account for more than 75% of the total reduction in PV-system prices.

The experience curve methodology was used to analyze the evolution of PV system prices and their components at the most granular level of disaggregation possible. The concept of experience or learning curve refers to the progress of a given technology that can be achieved by learning processes, which, broadly speaking, relate to increased experience and know-how in the production of a given technology.

Learning is not the only factor at play in the cost-reduction process of PV systems: economies of scale, R&D activities, and reductions in input prices are also considered to have had impacts on prices.

During the period 2002-16, the PV system prices in Italy had a learning rate of 16%, meaning that at each doubling of the domestic installed capacity, prices decreased by 16%. Among the different cost-components of PV systems, the highest learning rate was observed for soft costs (21%), followed by modules (20.5%), inverters (20%) and the BOS (17%).

The most recent projections on PV market growth as well as prices of PV systems and key components were analyzed in order to extract benchmark values and to derive a suitable methodology for projecting prices of PV modules, inverters, and BOS – all components whose prices are linked to global markets. The methodology used was based on observed learning rates for modules and inverters as estimated in the Italian PV market and on expert-based judgments reported in the literature for the BOS.

With the assumption of a global PV market growing along a staggered-CAGR path (with CAGRs decreasing from 18% between 2017-22 to 1.5% between 2013-35), prices of PV modules in the Italian market would reach about 280 EUR(2016)/kW by 2035. Prices of inverters are estimated to reach 80 EUR(2016)/kW, whilst the BOS is projected at 260 EUR(2016)/kW by 2035, respectively. These price projections will feed into the comprehensive scenario analysis presented in the following chapter.

# Chapter 4

# CHARACTERIZATION OF SCENARIOS

## 4.1 Introduction

A *scenario* can be broadly defined as “an internally consistent and reproducible narrative describing one possible way the future might unfold” (Nakicenovic et al., 1998: 1). Given this general definition, an *energy scenario* can be defined as a conceptual description of a possible evolution of the energy system, “with quantitative characteristics, as well as internally consistent assumptions and reproducible elements” (Nakicenovic et al., 1998: 1). Consequently, a scenario cannot be misinterpreted as a *forecast*, since the former is rather a possible pathway of how the future *could* unfold based on a “set of assumptions about key relationships and driving forces of change that is derived from our understanding of both history and our current situation” (Nakicenovic et al., 1998: 3)[42]. Scenarios are therefore a necessary component of the analytical framework that aims to estimate the economic impacts and opportunity costs to government of Conto Energia, the Italian feed-in tariff (FIT) program for photovoltaic (PV) technology.

---

[42] *Forecasting* can be defined as the process of predicting the state of a specific element using indicators. Forecasts are therefore more deterministic in nature than scenario projections.

Though the Conto Energia program was implemented between 2006 and 2013[43], its FIT payments will last until 2038, so its effects on the public budget will extend for another two decades. The program provided a strong market-pull effect for PV technology, with domestic market deployment reaching volumes (9 GW in 2011) that mobilized local learning effects, which were a non-negligible component in the reduction of domestic PV prices. In fact, by June 2017, utility-scale systems had already reached market parity in Italy (Qualenergia.it, 2017a). Hence, one of the benefits that can be attributed to Conto Energia is that of "pulling backward" in time the market break-even of PV technology, as compared to a hypothetical case having lower subsidies. This is, of course, one of the many benefits of PV diffusion, which include, among others, lower natural gas imports, reduced $CO_2$ emissions, and lower air pollution – all consequences of PV displacing fossil-fuel consumption for electricity generation(natural gas, in the case of Italy).

The costs of this program (which fall on final electricity consumers through a levy) are, however, hefty. They hover between EUR 6 and 6.5 billion annually (about USD 7 to 7.7 billion – equivalent to about 0.4% of the Italian GDP) until the end of the 2020s (GSE, 2017b), decreasing to EUR 1 billion in 2032, and then finally reaching zero in 2038 (GSE, 2017c). Therefore, the question of whether the same reductions in natural gas consumption and $CO_2$ emissions could have been achieved with lower *subsidization* costs, or even at the same cost (to pay for the FIT scheme) but with higher environmental benefits and economic impacts, is a compelling one. All of these elements make the case for assessing the opportunity costs to government

---

[43] As mentioned in section 2.5, the program also had a small "tail" of PV capacity installed between 2014-2016 for special categories of plants and owners.

of Conto Energia throughout this program's full life cycle (2006-38) and, most importantly, for this to be done using a *counterfactual scenario*.

## 4.2 Scenarios Framework and Main Assumptions

In order to estimate the opportunity costs to government of the Conto Energia program, an energy and economic metrics framework is developed to characterize the so-called *reference* and *counterfactual* scenarios. The indicators or metrics that make up the two scenarios are shown in Table 4.1.

Table 4.1 Energy and Economic Metrics in the Scenarios (2006-2035)

| Metric | Unit | Assumptions |
|---|---|---|
| Annual PV installations | MW | Counterfactual scenario does not use historical data for 2010-16 |
| Cumulative PV installations | MW | |
| Cumulative unit capacity | N.A. | Used to derive future price values in the experience -curve equation |
| PV electricity generated | GWh | Emission coefficient of 2.337 Mt $CO_2$/M toe for natural gas |
| Avoided consumption Natural Gas | Mtoe | |
| Avoided $CO_2$ emissions from natural gas | M ton | Emission factor estimated for Italy (see Box 4.2) |
| Soft -cost component of PV-system price | EUR/kW | Estimated as a function of domestic installations |
| PV-system prices | EUR/kW | Estimated as sums of price-components subjects to global learning and soft costs |
| PV installation investments | M EUR | |
| PV O&M Expenditures | M EUR | |
| Subsidies to PV installations | M EUR | No new financial incentives assumed after 2020 in both scenarios |
| Subsidies to EE Investments | M EUR | Only applies to counterfactual scenario |

Source: Author's assumptions

The time frame for the two scenarios is 2006-35[44]. Though FIT payments will continue to 2038, the entity of the payments after 2035 is negligible, and the procedure followed to estimate the *incentive budget* is designed to incorporate FIT payments projected for 2036-38 as well.

The first step in the scenario analysis is that of constructing a complete dataset for the reference scenario. Once the PV electricity generated, avoided natural gas consumption, and avoided $CO_2$ emissions for the 2006-35 time frame have been calculated for the reference scenario (RS), the values for these metrics will be used as benchmarks or constraints[45] for the counterfactual scenario (CS) as well.

The most important difference between the two scenarios is that the CS has less cumulative PV installations between 2010 and 2020. The lower effect on reducing natural gas consumption from PV (relative to the RS) is compensated by higher energy-efficiency (EE) investments. The RS incorporates the historical trend in reduction of energy intensity of the Italian economy until 2016, so the EE investments in the CS data are *in addition* to those embedded in the RS. As a result of these additional EE investments, the CS achieves the same benefits as the RS in terms of avoided natural gas consumption and avoided $CO_2$ emissions between 2010 and 2020. This implies that the CS has no negative impact (as compared to the RS) on the Italian energy system in terms of achieving the objective of the Renewable Energy Directive

---

[44] All metrics of the two scenarios, such as PV installations, prices, cost of subsidies, and impacts between 2006 and 2009, are assumed to be the same.

[45] Values of the reference scenario are used as ‘constraints’ in the counterfactual scenario when the latter incorporates them as fixed parameters.

2009/28/CE for Italy (a 17% ratio of renewable energy supply on gross internal consumption of primary energy).

The main assumption in constructing the CS is that PV electricity crowds out natural gas generation only, and not any other renewable energy sources (RES) such as, for example, wind. This assumption is likely to not match reality in the long run, since market-competitive RESs may very well start to compete with each other (e.g., utility-scale PV systems vs. wind) in a low-carbon system. However, this assumption has no impact on the main objective of this analytical work stream, that is, on the construction of a framework that can allow a comparison in relative terms between two scenarios contributing equally to objectives related to the European Union's Directives (namely, increasing the ratio of RE supply to gross internal energy consumption by 2020, and achieving the same $CO_2$ emissions reductions between 2006 and 2020).

The "constraint" that applies to both scenarios is the amount of PV generation achieved by 2030: both the RS and the CS reach a level of PV capacity generating 70 TWh in 2030, thus reaching the solar energy objective set forth by the National Energy Strategy for that same year. In both scenarios, a PV-system lifetime of 25 years is assumed, as is consistent with values reported in literature. This means that capacity installed between 2006 and 2010 ceases to generate electricity between 2031 and 2035, respectively. The so-called *PV-yield* is assumed at 1,250 kWh/kWp, which is the average yield for the years 2011-16 reported by GSE (2017b).

Soft costs for PV systems are calculated with the learning-curve equations estimated in chapter 3, using (a) cumulative PV capacity values from the scenario to obtain the so-called *cumulative unit capacity*, and (b) the estimated learning rate for soft costs (15%). PV-system prices are then obtained by summing the price projections on modules, inverters, and BOS components from chapter 3 (which are a function of global installations rather than domestic ones) and soft costs.

The next step in calculating scenario values is the estimation of annual investments in the construction and installation (C&I) of new PV systems and expenditures for the operation and maintenance (O&M) of active PV capacity. PV-C&I investments are obtained by multiplying PV-system prices by annual PV installations. PV-O&M expenditures in year t are calculated by multiplying PV capacity under O&M by the unit O&M cost (expressed in EUR/kW). PV capacity under O&M in year t is calculated by summing PV cumulative capacity installed in year t-1 and half of PV annual installations in year *t*[46]. Unit O&M costs for the two scenarios are projected to decrease from about 80 EUR/kW in 2010 to 25 EUR/kW in 2016, and remain constant throughout the scenario time frame 2017-2035[47]. These main scenario assumptions are summarized in Table 4.2.

### 4.2.1 Incentive Budget and Subsidy Mix

Total cumulative subsidies (defined herein as *incentive budget*) from 2006 to 2038 are assumed to be the same (in real terms) in both the scenarios. However, while the RS only includes subsidies paid for PV installations under the Conto Energia

---

[46] This is assumption is equivalent to assuming that, on average, half of annual PV installations are completed by the end of the first semester.

[47] Estimates for O&M costs between 2010 and 2016 were developed by the author, based on Politecnico di Milano (2012-2013) and GSE (2016b).

program, the incentive budget in the CS supports both PV and additional EE investments. The underlying principle of the CS is that by delaying support for PV technology, policymakers can benefit from global learning effects and reduce total subsidization costs in order for PV to contribute equally to the target of the National Energy Strategy by 2030, as in the RS. It is further assumed that the difference in subsidies spent to support PV and EE between 2010 and 2020 in the two scenarios is then “used” to support additional EE investments from 2021 to 2030.

Table 4.2 Assumptions Applied to Scenarios

| **Indicator** | **Assumption** |
|---|---|
| PV-System lifetime | 25 years |
| PV yield | 1,250 kWh/kWp |
| Learning-rate of PV soft costs | 15% (see chapter 3 for learning rates of modules, inverters, and BOS) |
| PV capacity under O&M in year *t* | Calculated as a sum of installed capacity in year *t-1* and half of annual installations in year *t* |
| O&M costs | Decreasing from 80 EUR [2016]/kW in 2010 to 25 EUR [2016]/kW in 2016 and remain constant (in real terms) between 2017 and 2035 |
| Impact on ratio of renewable energy on gross internal consumption by 2020 (Objective of Renewable Energy Directive 2009/28/CE for Italy set at 17.3%). | Same impact on ratio in two scenarios. Lower PV generation in CS is compensated by additional energy-efficiency investments (hence decreasing the denominator of the ratio) to achieve the same reductions in natural gas demand. |
| PV generation by 2030 | Approximately the same in both scenarios. PV meets the objective for solar energy by 2030 set in the National Energy Strategy (about 70 TWh). |

Source: Author’s assumptions and elaborations

The CS does not employ an FIT scheme to support PV technology, but is based instead on a mix of measures that include investment tax credits, accelerated depreciation, tax deductions for residential PV systems, and net metering. The indirect costs to taxpayers of the net-metering scheme are assumed to be the same in both scenarios. The investment tax-credit scheme for PV systems and the accelerated depreciation underlying the CS are assumed to last from 2010 to 2020. From 2020 onwards, both the CS and RS are built on the assumption that no financial incentives are put in place to support growth in the domestic PV market, which will be supported only by the net metering scheme and the requirement for new buildings to install a PV system.

As mentioned, subsidies for additional EE investments are foreseen from 2010 to 2020 in the CS, so that it can be "neutral" in terms of meeting the objectives of the European Renewable Energy Directive by 2020[48], and also from 2021 to 2030. The sum of cumulative subsidies for EE investments from 2010 to 2030 and for PV between 2006 to 2020 in the CS are assumed to be equal (in constant EUR) to the total subsidies of the Conto Energia program in the RS. Subsidies for PV and EE in the CS are financed through the same levy on final electricity prices used to pay for the Conto Energia incentives.

In order to make the subsidization costs of the two scenarios comparable, the present value of all historical and projected annual FIT payments for the Conto Energia program between 2006 and 2038 (totaling about EUR [nominal] 130 billion) was calculated using 2006 as base year (GSE, 2017a; 2017c). With a nominal "social"

---

[48] The methodology used to derive investments and subsidies for EE that characterize the counterfactual scenario is detailed in section 4.4.

discount rate of 5%[49], the estimated present value at the beginning of 2006 of FIT payments of Conto Energia amounts to about EUR 62 billion (equivalent to about EUR [2016] 71 billion). This value is used as an incentive budget (or *incentive envelope*) for supporting investments in PV and EE in the CS.

Further insights into the subsidization costs of the Conto Energia program can be gathered by estimating the capital-grant equivalent of FITs per unit of capacity installed in a given year (the methodology used for this estimation is detailed in Appendix A)[50]. The results of this estimation are shown in Table 4.3. The (unit) capital subsidy-equivalent of FITs decreased from about 7 EUR/W in 2006 to 2 EUR/W in 2016. This reduction trend is in line with that observed for PV system prices. However, as can be seen from the second column of Table 4.3, the estimated unit values for the capital-grant equivalent of FIT payments are higher than the reported PV-system prices for all the years analyzed. For example, in 2011, the capital-grant equivalent of FIT payments for PV capacity installed during that year under the Conto Energia program is double the average estimated PV-system price.

---

[49] The assumed 5% social discount rate value is equal to the sum of the nominal interest rate (about 3%) of a 20-year government bond expiring in September 2038 (BTP TF 2.95%) and an average inflation rate of 2%.

[50] Data on historical FIT payments between 2006 and 2016 from GSE (2017a) are divided by the Conto Energia scheme under which the PV capacity was installed. For example, 35% of FIT payments in 2015 were for capacity installed under the second Conto Energia scheme, 25% for PV capacity installed under the second Conto Energia scheme, etc. The data on projected payments (GSE, 2017c) only show total payments estimated for a given year (e.g. EUR 6.6 billion by 2027). Therefore, a new methodology had to be developed to disaggregate annual FIT payments per year of PV capacity installed. For example, 40% of projected FIT payments in 2027 are for capacity installed in 2011, 25% for PV capacity installed in 2010, etc.

Table 4.3 Capital-grant Equivalent of FIT Payments for PV Capacity Installed under Conto Energia, M EUR (2006-2016)

| Year | Unit capital-grant equivalent of FIT payments Eur[a]/W | Ratio of unit capital-grant equiv. of FIT to PV-system price | PV capacity installed MW | Total capital-grant equivalent of FIT payments M Eur[a] |
|---|---|---|---|---|
| 2006 | 6.89 | 112.15% | 9 | 65 |
| 2007 | 6.68 | 108.84% | 70 | 468 |
| 2008 | 5.93 | 112.68% | 338 | 2,004 |
| 2009 | 5.68 | 150.81% | 718 | 4,078 |
| 2010 | 5.54 | 161.51% | 2,321 | 12,866 |
| 2011 | 4.68 | 202.74% | 9,475 | 44,312 |
| 2012 | 3.52 | 174.80% | 3,580 | 12,585 |
| 2013 | 2.52 | 143.96% | 1,103 | 2,784 |
| 2014 | 2.01 | 114.18% | 92 | 185 |
| 2015 | 2.02 | 116.01% | 7 | 14 |
| 2016 | 2.03 | 146.81% | 20 | 41 |
| Total Cumulative | | | 17,734 | 79,402 |

Note: (a) Nominal Values

Data Source: GSE, 2017a; 2017c

## 4.3 Reference Scenario

The RS is built on historical data on PV installations and PV-system prices between 2006 and 2016, and projections on PV-market growth such that PV technology reaches the milestone of 70 TWh generated by 2030. As mentioned, this level of generation is consistent with the target of 72 TWh for solar energy (including concentrated solar power) of the National Energy Strategy (MSE, 2017). In order to reach this target, the annual growth rate of the Italian PV market is assumed to increase from 20% in 2017 to 35% in 2020, peaking at 40% in 2021, and linearly decreasing to zero in 2030, when annual PV installations are 5.5 GW (Table 4.4).

Cumulative PV electricity generation between 2017 and 2035 in the RS is 1,004 TWh, resulting in about 158 Mtoe of avoided natural gas consumption and 368

M ton of avoided $CO_2$ emissions[51]. If historical data from 2006 to 2016 is added to scenario projections so as to estimate results for the entire time-frame of the analysis, cumulative PV electricity totals about 1,130 TWh, with 176 Mtoe of avoided natural gas consumption and 412 Mt of avoided $CO_2$ emissions.

Table 4.4 Projections on PV Market and PV Generation in the Reference Scenario

| Indicator and unit | Year | | | | |
|---|---|---|---|---|---|
| | 2017 | 2020 | 2025 | 2030 | 2035 |
| Annual growth rate of domestic PV market (%) | 20% | 35% | 21% | 0% | 0% |
| Annual PV Installations (MW) | 459 | 1,007 | 3,736 | 5,533 | 5,533 |
| Cumulative Capacity (MW) | 19,404 | 21,730 | 34,343 | 59,983 | 84,185 |
| PV Electricity generated (GWh) | 23,489 | 26,003 | 39,782 | 70,090 | 102,581 |

Data Source: Author's elaboration

Soft costs for PV systems are projected to decrease from about 830 EUR/kW in 2016 to about 610 EUR/kW in 2035, when PV-system prices in the RS reach about 1,000 EUR/kW[52]. Investments in PV-C&I increase from about EUR 650 million in 2017 to about EUR 5,500 million in 2035, while PV-O&M expenditures increase from EUR 514 million to 2,250 million over the same period. Projections on PV-system prices, investments in new plants, and O&M expenditures for the RS are summarized in Table 4.5 (full scenario results are provided in Appendix B).

---

[51] Assuming an emission coefficient of 2.337 Mt $CO_2$/M toe for natural gas.

[52] Monetary values in the scenarios are expressed in constant (2016) Euros (EUR).

Table 4.5 Economic Projections on Italian PV Market in the Reference Scenario

| **Indicator and unit** | **Year** | | | | |
|---|---|---|---|---|---|
| | 2016 | 2020 | 2025 | 2030 | 2035 |
| Soft costs of PV-systems (EUR[2016]/kW) | 186 | 177 | 152 | 126 | 112 |
| PV-system prices (EUR[2016]/kW) | 1,385 | 1,128 | 927 | 793 | 729 |
| PV-installation investments (M EUR[2016]) | 530 | 1,136 | 3,464 | 4,391 | 4,032 |
| O&M expenditures (M EUR[2016]) | 860 | 918 | 1,404 | 2,473 | 3,620 |

Data source: Author's elaboration

## 4.4 Counterfactual Scenario

The CS aims to conduct a "what if" analysis based on an alternative policy pathway. The objective of constructing this scenario is to gather insights on the opportunity costs of the Conto Energia program and to define input data needed for economic impact analysis.

Economic impact analyses of specific renewable energy policies or programs often include a "no-policy" case as their counterfactual scenario. The analytical added value of this kind of no-policy scenario, however, does not help to align the analytical framework with the research rationale and research questions of this work. In fact, had Italian policymakers not opted to support PV technology with a FIT scheme in 2006, it is highly unlikely that there would have been no financial support mechanism for PV technology *at all* in Italy (when most members of the IEA-PVPS had at least one mechanism in place). Furthermore, what can be useful to policymakers, in order to design more efficient and effective energy policies in the future, is to have methodologies in place that develop alternative scenarios based on the same level of ambition to decarbonize the energy system, but through different policy and technology routes.

In light of the above considerations, the CS presented is constructed on three main assumptions (or constraints): (1) it achieves the same reductions in natural gas imports and $CO_2$ emissions reductions as does the RS between 2006 and 2020 (when Italy had to meet the target of the Renewable Energy Directive 2009/28/CE); (2) it also reaches a level of PV generation consistent with the target of the National Energy Strategy by 2030 (70 TWh); and (3) it "uses" the same level of cumulative subsidies that, in the RS, are employed to pay for FITs, but has a more balanced portfolio, including support for both PV deployment and additional (relative to the RS) EE investments.

The pattern of annual PV installations between 2010 and 2020 in the CS is significantly different from that in the RS[53], growing at an 11% CAGR and reaching about 2,200 MW in 2020. In this alternative pathway, installed PV capacity in 2016 is 8,700 MW, versus the 19,188 MW effectively operating at the end of that year. The assumed market-growth rate increases from 10% in 2017 to 20% in 2020, and starts to linearly decrease to zero in 2030, when annual installations reach 5,500 MW. Installed PV capacity in the CS is about 60,000 MW in 2030, with a generation of about 70 TWh (almost equal to generation in the RS). Cumulative PV electricity generation between 2010 and 2035 is 980 TWh, with 153 Mtoe of avoided natural gas consumption and 350 Mt of avoided $CO_2$ emissions. Scenario values on the PV market in the counterfactual case are summarized in Table 4.6.

---

[53] Annual PV installations between 2006 and 2009 in the counterfactual scenario are assumed to be the same as historical values (and thus, as the reference scenario), increasing from 12 MW in 2006 to 732 MW in 2009 (with a non-negligible 300% CAGR).

Table 4.6 Projections on PV Market in the Counterfactual Scenario

| Indicator and unit | Year | | | | | |
|---|---|---|---|---|---|---|
| | 2010 | 2016 | 2020 | 2025 | 2030 | 2035 |
| Annual growth rate of domestic PV market (%) | 10% | 10% | 15% | 11% | 0% | 0% |
| Annual PV Installations (MW) | 796 | 1,410 | 2,158 | 4,438 | 5,503 | 5,503 |
| Cumulative Capacity (MW) | 1,964 | 8,717 | 16,008 | 33,602 | 59,977 | 85,552 |
| PV Electricity generated (GWh) | 1,919 | 9,816 | 18,288 | 38,444 | 70,101 | 102,405 |

Data source: Author’s elaboration

In 2030, PV-system prices in the CS reach about 1,090 EUR/kW, a value that is only slightly higher than the RS. It is worth noting that this gap in PV-system prices between the two scenarios is much larger (about 100 EUR/kWp) in 2016, due to the lower cumulative capacity of the CS in that year. PV-C&I investments increase by a factor of 2.3 from 2016 to 2030, reaching about EUR 6 billion. O&M expenditures increase by an even larger magnitude between 2016 and 2030, when they are projected to EUR 1.4 billion (vs. EUR 0.2 billion in 2016) (see Table 4.7).

Table 4.7 Economic Projections on Italian PV Market in the Counterfactual Scenario (2016-2035)

| Indicator and unit | Year | | | | | |
|---|---|---|---|---|---|---|
| | 2010 | 2016 | 2020 | 2025 | 2030 | 2035 |
| Soft costs of PV-systems (Eur[2016]/kW) | 778 | 470 | 383 | 299 | 246 | 218 |
| PV-system prices (Eur[2016]/kW) | 3,409 | 1,670 | 1,334 | 1,074 | 913 | 834 |
| PV-installation investments (M Eur[2016) | 2,713 | 2,354 | 2,879 | 4,765 | 5,025 | 4,591 |
| O&M expenditures (M Eur[2016]) | 119 | 361 | 645 | 1,357 | 2,474 | 3,614 |

Data source: Author’s elaboration

Supporting PV deployment from 2006 in the CS is a mix of measures that include investment tax credits, accelerated depreciation, net metering, and tax deductions for residential PV systems. The assumed *subsidization impact* of these measures is an average unit (EUR/kW) capital-grant value, equivalent to 60% of PV-system prices. This is a much lower (and reasonable) value of the estimated capital-grant equivalent of FIT payments for PV capacity installed under Conto Energia between 2010 and 2013 (Table 4.3), exceeding 100% of estimated PV-system prices.

As mentioned, one of the main characteristics of the CS is the lower PV deployment between 2010 and 2020, and particularly from 2010 to 2013. This assumption was built in to differentiate the CS from the RS for the sake of assessing the opportunity costs to government of the Conto Energia program. The difference in PV cumulative capacity between the two scenarios at the end of 2013 is significant, with a gap of more than 13,000 MW. Though PV installations in the CS are higher from 2014 onwards, cumulative PV capacity at the end of 2020 is still lower than the RS (by almost 5000 MW). All other things being equal, with the level of PV deployment envisioned in the CS, Italy would not have reached the 2020 objective of the Renewable Energy Directive (renewables sources contributing to 17% of gross internal energy consumption).

### 4.4.1 Estimation of Energy-efficiency Investments and Subsidies

The lower cumulative PV installations in the CS (resulting in less avoided natural gas demand and $CO_2$ emissions reductions) between 2010 and 2020 is compensated by higher EE savings, which reduced natural gas consumption by an additional 19 Mtoe over the same period. As a result, the two scenarios achieve the same level of total avoided (cumulative) natural gas demand between 2010 and 2020 (about 35 Mtoe), and the same level of $CO_2$ emissions reductions (about 81 M tons).

The sectors in which natural gas demand is reduced are identified from the seminal study conducted by Beccarello (2011), who analyzed the potential savings and investment costs of several EE options for the period 2010-20 (Table 4.8). The EE options in the Table are ranked by increasing unit investment costs (M EUR [2016]/M toe)[54] in order to assess the cumulative energy savings potential on a step-by-step basis, beginning with the option having the lowest cost and ending with that having the highest. This step is normally used to construct marginal cost curves for EE options (Jacob, 2003), also called conservation supply curves (Olivier et al., 1983).

Table 4.8 Potential Energy Savings and Investment Costs in Selected Energy Efficiency Options from Beccarello (2011)

| EE option | Unit investment cost M Eur (2016) / Mtoe | Potential savings on Final energy demand 2010-2020 Mtoe | Potential savings on Primary energy demand 2010-2020 Mtoe | Cumulative savings on Primary energy demand 2010 - 2020 Mtoe | Total Investments 2010-2020 M Eur (2016) |
|---|---|---|---|---|---|
| Heat pumps | 80 | 5.1 | 11.7 | 11.7 | 408 |
| Lighting | 399 | 8.9 | 18.2 | 29.9 | 3,548 |
| Condensing boilers | 532 | 4.9 | 4.9 | 34.8 | 2,606 |
| Electric motors and inverters | 1,443 | 2.7 | 5.5 | 40.3 | 3,895 |
| UPS | 2,278 | 0.7 | 1.5 | 41.8 | 1,595 |
| Appliances | 3,920 | 5.3 | 10.8 | 52.6 | 20,778 |
| Refurbishing resid. buildings | 3,932 | 8.8 | 8.8 | 61.4 | 34,605 |
| Cogeneration | 4,153 | 2.8 | 12.6 | 74 | 11,629 |
| Road transport | 4,906 | 12 | 12 | 86 | 58,875 |
| Total |  | 51.2 | 86 |  | 137,938 |

Data source: Beccarello, 2011

As can be seen from the Table, the three EE options with the lowest unit-investment costs were assessed by Beccarello to have a total potential, in terms of

---

[54] The study done by Beccarello (2011) does not indicate where monetary metrics (total investments and subsidies for EE options for the whole period 2020-20) are in nominal or real terms. It is assumed here that investment and subsidy values extracted from Beccarello et al. are in constant EUR 2010.

primary-energy savings, of almost 35 Mtoe between 2010-20. This is almost twice the reduction in natural gas demand that needs to be achieved in the CS in order to compensate for lower PV generation.

The EE component of the CS is built on the assumption that the 19.7 Mtoe reduction in natural gas demand is achieved with balanced contributions from all three options with the lowest investment cost. It is assumed that the full potential, in terms of the primary-energy savings of the lowest-cost option (heat pumps with a potential of 11.7 Mtoe), is not entirely tapped in the CS, as part of this potential had most likely been already utilized between 2010 and 2016 as a result of the several incentives in place for EE (ENEA, 2017). The same constraint partly applies to the second-lowest cost option (lighting with a potential of 18.2 Mtoe).

With the objective of making the CS a realistic policy and technology pathway, it is assumed that this scenario achieves between 2010 and 2020 about 60% of the total EE potential of heat pumps (7 Mtoe), about 60% from lighting (11 Mtoe), and about 55% of the potential of condensing gas boilers (2.7 Mtoe), for a total of 19.7 of primary-energy savings. It is also assumed that these savings only displace primary energy demand for natural gas, given its prominent role in Italy for both electricity generation (about 40% of total electricity generation in 2016 [Terna, 2018]) and for heating in final uses. The additional investment costs between 2010 and 2020 in the CS, achieving the 19.7 savings in natural gas demand from the mix of EE options, amount to about EUR 12.9 million (Table 4.9). The average unit investment cost of the *EE portfolio* embedded in the CS amounts to about 330 M EUR/Mtoe, a figure that falls within the range of investment costs for EE measures (between 90 and 630 M EUR/Mtoe) reported by the IEA (2014a).

Table 4.9 Energy-demand Savings and Energy-efficiency Investments in the Counterfactual Scenario, 2010-2020

| EE option | Unit investment cost M Eur(2016) / Mtoe(a) | Share of potential reduction on primary energy demand utilized in scenario (%) | Savings on Primary energy demand 2010-2020 Mtoe | Savings on Final energy demand (b) 2010-2020 Mtoe | Total Investments 2010-2020 M Eur(2016) |
|---|---|---|---|---|---|
| Heat pumps | 80 | 60% | 7.02 | 3 | 245 |
| Lighting | 399 | 55% | 10.01 | 4.90 | 1,951 |
| Condensing boilers | 532 | 55% | 2.695 | 2.695 | 1,433 |
| Total | | | 19.725 | 11 | 3,629 |

Note: (a) Final energy demand; (b) assuming a conversion efficiency from natural gas to electricity of 43.5% for heat pumps and 49% for lighting

Source: Author’s elaboration from Beccarello (2011)

To estimate the subsidies needed to mobilize this level of investment, it is also necessary to define which sectors (e.g., residential, commercial, public) the EE potential would be effectively tapped into, as there were different incentives available between 2010 and 2016 for EE projects in the commercial, industrial, and residential sectors (Beccarello, 2010; ENEA, 2017). The CS assumes that 40% of EE investments take place in the commercial sector and 60% in the public sector to account for the fact that the buildings stock in these two sectors had likely seen lower EE improvements (on average) than the residential one between 2010 and 2016. In other words, in the CS, a larger share of EE potential is assumed to be available in the non-residential sectors than in the residential sector[55]. In the commercial sector, subsidies for heat pumps, condensing gas boilers, and lighting are implemented through a mix of incentives (e.g., rebates, tax-deductions) that are assumed to cover 40% of the upfront investment cost.

---

[55] In the CS, final energy demand between 2010 and 2016 is equal to historical values. This means that the CS already incorporates the distribution by sector of actual investments in EE projects between 2010 and 2016.

Though the category of “Subsidy” inherently cannot apply to EE projects undertaken by the public sector, it is assumed that the costs of such investments, as well as those of the subsidies that apply to the commercial sector, are financed through a levy on final prices of electricity (similarly to Conto Energia’s FIT payments). The assumptions underlying the CS on the share of the commercial and public sectors, the degree of subsidization as well as total subsidies, and direct costs to the government for EE investments are summarized in Table 4.10.

Table 4.10 Assumptions on (a) Sectoral Distribution of EE Projects and Subsidies; Scenario Results for Total Subsidies and Cost for EE Investments in the Public Sector in the Counterfactual Scenario

| EE option | Share of public sector in TFC reduction in scenario (%) | Public sector EE investments in scenario M Eur (2016) | Share of commercial sector on TFC reduction (%) | Commercial sector EE investments in scenario M Eur (2016) | Ratio of Subsidy to Total Investment cost in commercial sector 2010-2020 (%) | Total subsidies for EE projects in commercial sector cum. 2010-2020 M Eur(2016) | Total cost to government for EE investments cum. 2010-2020 M Eur(2016) |
|---|---|---|---|---|---|---|---|
| Heat pumps | 50% | 122.32 | 50% | 122.32 | 40% | 49 | 171 |
| Lighting | 50% | 975.73 | 50% | 975.73 | 40% | 390 | 1,366 |
| Condensing boilers | 50% | 716.65 | 50% | 716.65 | 40% | 287 | 1,003 |
| Total | - | 1814.70 | - | 1814.70 | - | 726 | 2,541 |

Source: Author’s elaboration based on Beccarello (2011)

Between 2010 and 2020, total subsidies for EE projects in the commercial sector amount to about EUR 0.7 billion. The investment costs for projects in the public sector total EUR 1.8 billion, so the total “Cost to Government” is EUR 2.5 billion, with a cost-to-government per unit of energy saved of 509 M EUR/M toe.

## 4.5 Comparison of the Two Scenario and a Summary of Results

Thanks to the Conto Energia FIT program, cumulative PV installations between 2006 and 2013 in Italy totaled about 18 GW, equivalent to more than 90% of operating capacity at the end of 2016 (19.2 GW). The CS has much lower installations between 2010 and 2013, but slightly higher than historical values from 2014 to 2016. The CS then projects higher installations between 2020 and 2035, to the extent that PV cumulative capacity between 2006 and 2035 in the two scenarios is almost equal; (scenario values for key indicators are summarized in Table 4.11).

Avoided natural gas demand from PV deployment between 2006 and 2020 is about 19 Mtoe higher in the RS, an amount that is, however, fully compensated by higher EE investments over the same time frame in the CS. As a result, the CS achieves the same effect on increasing the ratio of renewable energy supply on gross internal energy consumption, which is the relevant indicator for the target of the European Renewable Energy Directive by 2020.

By 2030, PV generation in the two scenarios amounts to about 20.5% of estimated electricity demand in Italy (the difference in PV capacity and generation in the two scenarios by 2030 is minimal, as the reference and counterfactual scenarios share the same constraint of generating about 70 TWh by 2030)[56]. By 2035, the share of PV electricity generation on projected electricity demand in the two scenarios increases to about 29%. Taking into account transmission losses, the share of PV on total electricity generation in the two scenarios is estimated to be slightly above 30%

---

[56] Electricity-demand projections until 2026 are derived from Terna (2017). From 2027 to 2035, an average annual growth of 0.65% is assumed. This is the average of the growth rates between 2016 and 2026 used in the baseline (*base*) and growth (*sviluppo*) scenarios of Terna.

by 2030. Effectively achieving this level of contribution to electricity supply will most likely require the integration of PV systems with energy storage (ES)[57].

Table 4.11 Summary Results for the Two Scenarios

| Indicator and unit | Time Frame | RS | CS |
|---|---|---|---|
| Cumulative PV installations (MW) | 2006-2013 | 17,822 | 4,836 |
| Cumulative PV installations (MW) | 2006-2020 | 21,705 | 15,983 |
| Cumulative PV installations (MW) | 2021-2035 | 65,919 | 71,483 |
| Cumulative PV installations (MW) | 2006-2035 | 87,624 | 87,466 |
| Avoided fossil-fuel primary energy consumption from PV - (Mtoe) | 2006-2020 | 34.36 | 15.59 |
| Avoided fossil-fuel primary energy consumption from EE(a) - (Mtoe) | 2006-2020 | - | 18.77 |
| Total Investments in Installation of PV plants/systems (M EUR[2016]) | 2006-2035 | 105,842 | 101,161 |
| Total Investments in EE options(a)(M EUR[2016]) | 2010-2020 | - | 3,629 |
| Total clean-energy investments | 2006-2035 | 105,842 | 104,790 |
| Total estimated subsidies for PV plants/systems (M EUR[2016]) | 2006-2035 | 80,876 | 18,924 |
| Total estimated subsidies and public investments for EE projects(a) (M EUR[2016]) | 2010-2020 | - | 2,541 |
| Total residual subsidies available for additional EE projects (M EUR[2016]) | 2021-2035 | - | 59,411 |
| Total subsidies/public investments for PV and EE (M EUR[2016])(b) | 2006-2035 | 80,876 | 80,876 |

Note: (a) EE: energy efficiency. This refers to energy-efficiency investments taking place in the counterfactual scenario between 2010 and 2020 that are "additional" with respect to 'baseline' EE investments; (b) Includes subsidies to PV installations, EE investments in the services (commercial) sector, and EE investments made by the public sector.

Source: Author’s elaboration

Total investments in PV systems in the RS between 2006 and 2035 are slightly higher than in the CS (106 vs. 101 EUR billion), as the latter marginally benefits from the “wait and see” strategy, which, as mentioned, aims at tapping global learning effects to take advantage of lower prices in PV-system components traded in global markets (e.g., modules, inverters).

---

[57] ES investments are not estimated in the scenarios, as the share of PV capacity with ES is assumed to be the same in the two scenarios, so it would not change the differential in terms of total investment costs.

The biggest difference in the two scenarios is in the subsidies needed to mobilize PV investments. Total estimated subsidies for PV market-pull between 2006 and 2035 (FIT payments and subsidies for residential installations) in the RS are EUR 72 billion, almost four times higher than the subsidies for PV estimated in the CS (about EUR 19 billion)[58]. These subsidies, amounting on average to 60% of the capital cost of PV systems, are assumed to be effective enough to mobilize 16 GW of projected annual PV installations between 2006 and 2020 in the CS.

This large gap on subsidies can be explained by the cost of the FIT program throughout its full cycle. In fact, if data on past annual FIT payments (from 2006 to 2016) and estimates on flows of undiscounted FIT payments from 2017 to 2035 are considered, the cumulative cost of the Conto Energia reaches almost EUR (nominal) 130 billion[59].

Subsidies to and public investments for EE projects between 2010 and 2020 in the CS amount to EUR 2.5 billion, which brings the total subsidization costs of this scenario to about EUR 18 billion over the same time period. Since the two scenarios are assumed to have the same total cumulative subsidization costs between 2006 and 2035 (EUR 72.3 billion), the CS has a residual "nest egg" available of about EUR 54 billion to support EE investments from 2020 to 2030. Assuming this residual is used to support EE investments targeting improvements in the thermal envelope of existing

---

[58] The 72,330 M EUR of PV subsidy costs in the reference scenario include an estimated 1,100 M EUR of costs for the tax-deduction scheme for residential PV systems between 2013 and 2020.

[59] Historical values from 2010 to 2016 from GSE (2017a); forecasted costs from 2017 to 2019 based on author's estimation; projected costs from 2020 to 2038 from GSE (2017c).

buildings, between 2020 and 2030, with an average unit cost of 4,000 M EUR/Mtoe (of energy saved)[60] and a 50% subsidization rate, there would potentially be about 20 Mtoe of additional reductions in final demand for natural-gas demand and 47 Mton of additional carbon emissions reductions as compared to the RS.

## 4.6 Break-even and Grid Parity Analysis

The reduction in PV-system prices projected in the two scenarios would obviously improve the competitiveness of PV technology relative to other sources of electricity generation. With between 66 and 71 GW of PV installations projected between 2021 and 2035 in the two scenarios, the question of whether and to what extent these levels of PV deployment might require the introduction of new market-pull mechanisms warrants investigation.

This question is obviously related to the prospect of PV competing with grid electricity in the market niches of distributed systems without any financial incentive. As mentioned, while utility-scale PV systems have already achieved so-called *market parity* in 2017 (Qualenergia.it, 2017a), PV diffusion in the niche industrial and commercial systems relies strongly on the net-metering scheme, and installations of

---

[60] This figure is based under the very conservative assumption that the average unit cost for measures increasing thermal insulation of buildings remains constant at the level estimated by Beccarello in 2011 (3,950 M EUR/ Mtoe). On the other hand, a portion of the lowest-cost potential savings estimated by Beccarello from efficient building envelope technologies had most likely been already utilized between 2010 and 2016, so the residual potential available by 2020 would be for projects with higher marginal EE costs.

residential PV systems are reliant on the tax deduction scheme (50% of total PV-system cost).

*Grid Parity* is defined by the IEA-PVPS as "the moment when PV can produce electricity at a price below the price (the Levelized Cost of Electricity [LCOE]) of electricity" (IEA-PVPS, 2016: 61)[61]. Literature on grid-parity prospects for PV technology has been increasing significantly since the publication of the IEA's seminal study on experience curves (IEA, 2000) and, over the last decade, an articulated "discourse" on grid parity has emerged. Hurtado Munoz et al. (2014) conducted an extensive up-to-date analysis of the literature related to PV grid parity, and concluded that many grid-parity studies are not characterized by an articulation and careful evaluation of the assumptions used for the grid-parity analysis in a specific geographical context. One of the elements in the discourse on the future of PV technology is the assumption that when PV systems achieve grid parity, the PV market will go through a phase of exponential growth (see, e.g., Diamandis, 2014).

Whether grid parity, as measured by LCOE equivalence with the price of grid electricity, is a good indicator for PV competitiveness for all kinds of grid-connected PV systems needs to be assessed, however. The LCOE-based concept of grid parity to owners of PV systems selling *all* of the electricity generated by the PV system to wholesale markets is straightforward. If the LCOE from the PV plant is lower than the expected average wholesale price over the time frame considered, PV-system owners will be able to profit from selling the electricity produced by the PV system to the grid. However, this concept of grid parity is less meaningful to those owners of PV

---

[61] The LCOE concept is discussed in detail in section 4.6.1.

systems that *also* self-consume the electricity generated (often referred to as *prosumers*). For the LCOE to be a meaningful metric to measure grid parity for prosumers, two (ideal) conditions needs to be fulfilled, namely that (a) 100% of the PV electricity be self-consumed (this could be in real-time or through specific net-metering schemes), and that (b) PV electricity self-consumed be valued exactly at full retail price of electricity (IEA-PVPS, 2016).

### 4.6.1 Grid-parity analysis of PV systems in Italy: the LCOE approach

In order to assess the prospects for PV competitiveness in the two scenarios, a grid-parity analysis based on LCOE is necessary. This analysis needs to examine whether PV systems in Italy have already reached grid parity (as compared to retail electricity prices) and, most importantly, whether or not grid parity, in and of itself, is a watershed in PV market-growth.

The achievement of grid parity depends on local conditions, such as solar radiation (and other factors affecting the LCOE), and on certain aspects concerning the specific electricity market where the PV system is operating. For instance, commercial entities installing PV systems usually have different retail electricity prices than do residential PV system owners. The analysis for grid parity in Italy should therefore consider different geographical regions (North, Center, South) and different markets (residential vs. commercial).

The electricity generation cost by PV systems is conventionally measured by the LCOE, as represented in equation 4.1:

$$LCOE = \sum_t ((Investment + O\&M) * (1+r)^{-t}) / (\sum_t (Electricity_t * (1+r)^{-t})) \qquad (4.1)$$

The numerator of equation 4.1 quantifies the discounted life-cycle costs of a PV system (the initial investment and operation and maintenance, which includes the replacement of the inverter) and the denominator quantifies the electricity produced during the life cycle of the PV system (IEA & NEA, 2010)[62].

Table 4.12 shows the assumptions used for the calculation of LCOE values for a 3 kW residential system and the results for three different PV-yield values[63]. Estimated LCOE values for a residential PV system in 2016 range from about 0.16 EUR/kWh in Southern Italy (PV-yield 1,350 kWh/kWp), to about 0.19 EUR/kWh in Northern Italy (PV-yield at 1,150 kWh/kWp). These values are below the average price of retail electricity in Italy reported for that year by the Italian Energy Authority at 0.1956 EUR/kWh (ARERA, 2017)[64]. Of all the assumptions used to calculate a cash-flow analysis, the choice of the discount rate is arguably the most subjective, as prospective owners of PV residential system might use different criteria to discount future cash flows. In fact, if the assumed real discount rate were increased to 7%, the

---

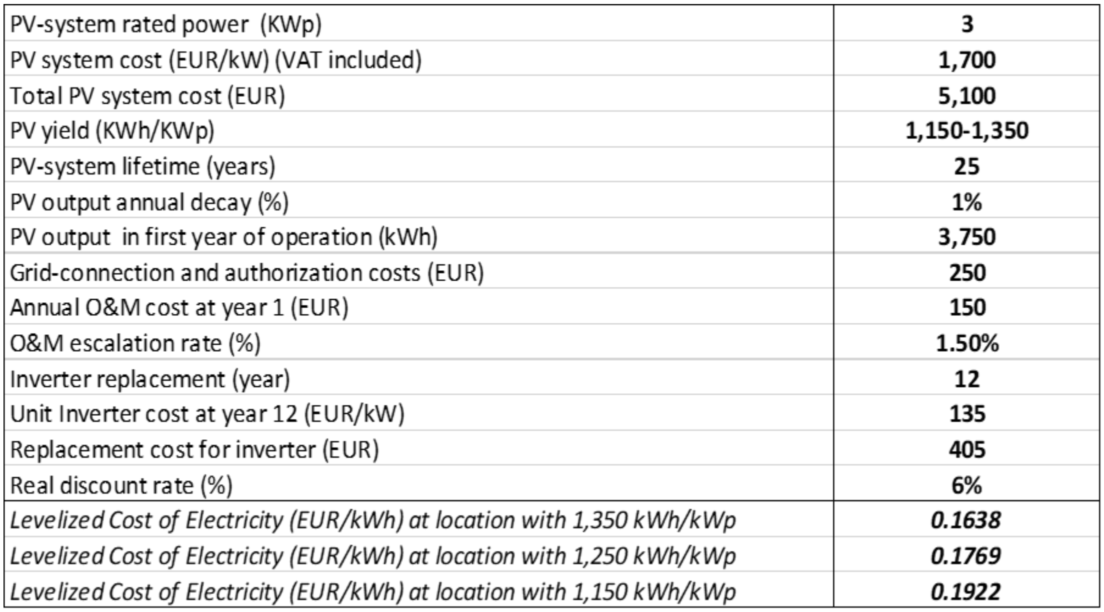
[62] Equation 4.1 is the result of a mathematical transformation of an LCOE equation that includes the price of electricity. This explains why physical units of electricity appear “as if physical production was discounted” (IEA & NEA, 2010: p.33).

[63] PV-system price is estimated from values reported in the National Survey Report of PV power applications in Italy (Tilli et al., 2017). The PV-yield value used is the 2011-2016 average PV yield reported by GSE (2017). PV-system lifetime and PV-output annual decay values are consistent with similar analyses published in the literature (e.g., Politecnico di Milano, 2016). Values for grid-connection and authorization costs are also from Politecnico di Milano (2016). The inverter-replacement costs at year twelve (EUR 135/kW) is estimated assuming a 10% reduction from values estimated for 2016 by author.

[64] With a consumption class between 2,500 and 3,500 kWh, the average electricity price (excluding taxes) reported by the Authority for 2016 is 195.6 EUR/MWh (ARERA, 2017).

LCOE for a PV-system in Central Italy would spike to about 0.19 EUR/kWh, but still be below the average retail electricity price.

Table 4.12 Assumptions for LCOE Analysis for a 3 kW Residential PV System in Italy, 2016



| | |
|---|---|
| PV-system rated power (KWp) | **3** |
| PV system cost (EUR/kW) (VAT included) | **1,700** |
| Total PV system cost (EUR) | **5,100** |
| PV yield (KWh/KWp) | **1,150-1,350** |
| PV-system lifetime (years) | **25** |
| PV output annual decay (%) | **1%** |
| PV output in first year of operation (kWh) | **3,750** |
| Grid-connection and authorization costs (EUR) | **250** |
| Annual O&M cost at year 1 (EUR) | **150** |
| O&M escalation rate (%) | **1.50%** |
| Inverter replacement (year) | **12** |
| Unit Inverter cost at year 12 (EUR/kW) | **135** |
| Replacement cost for inverter (EUR) | **405** |
| Real discount rate (%) | **6%** |
| *Levelized Cost of Electricity (EUR/kWh) at location with 1,350 kWh/kWp* | ***0.1638*** |
| *Levelized Cost of Electricity (EUR/kWh) at location with 1,250 kWh/kWp* | ***0.1769*** |
| *Levelized Cost of Electricity (EUR/kWh) at location with 1,150 kWh/kWp* | ***0.1922*** |

Source: Author's elaboration

From these results, it derives that residential PV systems in Italy have already achieved grid parity, if the definition of the latter is based on LCOE equivalence with retail electricity prices. However, as mentioned, as of 2018, residential PV systems in Italy are still subsidized with a 50% tax-deduction scheme, which has been replacing FIT payments as support mechanism in this niche since mid-2013. This incentive was not included in the LCOE estimation, but if included, the LCOE for residential PV systems in Central Italy would be as low as 0.11 EUR/kWh.

Table 4.13 summarizes the assumptions used for the calculation of LCOE values for a 100 kW commercial system and the results for the same three PV-yield values used for the residential system[65]. With LCOE values ranging from 0.13 to 0.15 EUR/kWh, commercial PV systems in Italy had also achieved grid parity in 2016, as the level of electricity prices reported by the Energy Authority for customers in the medium-voltage market segment is 0.18 EUR/kWh)[66].

Despite both residential and commercial PV-systems having already achieved LCOE-base grid parity in 2016, with 316 MW, the level of installations for these two segments in that year is significantly below what was installed in 2012 under the Conto Energia program (1,813 MW). This suggests that LCOE-based grid parity does not necessarily correlate with an acceleration in technology diffusion. It follows that the concept of LCOE-based grid-parity might have limited value for any PV technology-diffusion analysis of PV systems aimed at projecting PV installations in a post-subsidy market environment. Several factors might be at play in making LCOE-based grid parity an imperfect benchmark as a market break-even factor.

---

[65] The assumed value for grid-connection and authorization costs is from Politecnico di Milano (2016). The inverter-replacement costs at year twelve (EUR 135/kW) is estimated by the author assuming a 10% reduction from values estimated for 2016 by author. The value for O&M costs (9,000 EUR at year 1) is also based the author’s estimates of a unit cost of EUR 26/kW. For all other assumptions, see footnote 52.

[66] The average electricity price (excluding taxes) reported by the Italian Energy Authority for the medium-voltage (*media tensione*) segment in 2016 is 177.10 EUR/MWh (ARERA, 2017).

Table 4.13 Assumptions for LCOE Analysis for a 100 kW Commercial PV System in Italy, 2016

| | |
|---|---|
| PV-system rated power (KWp) | **100** |
| PV system cost (EUR/kW) VAT included | **1,300** |
| Total PV system cost (EUR) | **130,000** |
| PV yield (KWh/KWp) | **1,350** |
| PV-system lifetime (years) | **25** |
| PV output annual decay (%) | **1.00%** |
| PV output (kWh) | **135,000** |
| Grid connection and authorization costs (EUR) | **5,000** |
| Annual O&M cost at year 1 (EUR) | **2,600** |
| O&M escalation rate (%) | **1.50%** |
| Inverter replacement (year) | **12** |
| Unit Inverter cost at year 12 (EUR/kW) | **130** |
| Replacement cost for inverter (EUR) | **13,000** |
| Real discount rate (%) | **8%** |
| *Levelized Cost of Electricity (EUR/kWh) at location with 1,350 kWh/kWp* | ***0.1291*** |
| *Levelized Cost of Electricity (EUR/kWh) at location with 1,250 kWh/kWp* | ***0.1395*** |
| *Levelized Cost of Electricity (EUR/kWh) at location with 1,150 kWh/kWp* | ***0.1516*** |

Source: Author’s elaboration

A grid parity analysis of PV systems based only on the LCOE criterion implicitly assumes that the value of generate PV electricity is equal to the retail electricity price. In most existing regulatory frameworks, however, the electricity generated by a PV system that is not self-consumed is not valued at the full retail electricity price. When PV generation is higher than consumption load, excess electricity is fed into the distribution grid, and the rate at which this electricity will be valued depends on the specific net-metering regime in place. In fact, even the most favorable net-metering regimes in countries monitored by the IEA-PVPS program do not provide for a compensation equivalent to the full price of electricity (defined as *full net metering*), as some of the dispatch charges and fixed fees included in the retail price are not included in the net metering compensation (IEA-PVPS, 2016). Even in those cases where the net-metering regime would grant PV system owners a compensation equivalent to the full retail electricity price, it should be questioned whether and to what extent the decision of prospective PV system owners to invest and install a PV system should be based on the LCOE metric.

### 4.6.2 IRR-based Approach to Assess Market Competitiveness

Analyses on the financial viability of investments on PV systems in Italy periodically undertaken by the Energy& Strategy Group of the Politecnico di Milano (2008-2014) are based on an approach to estimating grid parity that is different from that of LCOE. This alternative analytical approach to grid parity is based on the Internal Rate of Return (IRR) of the investment, which arguably better reflects the decision-making process of past and potential PV system owners. The approach defines grid parity or *market break-even* as a level of PV system prices that can guarantee minimum IRR values to subjects investing in PV systems. In the analysis carried out by the Politecnico di Milano in 2014, this IRR target was set at 4% for residential PV systems and at 6% for commercial and industrial systems. Their analysis concluded that if incentives are not accounted for, PV technology already reached grid parity in Italy in the market niche of commercial applications in the southern regions of Italy in 2013[67] (Politecnico di Milano, 2014).

To estimate IRR values of investments in distributed PV systems in Italy in 2016, cash-flow analysis was conducted for a 3 kW residential PV system and a 150

---

[67] With average market prices as of December 2013, and if a lifetime of 30 years is assumed.

kW commercial PV system. The assumptions and results for the two cases are presented in Tables 4.14 and 4.15.

In 2016, a residential PV system with a full-equity investment in Central Italy achieved an IRR of about 8.50% (and a payback in 9 years). This result is contingent upon the 50% tax-deduction scheme: without tax deduction, the IRR would decrease to 3.70%. The IRR of a PV-system investment with more favorable solar irradiation values, as are typical in Italy, would only marginally increase to 8.70% (simple payback would also be at 9 years), while the IRR without the 50% tax-deduction scheme would be 3.8%. The IRR values without the tax deduction scheme are not far from the 4% threshold identified by the Politecnico di Milano. Yet, even with effective IRR values above 8%, residential PV installations up to 3 KWp in 2016 were, with 50 MW, significantly lower than installations in the same market segment in 2012 (about 130 MW). This “under-performance” might suggest a possible market saturation in so-called *sweet spots* (IEA, 2015) in the residential PV market, made of single-house owners that are more likely to adopt innovations, such as so-called *early adopters* or *innovators* who, for the sake of adopting a new innovation, might be willing to accept lower return rates (Rogers, 2003). Another possible category for sweet spots might be single-family houses having favorable roof orientations.

The break-even point for residential PV systems estimated by the Politecnico di Milano (2014) at a 4% IRR could be reached with a price of about 1,550 EUR/kW in Central Italy. This value is reached in 2019 in the RS and in 2020 in the CS. It follows that if, between 2017 and 2019, the (a) LR values observed from 2002 to 2016 for all components of PV systems are maintained, and if (b) the 25% CAGR in PV installations projected in the reference scenario is achieved, then residential PV systems without incentives will achieve break-even (as defined by a 4% IRR) by the end of 2019.

Table 4.14 Cash-flow Analysis of a 3 kW Residential PV System in 2016: Assumptions and Results

| | |
|---|---|
| PV-system rated power (KW$_p$) | **3** |
| PV system cost (Eur/kW) VAT included | **1,550** |
| Total PV system cost (EUR) | **4,650** |
| Total Debt | **0%** |
| Total Equity | **100%** |
| PV yield (kWh/Kwp) | **1,150-1,350** |
| PV output annual decay (%) | **1%** |
| PV output (kWh) | **3,450-4,050** |
| Electricity demand (kWh) | **3,000** |
| Percentage of Self consumption (%) | **30%** |
| PV electricity self-consumed (kWh) | **1,035-1,215** |
| Electricity consumed from the grid (kWh) | **1,785-1,965** |
| PV Electricity fed into the grid (kWh) | **2,415-2,835** |
| Electricty price rate (EUR/kWh) | **0.1956** |
| Electricity price escalation | **1%** |
| Net-metering compensation (EUR/year) | **263** |
| Tax deduction on capital cost (%) | **55%** |
| Annual O&M cost at year 1 (EUR) | **150** |
| O&M escalation rate (%) | **1%** |
| Grid connection and authorization costs (EUR) | **30** |
| Inverter replacement (year) | **12** |
| Unit Inverter cost at year 12 (EUR/kW) | **135** |
| Replacement cost for inverter (EUR) | **405** |
| *IRR in Southern Italy (1,350 kWh/kWp)* | ***8.67%*** |
| *IRR in Central Italy (1,250 kWh/kWp)* | ***8.53%*** |
| *IRR in Northern Italy (1,150 kWh/kWp)* | ***8.38%*** |

Source: Author's elaboration

The cash-flow analysis of the 150 kW PV-system (Table 4.15) indicates that this investment is already above the 6% IRR break-even, with values ranging from

7.90% in Northern Italy to 9.30% in Southern Italy[68]. The net-metering scheme, which provides economic compensation for PV electricity fed into the grid at higher than wholesale electricity prices, had a non-negligible effect on the financial performance of these systems. The estimated net-metering compensation per unit of electricity injected into the grid is about 10.5 EUR/MWh, that is, well above the average wholesale electricity prices at 60 EUR/MWh (ARERA, 2017).

Overall, cash flow analysis suggests that, based on the IRR criterion, both residential and commercial PV systems are approaching market break-even. Secondly, both the tax deduction and the net-metering schemes will need to be maintained to ensure at least constant levels of distributed PV installations while the transition to a fully self-sustaining market is still underway.

With annual PV installations in the two scenarios increasing from about 1,000-2,000 MW in 2020 to 5 GW in 2030, an additional aspect that warrants analysis is the question of to what extent this ramping up of installations will require an extension of the existing mechanisms or the re-introduction of financial incentives for distributed systems, or whether, on the other hand, these deployment levels can be achieved with a self-sustaining market for both distributed and utility-scale PV systems (the latter having already achieved market parity). In other words, assuming that market competitiveness, as defined by IRR break-even levels, is also achieved for distributed

---

[68] Due to the complexity of estimating annual revenues from the net-metering scheme, the cash-flow analysis for the 150 kW PV-system was conducted with the online software “Simulare” available at https://www.ingalessandrocaffarelli.com/download/category/4-software.html.

PV systems between 2020 to 2030, will these IRR values be enough to mobilize the level of annual installation projected in the two scenarios?

Table 4.15 Cash-flow Analysis of a 150 kW Commercial PV System in 2016: Assumptions and Results

| | |
|---|---|
| PV system rated power (KWp) | **150** |
| PV system cost before VAT (EUR/kW) | **1,385** |
| Total PV system cost before VAT (EUR) | **207,750** |
| Total Debt | **70%** |
| Total Equity | **30%** |
| Interest rate | **5.00%** |
| Loan Maturity (years) | **15** |
| Annual loan payments (EUR) | **14,011** |
| Capital budgeting (years) | **25** |
| PV yield (KWh/KWp) | **1,160-1,350** |
| PV output annual decay (%) | **1%** |
| Annual electricity consumption (kWh) | **226,248** |
| Percentage of self-consumption | **58%** |
| Electricty (purchase) price rate (EUR/kWh) | **0.19** |
| Escalating rate of electricity price | **1.50%** |
| Unit Net-metering compensation in year 1 (EUR/kWh) | **0.10** |
| Annual O&M cost at year 1 | **1,500** |
| Insurance cost at year 1 (EUR/kWp) | **10** |
| O&M and Insurance escalation rate | **1.50%** |
| Extra-ordinary maintenance (year) | **12** |
| Unit cost for extra-ordinary maintenance (EUR/kW) | **130** |
| Total extra-ordinary maintnance costs at year 12 (EUR) | **19,500** |
| Depreciation coefficient | **9.00%** |
| Tax rate | **31.40%** |
| Property tax (EUR/kW) | **10** |
| *IRR in Southern Italy (1,350 kWh/kWp)* | ***9.29%*** |
| *IRR in Central Italy (1,250 kWh/kWp)* | ***8.61%*** |
| *IRR in Northern Italy (1,150 kWh/kWp)* | ***7.90%*** |

Source: Author's analysis

One way to gather useful insight to answer this question could be by looking at the IRR values of distributed (non-utility scale) PV systems achieved (on average) with the fifth Conto Energia scheme in 2012, when installed capacity for this market segment was about 1.8 GW. An ex-post cash-flow analysis for PV systems installed in 2012 was conducted to estimate the IRR values for distributed systems. The IRR of a 3 kW residential PV system installed in Central Italy in the first semester 2012 with the fourth Conto Energia is 11.94% IRR, whereas that of a 150 kW is 14.93%[69].

It is possible to estimate when these IRR values achieved in 2012 with the Conto Energia could be reached in the two scenarios without incentives. The first step in this ex-ante cash flow analysis of PV competitiveness in the two scenarios is to estimate PV system prices for residential and commercial PV systems (as only average PV-system prices, including all categories, were estimated in the previous steps). In 2016, the ratio of a 3 kW residential PV system price to average price was about 125%, whereas the ratio of 150 kW commercial PV-system price to average price was approximately equal to 100%. These ratios are assumed constant throughout the scenario time frame 2018-35.

---

[69] Main assumptions for residential PV systems: PV-system price at 2,650 EUR/kWp, 70% debt at 5% interest rate, 38.16% self-consumption of PV electricity, electricity price at 0.21 EUR/kWh. The feed-in tariff for this category of PV systems in the first semester 2012 was 0.24 EUR/kWh and the estimated net-metering compensation in year 1 obtained from the SIMULARE software is EUR 192. Main assumptions for commercial PV system: PV-system price at 1,800 EUR/kWp, 70% debt at 5% interest rate, 58% self-consumption of PV electricity, electricity price at 0.19 EUR/kWh. The feed-in tariff for the first semester 2012 for this category of PV systems was 0.206 EUR/kWh and the estimated net-metering compensation in year 1 obtained from the SIMULARE software is EUR 5,750.

In both the reference and counterfactual scenarios, the 12% IRR that was achieved in 2012 by a 3 kW residential PV system can be reached only  with financial incentives in the scenario time frame[70]. By 2035, in the reference scenario, when the projected residential PV system price reaches 910 EUR (2016)/kW, the IRR for a PV system in Central Italy is about 8% (and lower in the counterfactual scenario, due to PV system prices being slightly higher). The gap for commercial systems between the estimated average IRR values observed in 2012 and those projected towards the end of scenario time frame is narrower than residential PV systems. However, by 2035, a 150 kW PV system in Central Italy with a price of 730 EUR (2016)/kW and no support in net-metering compensation only achieves a 14.13% IRR, versus the 14.93% estimated for the same system in 2012[71].

It can be surmised that achievement of the PV-installation levels needed between 2020 and 2030 in the residential and commercial PV-market niches in order to reach the target of 70 GWh PV generation (embedded as a constraint in both the reference and counterfactual scenario) could be challenging without the market-pull effect of current or new support mechanisms or without an acceleration of the historical price-reduction trend for PV systems. To accelerate PV adoption, an alternative to conventional support mechanisms would be to act at a higher level of policy and regulatory frameworks, by addressing the issue of potential market failures

---

[70] Assuming no tax-deduction scheme and a unit net-metering compensation equal to an average wholesale electricity price of 60 EUR/MWh. All other assumptions are the same as in Table 4.14.

[71] Assuming that the PV electricity injected into the grid is valued at an average wholesale electricity price of 60 EUR/MWh. All other assumptions are the same as in Table 4.14.

resulting in very high *elasticity* values of technology adoption to financial performance.

## 4.7 PV Competitiveness and Market Failures

With PV having already achieved market parity in utility-scale plants, and approaching IRR break-even values in PV distributed systems in Italy, the issue relevant to energy policymakers is what technology adoption rates can be expected in a self-sustaining market.

As the ex-ante cash flow analysis of the PV scenarios has shown, even after market break-even is reached, the effective rate of adoption might still be lower than in the period when financial incentives were supporting deployment. A factor that can explain the marked under-performance of technical and financially viable technologies is so-called *market failures*.

Market failures are often cited to explain slow rates of adoption of EE technologies or even distributed renewable energy technologies like solar hot-water systems (SHW) (Yang, 2010). In specific geographical contexts characterized by high energy prices and very high solar radiation (e.g., Hawaii), SHW provide savings in electricity or natural gas costs to homeowners high enough to reach the benchmark value for payback time considered for market competitiveness (e.g., 4 years). However, despite reaching market break-even, SHW systems still require subsidies for their market uptake in many countries as a result of several market failures. Among the market failures cited in literature that act to slow down the diffusion of market-competitive sustainable energy technologies are the lack of information of potential users, existing barriers to access to leveraged capital, and the use of very high implicit discount rates by prospective adopters, particularly in the residential sector (Linares and Labandeira, 2010). These barriers are likely to apply to the diffusion of market-competitive distributed PV systems in Italy as well, and will require the implementation of effective policy frameworks in order to meet the objective of the National Energy Strategy foreseen for PV by 2030.

### 4.8 Summary

Two scenarios were constructed to develop all the metrics needed to estimate the so-called *subsidization costs* of the Conto Energia program, as well as investments mobilized throughout the full cycle of this program, and to compare such metrics with an alternative policy pathway. The reference scenario is built on historical PV installations from 2010 to 2016 (significantly spurred by Conto Energia from 2010 to 2013), and a projected diffusion path that would meet the objective for PV generation of the Italian National Energy Strategy by 2030 (70 TWh). The counterfactual scenario is built on the assumption of much lower PV installations between 2010 and 2013, and higher investments in EE investments in order to achieve the same reductions in natural gas demand as the reference scenario between 2010 and 2020. PV installations in the counterfactual scenario are higher from 2014 onwards, and installed PV capacity by 2030 is the same as in the reference scenario. Both scenarios achieve the 2020 objective of renewable energy sources, contributing to 17% of gross internal consumption as per the Renewable Energy Directive 2009/28/CE.

The most striking difference in the two scenarios is in the subsidization costs. Between 2010 and 2020, subsidies paid to support PV deployment in the reference scenario amount to EUR 73 billion. In the counterfactual scenario, subsidies paid to support PV deployment and additional investments in energy efficiency projects total about EUR 17 billion. Cumulative PV investments between 2006 and 2035 in the reference scenario are EUR 106 billion, versus EUR 101 billion in the counterfactual scenario, suggesting that a *wait and see strategy* that postpones support to PV deployment to benefit from global learning effects has a much bigger effect on subsidization costs than on investments.

Annual PV installations in the two scenarios reach above 3 GW towards the end of the 2020s. It could be presumed that this level of installations is feasible in a self-sustaining market where PV diffusion does not need to be spurred by support mechanisms, a condition that is often related to the *grid parity* concept. At the end of 2016, distributed PV systems were already in grid parity, as defined by a condition where the LCOE from PV systems is lower than retail electricity prices. However, PV installations in 2016 were lower than in 2013 by almost one order of magnitude. This suggests that the achievement of grid parity, as expressed by an LCOE equal or lower than retail electricity price, is not a meaningful milestone for analyzing the prospect of PV diffusion.

A more meaningful way to assess the market competitiveness of distributed PV systems is by defining *market break-even* as the condition where specific thresholds of internal return rates (IRR) of investments in PV systems are achieved. In this light, IRR values of investments in residential and commercial PV systems without support mechanisms were estimated to be close to break-even values in 2016. However, the realization of a self-sustaining PV market between 2020 and 2030 may still not reach the necessary growth rates to achieve the levels of PV diffusion needed to meet the objective of the National Energy Strategy by 2030 that is embedded as constraint in the two scenarios.

## Chapter 5

# MODELING APPROACHES FOR ECONOMIC IMPACT ANALYSIS OF RENEWABLE ENERGY DEPLOYMENT

### 5.1 Economic Effects Relevant to Impact Analysis

Economic impacts of renewable-energy (RE) diffusion, such as variations in gross domestic product (GDP) and employment, are the results of different effects and mechanisms playing out in several economic sectors throughout the product value chain.

The first and most important categorization to consider distinguishes direct, indirect, and induced effects (Miller & Blair, 2009). *Direct effects* can be defined as changes in output, employment, and value added in an economic sector that have been triggered by an “exogenous” (e.g., policy-driven) variation in demand for commodities (including services) produced by that same sector (e.g., an increase in installations of PV-system integrators as a result of an incentive scheme). *Indirect effects* are variations in output, employment, and value added in those industries that supply inputs to the sector where the direct effects are taking place. An example of indirect effects of investments in  the construction and installation of new PV systems is the increase in production of PV modules in order to supply system integrators. Those industries where indirect effects are realized are often referred to as *linked industries*. *Induced effects* result from a variation in employees’ income (including that of new employees) in those industries affected by direct and indirect impacts (e.g., the increased purchasing power of formerly unemployed individuals who are hired by the PV sector).

In general, the diffusion of new technologies produces changes in economic variables (GDP, employment, etc.) because of adjustment reactions from economic agents (i.e., households and companies). Such adjustment reactions produce structural effects that will vary across different economic sectors and regions. Ragwlitz et al. (2009) discuss three relevant economic mechanisms in their analysis of the economic impacts of RE diffusion: (a) Structural demand mechanisms; (b) price mechanisms; (c) multiplier mechanisms. These three mechanisms will be discussed in the following sections.

## 5.2 Structural Demand Effects

*Structural demand* and *price effects* or *mechanisms* are interlinked in a rather complex cause-effect relationship that makes it virtually impossible to separate the net effects of these two economic mechanisms (Ragwlitz et al., 2009). However, for the sake of a clearer description of the theoretical framework, unless stated otherwise, the structural demand effect will be described as if it were occurring independently of the price effect. In a neoclassical-economy theoretical framework, an increase in the diffusion rate of a renewable-energy technology is represented by shifts in both demand and supply (under the hypothesis of a fully competitive market) for RE systems. New investments to construct and install RE plants will result in increased production capacity and energy produced by such plants. Such process can be depicted by a (rightward) shift in the supply curve for renewable energy (e.g., more electricity from PV systems, higher production of biofuels). A policy-induced variation in investments in the RE industry determines structural economic changes that can result in either positive or negative economic impacts (e.g., higher or lower output and employment). This would apply not only to economic sectors within a national economy but also to a country on the whole (e.g., a reduction in natural gas exports due to growth in RE electricity “crowding out” natural gas consumption at the global level).

Structural demand effects can be divided into: (a) investment impulses; (b) operation and maintenance impulses; and (c) trade impulses.

### 5.2.1 Structural Investment Impulses

Increased investments in RE systems are realized through a higher volume of economic activity for installers (e.g., system integrators, electric utilities, and contractors involved in engineering, procurement and construction [EPC]) and manufacturers of RE technologies, as well as for providers of RE-related services (e.g., trading of green certificates). On the other hand, investments in new RE systems might crowd out investments in industries producing electricity from “conventional sources” like fossil fuels or natural gas, or from other RE technologies.

The economic impacts of investments in new RE systems can be divided in direct and indirect impacts. In both categories there can be either positive or negative impacts.

*Positive direct effects* of RE investments in the power sector concern those economic sectors directly active in the installation phase of new RE capacity (e.g., EPCs or system integrators in the case of RE systems generating electricity).

*Negative direct impacts* are the result of displaced investments in those sectors or industries that are crowded out by renewable power, such as, for example, conventional utilities with plans to invest in new generating capacity from coal or natural gas.

*Positive indirect effects* concern those economic sectors that are linked to the renewable-power industry, such as, those supplying goods or services that are necessary for the installation of RE plants. Some examples of linked sectors that are indirectly impacted by increased investments in RE capacity are producers of system components (e.g., wind turbines, solar thermal collectors), companies that engineer and install production lines for system components (e.g., for PV module or biofuel production plants), providers of IT-services (e.g., developers of applications that can monitor electricity generation from RE power plants), and producers of raw materials (e.g., steel, concrete, silicon, and critical raw materials used in renewable-energy technologies like silver). Furthermore, increased demand for RE systems is also reflected in higher volumes for other auxiliary activities such as planning (which might be outsourced by system integrators to specific service providers) and financing. All these linked industries will have to raise output in order to meet increased demand from companies active in RE-system installation.

*Negative indirect impacts* of investments in new RE capacity will concern all those sectors and companies that are involved in the construction of new fossil fuel plants, as well as suppliers of technologies such as steam turbines or end-of-pipe pollution-control equipment. RE-power deployment will also have negative indirect effects on the fossil-fuel extraction industry, such as by reducing hydrocarbon's upstream activities.

### 5.2.2 Structural Operation and Maintenance Impulses

Increased operation and maintenance (O&M) expenditures are related to the generation of energy (that can be either electricity or heat or both[72]) from new RE-power systems as well as to activities undertaken to maximize the operating performance of operating systems. All these activities begin right after the installation or construction of RE systems. Operation and maintenance activities are also characterized by both positive and negative impacts.

The positive direct effects of the O&M of existing RE capacity consist in all the economic activities needed to generate renewable energy. These activities are related to the use of different inputs into the production process, such as human labor, fuels (particularly in the case of RE plants using biomass), or the replacement of system components. Most of the O&M activities in the RE-power industry have a high intensity of human labor compared to conventional power (Ragwitz e al, 2009). This higher labor intensity however might be related to the fact that RE industries are relatively "immature", and so subject to significant potential gains in terms of labor productivity (Cameron & van der Zwann, 2015). Direct negative impacts resulting from O&M activities in the RE power sector consist in lower output and employment in those energy-generating industries and sectors that are crowded out by increased generation of RE electricity or heat. An example of such direct negative economic impacts is that of decreased production volumes (that is, output) for companies operating fossil fuel power plants.

---

[72] For example, (1) electricity generated from PV or wind systems (2) heat generated by biomass-fueled power plants and distributed in district heating systems and (3) electricity and heat co-generated by biomass-fueled plants.

Positive indirect effects of the O&M of new RE systems will arise from the purchase of products and services of linked industries, for example when the maintenance of a PV system requires the substitution of basic components such as the inverter. Negative indirect effects of the operation of RE systems will arise from reduced economic activity in utilities producing electricity and heat that are subject to the aforementioned negative direct effects. For example, lower electricity produced from fossil-fuel power plants might translate into a contraction in demand for products and services that are necessary for the operation and maintenance of these plants (e.g., companies that operate as service providers to the utility).

### 5.2.3 Structural Trade Impulses

Increased investments in RE systems and higher production of energy from renewable energy sources (RES) can have significant effects on the trade balance of a country. Two basic examples of *trade impulses* related to renewable energy deployment that are reflected in an increase in surplus or decrease of trade-balance deficit are increased exports of RE technologies and reductions of fossil-fuel imports. Positive effects on the trade balance also include reductions in imports of technologies linked to power generation from fossil fuels (e.g., gas turbines, scrubbers for coal thermal power plants). Negative effects of RE deployment on the trade balance can consist of increasing imports of RE system-components or RE fuels (e.g., bioenergy carriers like wood pellets).

Ragwlitz et al. (2009) pointed out that if the costs of an incentive scheme supporting RE growth fall on energy-intensive industries competing in international markets, any positive impacts of such incentive-driven market growth might be compensated by negative effects on external trade. If, on the other hand, the burden of the incentive costs falls on utilities that are enjoying monopolistic profits, negative trade effects could be limited.

## 5.3 The Price Effect

Another economic mechanism from which RE deployment[73] can produce economic impacts is the so-called *price effect*, which, in microeconomic theory, is defined as the sum of income and substitution effects (Nicholson, 1998). One example of price effect arising from a policy-driven increase in RE demand is when financial incentives used to support demand for renewable energy are funded through a levy on electricity, increasing electricity prices to final users. This results in a variation of the relative price of energy, to which households might react by reducing consumption and increasing demand for other goods (substitution effect)[74]. Furthermore, relatively higher energy prices will reduce households' available income, potentially causing them to reduce expenditures (income effect).

In economic impact analysis, the price effect determines the difference between gross economic impacts and net economic impacts. The negative economic impacts (i.e., variation in output, value added and employment) of reduced

---

[73] Such deployment can either be policy-induced or the result of factors that are exogenous to policy choices (e.g., a technology breakthrough or the "price shock" of a competing product or service).

[74] Even if the individual consumer were to stay on the same indifference curve, according to microeconomic theory, consumption patterns would be changed to have the marginal rate of substitution equal the new price ratio (Nicholson, 1998).

expenditures by households due to higher energy prices might be so high as to compensate the positive gross impacts caused by the structural demand effects.

The extent of the impact of higher energy prices on household consumption will depend on the price elasticity of demand for energy and for other goods. In fact, given that demand for energy is notoriously more inelastic than demand for other goods, the effect of reduced available income (graphically displayed by a shift to the left of the budget constraint curve) due to higher energy prices might be a more significant reduction (in relative terms) of demand for other goods and services than for energy itself (Nicholson, 1998).

If the costs of incentives to support RE deployment are not passed directly to the consumers of energy goods but fall on the government instead, the latter might decide to reduce public expenditures in order for these incentives to be “budget neutral”. The cost opportunity of reduced public expenditures to pay for subsidies can be considered the public sector equivalent of the income effect. If inefficient public expenditures are decreased, the overall negative economic impacts will be lower than the case in which public investments with a high multiplier (e.g., in infrastructure) are crowded out. If general taxation is increased to pay for incentives (e.g., through an increase in personal income tax), these will result as income effects to households.

## 5.4 Multiplier Effects

An economic mechanism that can play a significant role in determining the kind and entity of economic impacts generated by RE deployment is the *multiplier effect*. This concept captures economic impacts arising from changes in several economic variables, such as: (a) economic output; (b) employment; (c) income earned by households; and (d) value-added. The multiplier concept is based on the difference between the initial effect of an exogenous change in demand for a given product or sector (e.g., increased investment in RE capacity and increased supply of energy from RES) and the total, final effect produced by this change.

The *initial effect* can be defined as the direct effect of an increase in demand for a commodity or entire economic sector. The *total effect* can either be (a) the sum of direct and indirect effects[75], or (b) the sum of direct, indirect, and induced effects if the effects on household income are also considered (Miller and Blair, 2009)[76]. For example, the total effect of an increase in RE-power investments can consist in the increased economic activity of RE installers (direct effects), increased production in industries linked to RE installers (e.g., manufacturers of system components), and economic effects arising from the additional income spent by households whose members are employed by the industry increasing production.

Higher income of household members employed in the RE-power sector and in those sectors linked to it would be reflected in increased consumption that "reverberates" throughout the economy until the income multiplier effect exhausts itself. However, an opposite effect should also be accounted for: consumption may be reduced by those households whose members are employed in sectors negatively impacted by increased RE demand. For example, as a result of RE-market growth, large industry conglomerates supplying technologies to utilities generating electricity

---

[75] This is the case for an I-O model that is "open to households".

[76] If an I-O model only assesses direct and direct effects, it is defined as a model "closed to households".

from fossil fuels might have to lay off their personnel[77], resulting in a negative income multiplier effect.

## 5.5 Literature Review on Economic Impact Analysis of Renewable-energy Diffusion

Economic impact analyses of RE deployment have been carried out since at least the early 2000s, for different technologies and on different geographic scales. Most of these studies have looked at the employment impacts of policy-induced RE deployment.

One of the first efforts to analyze the economic impacts of RE deployment is the MITRE (*Monitoring & Modeling Initiative for the Targets of Renewable Energy*) study, carried out in the European Union (EU). This analysis, published in 2003, concluded that renewable energy development in Spain, as well as across Europe, would result in a net positive impact in terms of employment (EUFORES, 2018).

Hillebrand et al. (2006) looked at the impacts of the feed-in tariff (FIT) program introduced in Germany in 2003 and concluded that this support policy would result in increased employment between 2004 and 2008 in parallel with the rapid growth of the RE industry. However, net employment was found to be negative after 2010, due to reduced market growth combined with the higher costs of RE technologies compared to conventional sources.

---

[77] One recent example is the decision by General Electric to lay off 12,000 people in their power equipment division (mostly serving gas and coal-fired power plants), allegedly as a result of the rise in the RE market (Crooks and Samson, 2017).

McDonald et al. (2006) simulated a switch from crude-oil production to bioenergy (switchgrass) in the United States (US), using a computable general equilibrium model (see section 5.6). The results of the simulation show a slight decrease of GDP as a result of lower economic efficiency in the biofuel production process. Furthermore, the expansion of bioenergy production in the US was shown to determine a contraction in agriculture production, causing higher prices for agricultural commodities in the global market, resulting in an overall net decrease in welfare at the global level.

In a seminal work, Lehr et al. (2008) assessed the economic impacts of renewable energy deployment in Germany from 2005 to 2030 in the frame of several scenarios, each incorporating different values for key parameters (e.g., prices of RE systems and conventional sources). All the scenarios analyzed had net positive employment impacts except one, which was characterized by “extreme” conditions, such as no exports of RE technologies and very low energy prices ($30 per barrel of oil in 2020). According to Lehr et al., a specific feature of the German context positively and significantly impacting net employment effects is the high share of exports on domestic production of RE technologies.

The report *Study of the Effects on Employment of Public Aid to Renewable Energy Sources* by Alvarez et al. (2009) applied two indexes (see section 5.6) to analyze the efficiency of RE subsidies in terms of job creation. It was found that, on average, for each job created by the renewable-energy industry in Spain through incentive-driven market growth, there was a loss of 2.2 jobs in the Spanish economy. Alvarez et al. then applied the same ratio used for Spain to estimate the employment impacts of subsidy-driven RE development in the United States. The results, based on the application of the ratios, suggested that there would be job losses as a result of public support for renewable energy in US as well.

The EmployRES study looked at the impacts of RE-deployment to meet the European Union targets by 2020. The study concluded that policy-induced RE deployment in the EU would result in net positive economic impacts, including increased employment. Achieving the target of 20% RE generation by 2020 in the EU would generate 410,000 additional jobs and an increase by 0.24% of the EU gross domestic product (Ragwitz et al. 2009).

Frondel et al. (2010) is among the studies that have found negative economic impacts arising from incentive-driven RE deployment, and maintains that the higher capital costs of RES would be reflected in higher energy prices for the German economy. Frondel et al argue that higher energy prices due to an increasing share of renewable energy in the supply mix would cause job losses in other sectors of the economy that would more than offset increased jobs in the RE sector.

In a more articulated analysis built on their previous study of 2008, Lehr et al (2012) analyzed the labor market implications of large investments in RE in Germany from 2009 to 2030. Different assumptions on fossil fuel prices, domestic installations, and exports were used to develop alternative scenarios. Net-positive employment effects characterize almost all of the scenarios analyzed, with a central scenario having additional net employment effects of about 150 thousand units in 2030.

In sum, the majority of the economic-impact analyses (EIA) reviewed suggested positive economic impacts arising from RE deployment. However, two of the four studies reviewed analyzing the impacts of RE diffusion in Germany found negative economic effects, calling into question RE’s real additional contribution in terms of /net economic growth and employment. One possible explanation for these contradictory results, for the same country and for similar time frames, is the lack of inclusiveness of all the relevant parameters of the modeling approaches, leading to biased results (Ragwitz. et al., 2009).

## 5.6 Modeling Approaches to Economic Impact Analysis

The literature reviews suggested that at least four different modeling approaches could be used to estimate the economic impacts of renewable energy diffusion. These four approaches are:

- Employment factors and other indexes
- Input-Output (I-O) models
- Macroeconomic models
- Integrated modeling frameworks

Breitschopf et al. (2011; 2012) reviewed EIA methodological approaches and developed methodological guidelines for estimating the employment impacts of renewable-electricity deployment. They group EIA studies into two broad categories: gross-employment studies and net-employment studies, the former only looking at jobs in the RE and upstream industries. Bretischopf et al. recommend use of the employment-factor and gross I-O model to estimate job impacts in the RE and linked industries. The *net I-O model* (looking at induced effects) and *full economic model* approaches are instead recommended to analyze the impact on economy-wide employment.

*Employment factors*, expressed by Full-Time Employees (FTE) per unit of capacity, are widely used to estimate direct employment of the construction and installation as well as operation of RE systems (Breitschopf et al., 2012; Greenpeace et al., 2015; Cameron & van der Zwaan, 2015). Other kinds of indexes can also be used to estimate the economic efficiency of RE diffusion. However, the analytical value of such metrics varies significantly with the methodology used to develop them. For example, Alvarez et al (2009) developed two indexes to assess the economic efficiency of jobs created by subsidies supporting market growth of the renewable-energy sector versus jobs created in the broader economy. The two indexes are:

$$\frac{\text{Subsidy to renewables per worker}}{\text{Average capital per worker}} \tag{5.1}$$

$$\frac{\text{Annual subsidy to renewables per worker}}{\text{Average productivity per worker}} \tag{5.2}$$

Lantz and Tegen (2011) from the National Renewable Energy Laboratory (NREL) criticized the index-based methodology used by Alvarez et al., largely on the grounds of inconsistency found between the data obtained from the ratios and the insights derived for the economic impact analysis[78]. In this critique, Lantz and Tegen argue that firstly, the two ratios are not employment impact metrics per se and cannot be used to estimate net job gains or losses. And secondly, they assert, comparing the costs of job creation in the RE sector with the broader economy fails to incorporate the wider variability of labor costs among economic sectors. For example, the costs of creating employment in sectors requiring advanced know-how would be higher than in

---

[78] The elements detailed in the critique from Lantz and Tegen were relevant to the development of the methodological framework for this analysis and therefore are discussed in detail in this section.

those sectors requiring less technical skills. And the RE sector is considered to be one where technical personnel would require – on average – costlier training than would the average worker. As a result, economy-wide averages may not be adequate for such comparisons, and the use of a range of metrics across different industrial sectors should be preferable. Lantz and Tegen further stress that a better parameter for assessing the job impacts of the RE sector would be the cost of job creation in a similar sector, such as, for example, conventional-electricity generation (the production of which is displaced by RES electricity). An additional aspect that points to the inconsistency or inaccuracy of the methodology used by Alvarez et al. is the lack of inclusion of the effects of export on employment, which for countries such as Germany and Spain (particularly for wind energy) can be an important factor in the economic impact (Lehr et al., 2008). In a more dynamic frame where renewable energy technology sales are expected to increase over time, the early investments of lead countries like Germany can have long-term positive economic effects that greatly offset short-term costs.

The use of *employment coefficients* is another simple approach used in economic impact analysis. In its simplest configuration, it aims to estimate the effects of increased production in a specific economic sector on employment in that same sector. The direct employment coefficient is calculated using the following ratio:

$$\frac{\text{Number of employees in sector } \mathbf{i} \text{ in year } \mathbf{t}}{\text{Turnover of sector } \mathbf{i} \text{ in year } \mathbf{t}} \tag{5.3}$$

Looking at employment only in the sectors impacted by the direct economic effects, however, has limited analytical added value for economic-impact analysis, as it disregards the aforementioned indirect effects on the linked industries. For example, one sector might have a relatively high employment coefficient, as defined in equation 5.3, but might also source a significant share of its production inputs abroad. Hence, the overall employment impacts in the domestic economy of increased production in this sector might be lower than in another sector having a lower (direct) employment coefficient but sourcing a higher share of its inputs from the domestic economy.

An *Input-Output model* consists of a "system of linear equations each of which describes the distribution of an industry's product throughout the economy" (Miller & Blair: 1)[79]. The Input-Output framework is often referred to as *interindustry analysis*, as its core purpose is to analyze the interdependence of industries in an economy. I-O modeling can analyze the broad range of (positive and negative) direct, indirect, and induced economic effects of an increase in market demand for a specific industry, while it does not "capture" impacts arising from the price effect. The JEDI (Jobs and Economic Development Impacts) family of models uses the I-O framework to estimate employment impacts of renewable-energy deployment (NREL, 2015).

Arora (2013) lists three different kinds of macroeconomic models that could be used to estimate the impacts of government policies and to run short-term and long-term forecasts: macro-econometric models, Computable General Equilibrium (CGE) models, and Vector Autoregressive (VAR) models.

*Macro-econometric models* are composed of a set of equations based on standard macroeconomic theory, the parameters of which are estimated from historical data. Broadly speaking, a standard macro-econometric model would be based on Keynesian theory for short-run modeling (demand determines variable outcomes),

---

[79] The I-O modeling framework is discussed in further detail in ch. 6.

while long-run modeling is “dominated” by supply in the frame of the neo-classical growth model of Solow and Swan (Arora, 2013). While macroeconomic theory shapes the model’s general specification, macro-econometric models can provide significant “flexibility in tailoring individual equations and variables to the needs of the modeler” (Arora, 2013: 2). For example, one advantage of the macro-econometric models cited in the literature is that they can be more easily integrated with bottom-up technology models (Ragwitz et al., 2009). Examples of macro-econometric models applied to analyze impacts of energy policies are the *Global Insight* U.S. macroeconomic model and the *Oxford Economics* global economic model, both used by the US’s Energy Information Administration (Arora, 2013). In a European context, one example of the macro-econometric models applied to estimate economic impacts of renewable-energy deployment is NEMESIS, which was used for the EmployRES study (Ragwitz et al., 2009).

A *CGE model* is “a system of equations that describes an economy as a whole and the interactions among its parts” (Burfisher, 2011: 11). The equations of a CGE model describing the supply and demand of an economic system are subject to specific market constraints; they are solved in an iterative process where supply and demand reach equilibrium for a set of endogenous prices. Exogenous variables include input prices, consumer income, elasticities, and others. CGE models are widely applied to evaluate climate-change mitigating policies at global and regional level (e.g., Peterson, Schleich, & Duscha, 2011; Bosetti et al., 2009), but they have also been used to assess the impacts of both renewable-energy deployment and EE policies (e.g., McDonald et al., 2005; IEA, 2012).

One of the main differences between macro-econometric models and CGE models is that equations in the former models might not necessarily be derived from the traditional optimality condition, even if the behavior of the different agents is still subject to utility or profit maximization.

*VAR models* are based on a "system of equations where each variable in the system is regressed on a set of its own lagged values and lagged values of each of the other variables" (Romer, 2012: 225). While modern VAR models have received significant attention within the context of monetary policy, the literature reviews did not provide indications for their use in assessing the economic impacts of energy policies.

Both CGE and macroeconomic models used for the economic impact analysis of renewable-energy diffusion are usually combined with our models (e.g., bottom-up technology diffusion models, I-O models) in *integrated modeling frameworks*. The modeling framework used by Lehr et al. (2008; 2012) for estimating the net macroeconomic effect of RE deployment in Germany was based on an Input-Output model (an I-O vector for the renewable energy sector in Germany was developed from the conduction of more than 1000 interviews) and on the macro-econometric model PANTHA REI with the inclusion of export and foreign trade effects. A technology-simulation model, a static multi-regional I-O model, and two macro-econometric models (NEMESIS and ASTRA) were used for the EmployRES study by Ragwitz et al. (2009). The REMI (Regional Economic Models, Inc) model, which has been extensively used in the US to assess the regional impacts of energy and environmental policies, is based on four major approaches: Input-Output, General Equilibrium, Econometric, and spatial-economy modeling (REMI, 2018).

## 5.7 Assessment of Economic Mechanisms Relevant to EIA of PV Deployment in Italy under the Conto Energia Program

The positive direct effects of the growth in the Italian PV market fostered by the Conto Energia program included investments in PV installations (defined as structural investment impulse in the classification discussed in section 5.2) and O&M expenditures (also defined as a structural impulse in the aforementioned classification). The market-growth phase in PV installations in Italy that started in 2006 with the introduction of the FIT program peaked in 2013 with 9.3 GW of installed capacity and investments in PV installations of about EUR 21.5 billion (about 1.4% of Italian GDP), while operation and maintenance expenditures totaled about EUR 0.5 billion. Table 5.1 summarizes the structural investment and O&M impulses estimated between 2006 and 2016 relevant to an economic impact analysis of PV deployment in Italy. The turnover of linked industries (e.g., producers of PV modules, inverters, support structures, cables) was as significant in absolute volumes, with an estimated EUR 15.7 billion in 2016[80].

Most of the negative direct effects of the PV-market growth in Italy driven by the Conto Energia program fell on utilities operating natural-gas power plants. In fact, during the period 1999-2007, there had been a significant growth of fossil-fuel capacity in the electricity sector, most of which were natural gas combined-cycle power plants. As a result of the growth in electricity generation from PV systems, the average capacity factor of natural gas power plants that entered into operation before 2006 was significantly reduced (relative to the level forecasted by the utilities).

---

[80] The production of PV modules is classified here as a “linked industry”, following the classification of Ragwlitz et al. (2009).

Therefore, the negative impulse of RE investments on the fossil fuel sector in Italy was likely not the crowding out of future investments on fossil-fuel plants (this was a sunken cost), but rather the reduction in output (and therefore revenues) of already existing natural-gas power plants.

Table 5.1 PV-Construction & Installation Investments and Operation & Maintenance Expenditures in Italy, 2006-2016

| Year | Structural investment impulse: PV-installation investments (M Eur)[a] | Structural operation and maintenance impulse: PV operation and maintenance expenditures (M Eur)[a] |
|---|---|---|
| 2006 | 74 | 1 |
| 2007 | 431 | 5 |
| 2008 | 1,778 | 26 |
| 2009 | 2,721 | 70 |
| 2010 | 7,965 | 176 |
| 2011 | 21,460 | 511 |
| 2012 | 7,334 | 913 |
| 2013 | 2,455 | 1,039 |
| 2014 | 720 | 1,059 |
| 2015 | 534 | 937 |
| 2016 | 511 | 860 |

Note: (a) Nominal values

Data Sources: Author's estimates based on Castello et al., 2003-2015; Tilli et al., 2016-2017; Politecnico di Milano, 2009-2016, and GSE, 2016b.

At the peak of PV-market growth in 2011, almost all of the Italian industries producing PV cells had already ceased their operations (due to an inability to compete with Chinese producers), while domestic production of PV modules (including from thin-films) met only less than 5% of domestic demand. As for inverters, in 2011, the domestic industry was able to meet a much higher share of demand (50%) than for modules (Castello et al., 2012). As aforementioned, the electricity generated from PV capacity, by displacing electricity produced from natural-gas fired power plants, also had a positive effect on the trade balance by reducing natural-gas imports. It could be surmised that the most important direct and indirect trade effects of PV deployment under the Conto Energia program were an increase in imports of cells and modules and a reduction in imports of natural gas. However, a comprehensive analysis of trade effects of RE deployment should also consider the import share of the full value chain of the electricity generated from RE systems versus the electricity generated from conventional power plants. In fact, Ragwlitz et al. (2009) estimated that the import share of the complete value chain of conventional electricity in Italy is as low as 17%, suggesting that most, if not all, of the equipment used to generate power was produced by Italian industries, so there was no benefit in terms of reducing imports of such equipment. Since the objective of this analysis is to compare two scenarios that are neutral in terms of natural gas imports, and there were no impacts on the trade balance of power generating equipment, trade effects were not considered a critical element in deciding which modeling framework to use for the EIA.

The analytical relevance of the income and substitution effects for an economic impact analysis of PV growth under the Conto Energia program is linked to the way this incentive mechanism has been funded. As mentioned, its costs are financed through a levy on retail electricity prices paid by households and firms. According to microeconomic theory, higher electricity prices (as a result of this levy) would result in income and substitution effects, with decreased expenditure on other goods and services. In fact, one of the main critiques of the Italian feed-in tariff scheme is that it produced higher costs of electricity to small-to medium companies who, due to their relatively low volumes of electricity demand, cannot buy electricity directly from the wholesale market. The two scenarios are also neutral in terms of price effects, as the counterfactual scenario is assumed (in the long term) to have the same subsidization costs as the reference scenario, and would use the same levy on electricity prices to support PV growth and EE investments. Consequently, the price effect was not deemed to be a critical element in the choice of the modeling framework for the economic impact analysis.

It should be mentioned that policy-induced PV growth might have resulted in positive price effects. Barnham et al. (2013) observed that increased electricity generation from wind and PV in Germany and Italy caused significant reductions in wholesale electricity prices; unless this reduction in costs was captured by oligopolistic profits of electricity-distribution utilities, there was also a benefit to consumers in terms of lower electricity bills. Higher electricity generation from PV might have also impacted positively on the overall economic efficiency of the Italian electricity system, by increasing competitiveness in the wholesale market. This effect on wholesale electricity prices is relevant to conducting an EIA of PV growth under Conto Energia, however it would require an ad hoc modeling framework (e.g., a dispatch model of the Italian electricity system combined with a macroeconomic model)[81].

Multiplier effects can be considered a critical element for assessing the economic impacts of PV deployment fostered by Conto Energia. In particular, the two multipliers that are expected to provide significant insights for answering the research question on economic impacts of the FIT scheme in the comparative scenario

---

[81] This type of modeling framework was not available to the author.

framework are the output and employment multipliers. This is because it is of significant analytical value to understand whether or not the counterfactual scenario, with a more balanced use of financial resources that includes EE investments, is more efficient in terms of leveraging output and employment.

An assessment of the relevance of different economic mechanisms to the EIA in the frame of the comparative scenarios suggested that the use of an Input-Output model be the most appropriate framework to carry out the economic impact analysis. The I-O analysis in the following chapter will be focused on estimating the direct, as well as indirect, output and employment effects of the reference and counterfactual scenarios.

## 5.8 Summary

The most basic, standard categorization of economic impacts (e.g., variations in output, value added, and employment) arising from RE diffusion is between direct, indirect, and induced effects. While *direct effects* refer to RE industries increasing output and employment to meet higher final demand for RE systems, *indirect effects* account for impacts to linked or upstream industries, such as producers of system components like PV modules or wind turbines. The estimation of *induced effects* incorporates the positive effect on final demand from new employees in the RE and linked industries. These effects can also be negative if higher demand for RE systems crowds out production from competing industries. Gross economic impacts include only effects to RE and linked industries, whereas net economic impacts also incorporate effects on industries negatively impacted by RE deployment.

There are different economic mechanisms through which the increase in demand for RE systems “reverberates” throughout the economic system to determine economic impacts. So-called *structural investment impulses* consist in new demand for the construction and installation of RE systems, activities that are usually undertaken by electric utilities, system integrators, or companies active in engineering, procurement, and construction (EPC). Once the installation of a PV system is completed, economic impacts will arise from *structural operation and maintenance impulses*, that is, the expenditures needed for ensuring continuous operation and performance in energy generation. *Structural trade impulses* are imports or exports of services related to the construction or operation of RE systems, and any linked RE-system component and services from upstream industries. The so-called *price effect* is a fundamental mechanism for considering economy-wide effects if RE diffusion results in higher energy prices (e.g., new levies to pay for feed-in tariffs).

The literature review suggested that RE deployment is, in most cases, accompanied by net positive economic impacts, partly arising from the condition that RE industries active in the construction and installation segment are, on average, more employment-intensive than are the incumbent, fossil-based industries. This employment advantage, however, might have to do with the relatively less mature stage of RE industries, which still have a significant margin for gain in improved labor productivity.

There are four major modeling approaches used for economic impact analysis of RE deployment: (a) employment factors and other indexes; (b) input-output models; (c) macroeconomic models; and (d) integrated modeling approaches. The input-output approach was assessed as the most appropriate framework for carrying out the economic impact analysis of PV deployment in Italy. The two main reasons for this choice are the accessibility of data and tools necessary for the I-O analysis as well as the fact that the scenarios used for the economic impact analysis are “neutral” in terms of price effects.

# Chapter 6

# INPUT-OUTPUT ANALYSIS

## 6.1 The Input-Output Analytical Framework

An *input-output* (I-O) *model*, in its most basic form, is a system of linear equations describing the distribution of an industry product throughout the economy. The input-output analytical framework was developed by Wassily Leontief in 1936, and the term *Leontief model* is commonly used to refer to input-output analysis in general. Since the 1950s, many extensions have been developed, and the basic concepts first described by Leontief have since been applied to many different types of economic analysis (Polenske & Skolka, 1976; Miller, Polenske, & Rose, 1976; Miller and Blair, 2009).

Equation (6.1) shows the distribution of a sector i product through its sale to other sectors, and on to final demand:

$$x_i = z_i + \cdots + z_{ij} + \cdots + z_{in} + f_i = \sum_{j=1}^{n} z_{ij} + f_i \tag{6.1}$$

where $x_i$ is the sectoral output, $z_{ij}$ is the interindustry flow from sector *i* to sector *j* (the intermediate inputs to the production of sector *j*), and $f_i$ is the final demand for sector *i*'s product (e.g., demand from households or governments).

In an economy with *n* sectors, there will be *n* equations representing the output sold to all these sectors. The information in the *n* equations can be summarized in matrix notation[82] as

$$\mathbf{x} = \mathbf{Zi} + \mathbf{f} \tag{6.2}$$

An *input-output table* provides a representation of all the transactions of goods and services between different sectors of the economy and the rest of the world. Data entries in the I-O table are the monetary values of *intermediate inputs* (the *zs* in equation [6.1] above), that is, the transactions between the different sectors of the economy (from selling sector *i* to buying sector *j*) necessary to produce a given output (the *xs* in equation [6.1] above). In an I-O table, the columns quantify, in monetary units, these intermediate inputs, received from other economic sectors and the so-called *payments sector*, which includes imports and value-added activities (e.g., labor services, taxes, and the remuneration of capital)[83]. The *output* row consists of transactions for the delivery of goods and services to other sectors as intermediate goods or to final demand. So-called *symmetric input-output tables* (SIOT) are closed accounting frameworks, in that the sum of the inputs (in monetary value) and the sum

---

[82] In the matrix notation used in this chapter, lowercase bold case letters denote column vectors (e.g., **x** and **f**), uppercase bold letters are used for matrices (e.g., **Z**), and **i** represents a column vector of 1s. Post-multiplication of a matrix (e.g., **Z**) by **i** creates a column vector (e.g., **x**), the elements of which are the row sums of the matrix.

[83] The inputs in a column vector correspond to the elements of a production function.

of the outputs are equal for each sector. Values for inter-industry transactions or "flows" are obviously related to the output of the buying sector (the more output demanded, the more inputs needed) and, most importantly, to its production function. Table 6.1 is a 3x3 I-O table of the Italian economy in 2010 (ISTAT, 2017), with the "Payments sector" including (a) all value-added elements (capital, labor, government) and (b) imports of intermediate products[84] .

Table 6.1 3x3 Input-Output Table of Inter-industry Flows of Goods in the Italian Economy, 2010 (EUR[2010] million)

| **Selling sector** | **Buying Sector** | | | | | |
|---|---|---|---|---|---|---|
| | **Agriculture** | **Industry** | **Services** | **Total intermediate inputs** | **Final Demand** | **Total output** |
| Agriculture | 5,351 | 26,996 | 6,155 | 38,501 | 21,815 | 60,316 |
| Industry | 11,520 | 641,388 | 183,463 | 836,371 | 808,360 | 1,644,731 |
| Services | 4,919 | 267,190 | 485,360 | 757,469 | 1,028,673 | 1,786,142 |
| | | | | 1,632,342 | 1,858,848 | 3,491,189 |
| Payments | 38,526 | 709,157 | 1,111,164 | 1,858,848 | | |
| Total Outlays | 60,316 | 1,644,731 | 1,786,142 | 3,491,189 | | |

Data source: ISTAT, 2017.

The relationships between the inputs required for a given output and that same output are expressed in I-O analysis through the use of *technical coefficients*. For example, the monetary value of PV modules (selling sector with index *i*) bought by PV-system integrators (buying sector with index *j*) – as expressed by $z_{ij}$ divided by the total economic output of PV-system integrators ($x_j$) – forms the ratio $z_{ij}/x_j$, denoted by $a_{ij}$:

---

[84] The Italian Statistical Service (ISTAT) publishes the symmetric I-O table every five years. At the time of this chapter's writing, the I-O Table for year 2015 was not yet available.

$$a_{ij} = z_{ij}/x_j \tag{6.3}$$

Intermediate-input values in Table 6.1 were divided by sectoral output (the column's total in Table 6.1) to obtain a 3x3 table of technical coefficients for the Italian economy in 2010 (Table 6.2).

Table 6.2 3x3 Technical Coefficients for the Italian Economy, 2010

| **Selling sector** | **Buying Sector** | | |
|---|---|---|---|
| | **Agriculture** | **Industry** | **Services** |
| Agriculture | 0.09 | 0.02 | 0.00 |
| Industry | 0.19 | 0.39 | 0.10 |
| Services | 0.08 | 0.16 | 0.27 |

Data source: ISTAT (2017)

From equation (6.3) defining technical coefficients, equation (6.1) can then be rewritten as

$$x_i = a_{i1}x_1 + a_{ii}x_i + \ldots + a_{in}x_n + f_i \tag{6.4}$$

The technical-coefficient matrix **A** can be represented by introducing the diagonal matrix $\hat{\boldsymbol{x}}$ in the following equation (Miller and Blair, 2009):

$$\mathbf{A} = \mathbf{Z}\hat{\boldsymbol{x}}^{-1} \tag{6.5}$$

while the matrix expression for (6.4) would be

$$\mathbf{X} = \mathbf{Ax} + \mathbf{f} \tag{6.6}$$

which can be transformed into

$$\mathbf{(I - A)x = f} \tag{6.7}$$

where **I** is the identity matrix with ones on the main diagonal and zeros for all other values. The unique solution to (6.7) is given by:

$$\mathbf{x = (I\text{-}A)^{-1}f = Lf} \tag{6.8}$$

where $(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{L}$ is known as the *Leontief inverse* or *total requirements matrix*. The structure of the equations summarized in (6.8) is

$$x_i = l_{i1} + \ldots l_{ij}f_j + \ldots l_{in}f_n \qquad (6.9)$$

which underlines the dependence of gross output for sector *i* on final demands for all other sectors (this dependence or relationship can be represented in differential calculus as $\partial x_i / \partial f_j = l_{ij}$ ). Consequently, an increase in final demand for a given buying sector *j* as expressed by $\mathbf{f}_j$**'** will determine increases in outputs in all linked sectors, with the Leontief inverse matrix expressing these relationships between the marginal increase in demand from the buying sector and the marginal increase in output from the sectors selling goods or services to the former. The new output **x'** can be calculated by post-multiplication of the **f'** vector with the Leontief-inverse matrix

$$\mathbf{x}' = \mathbf{L}\mathbf{f}' \qquad (6.10)$$

The concept of *output multiplier* expresses the magnitude of the increase in output in all linked sectors as a result of increased final demand. The output multiplier for sector *j* is defined as "the total value of production in all sectors of the economy that is necessary in order to satisfy a currency's worth of final demand for sector *j*'s output" (Miller & Blair, 2009: 245). Broadly speaking, the multiplier concept is based on the difference between the initial effect of an exogenous variation in a parameter and the total effect of that change. An output multiplier can be *simple,* if it includes only direct and indirect effects in an I-O model that would be "open" to households, whereas a *total* output multiplier would also include induced effects (see section 5.4) in an I-O model "closed" to households. The simple output multiplier for sector *j* – $m(o)_j$ – can be calculated from the Leontief-inverse matrix with the formula:

$$m(o)_j = \sum_{i=1}^{n} l_{ij} \tag{6.11}$$

A related concept is that of the *employment multiplier*, defined as "the employment generated by an additional monetary unit of final demand for sector *j*" (Miller & Blair, 2009: 251). The employment multiplier is calculated from the Technical-Coefficient and Leontief-Inverse matrices using the following equation:

$$m(e)_j = \sum_{i=i}^{n} a_{n+1} l_{ij} \tag{6.12}$$

in which $a_{n+1,j}$ is an additional row added to the **A** matrix including the *employment coefficients* for all sectors[85]. This equation is derived from the one used for calculating the simple[86] household income multiplier for sector *j* (Miller & Blair, 2009: 251). The unit used for the employment multiplier is jobs[87]/M USD.

I-O modeling as described above can be considered *static*, as the interactions among industries is based on fixed coefficients derived from the SIOT available for a given year. For this reason, I-O models are generally used only for short to medium-term (e.g., up to 10 years) assessments of economic impacts. However, a dynamic element can be included in I-O modeling when capital goods are considered among the production inputs (Miller & Blair, 2009). So-called *dynamic I-O models* account for

---

[85] *Employment coefficients* are ratios of employees to output value in a specific economic sector.

[86] The term 'simple' in the context of income and employment multipliers refers to the use of elements in the L matrix with household exogenous to estimate these multipliers.

[87] Employment in the PV-C&I sector is often expressed in FTEs or person-year (Breitschopf et al., 2013; Cameron & van der Zwann, 2015) to reflect the temporary nature of labor requirements in this sector. See section 6.5.

the fact that a portion of input goods (e.g., machinery) are not used immediately for production, and hence, capital stock used for production can be incorporated into an I-O table through *capital coefficients*. Other examples of dynamic I-O models can be found in those incorporating estimates of production lags in the economy. Overall, as compared to static I-O frameworks, the application of dynamic I-O models has been limited.

Complex methodological issues in I-O analysis arise when the industry analyzed is characterized by the production of secondary products, subsidiary products, joint products, and by-products (Miller and Blair, 2009: 214). In these cases, the approach required for constructing an I-O table is the so-called *commodity-by-industry approach*, which presents several methodological problems. The most significant of these is that the commodity-by-industry framework, designed to make the original Leontief framework more suitable to account for secondary products, at times generates negative elements, whereas in the more general technical coefficients **A** matrix, or in the Leontief inverse, there are no negative elements. Fortunately, for the sake of the proposed analysis, the two PV economic sectors analyzed – the industry installing new PV systems (composed of various actors like small system-integrators, engineering and procurement [EPC], or integrated utilities) and the one operating and maintaining existing PV systems – do not produce secondary products of any relevance to justify the use of the commodity-by-industry approach.

## 6.2 Literature Reviews on Application of I-O frameworks to RE and PV Deployment

Literature on the economic impact analysis of renewable energy (RE) and PV deployment based on I-O models has been expanding significantly since the early 2000s, and this sectoral application of I-O methodology is nowadays considered a consolidated approach[88]. The following is a general overview of the literature that proved most useful for this analysis.

Ciorba, Pauli & Menna (2004) carried out a techno-economic analysis of a policy-induced demand for PV technology that focused on investment for a 4 MW module production plant in Morocco. This study is among the first (if not *the* first) analyses to apply I-O methodology using a “dedicated” vector for the PV-module manufacturing sector. Their analysis revealed that, in terms of output and employment generated by PV-module production, economic effects depend to a great extent on whether PV cells could be manufactured domestically or not. In the scenario where cells are manufactured domestically, the output multiplier (including induced economic effects) was estimated to be 2.5 higher than the scenario in which PV cells are imported.

A multi-regional I-O model was used by Ragwitz et al. (2009) in the integrated methodological framework applied to estimate employment impacts of RE deployment in the European Union by 2020. The I-O approach followed by Ragwitz et al. consisted in the creation of specific production vectors by economic sector, and by

---

[88] A list of publications using the JEDI-model family (based on the I-O framework) to estimate the economic impacts of RE deployment is provided by NREL (2018).

country for each RE technology, including PV. The structure of PV installation costs underlying the vector for the photovoltaic industry was based on estimates of the shares of each cost component and the allocation of these cost components to a specific economic sector in the I-O table. The installation component, for example, with an average share of 15% on total PV-system cost, was allocated to the economic sector "Construction".

Barbarella et al. (2009) estimated the economic impacts of a scenario of PV deployment in Italy reaching 8,500 MW of cumulative installed capacity[89] and 1,150 MW of annual installations by 2020. Barbarella et al. broke down costs for the PV-related economic sub-sectors: (a) investments in new PV plants and (b) operation and management (O&M) of existing plants, and then allocated each cost component to a specific sector in the I-O table. The estimated simple (not including induced effects) employment multipliers for the two PV sectors in 2009 (when Italy still had a sizeable PV-module industry) were 12.85 (jobs created/M EUR of final demand) for PV-system installation and 20 for PV-system O&M.

Lehr et al. (2012) compared the cost structure of PV and wind-energy systems with that of conventional fossil-fuel systems, and underlined the strong differences in the cost distribution for these three technologies, in which the intermediate inputs are sourced from different sectors. This marked difference required the introduction of new vectors in I-O tables for specific renewable-energy technologies (RET) such as PV, even when there is already a disaggregated vector for the RE sector as a whole.

---

[89] This level was achieved as early as 2011.

Breitschopf et al. (2013), in their report on methodological guidelines for estimating the employment-impacts of renewable-electricity deployment, discuss in detail the differences between gross I-O and net I-O models. They suggest four major steps for estimating gross output and employment impacts of RET deployment: (a) determining system boundaries; (b) determining expenditures for RE use; (c) calculating domestic output by RE technology and industry; and (d) calculating direct and indirect employment[90].

The 2015 edition of the *Energy [R]evolution* report by Greenpeace et al. (2015) estimates the direct employment effects of RE deployment through 2030, under two different scenarios. The methodology used to calculate RE jobs is based on employment factors derived from literature and on estimated regional multipliers to correct for differences in PV labor productivity in ten main regions in the world. Employment factors for PV construction and installation and PV O&M for the OECD Europe region were estimated at 13 (FTE/year)/MW and 0.7 FTE/MW, respectively. Technology-decline factors were also estimated to account for reductions in employment intensity due to labor productivity, with the employment factor for PV assumed to decrease by 41% between 2015 and 2030 (corresponding to an average annual decline factor of 3%; Rutovitz et al., 2015).

Cai et al. (2016) carried out an ex-post EIA of Italian RE policies with I-O tables for four RE technologies (including PV). It was found that PV was responsible for 35% of jobs created during the 2006–14 period in the RE sector. However, there

---

[90] These methodological steps were also followed by the author.

were significant export leakages due to PV-cell demand being almost entirely met by foreign producers. In fact, Cai et al. reported that from 2009 to 2012, Italy imported about EUR 20 billion worth of solar PV cells and estimated that imports accounted for about half the value of final demand for the four RE technologies analyzed. The conclusion of Cai et al. on policy-induced RE deployment in Italy was that economic impacts "had been unequivocally lower than expected" (Cai et al., 2016: 1).

GSE (2016b) – as part of its institutional activities – assessed the economic impacts of investments in new RE plants and O&M activities for existing RE plants for seven RE technologies (including PV) in Italy from 2012 to 2015. Economic impacts analyzed include value-added and employment effects with a disaggregation among direct, indirect, and induced effects. Included in the dataset of the study are also direct employment figures for PV-installation and PV-O&M, from which it was possible to derive employment factors. Between 2012 and 2015, employment factors, estimated from GSE data on employment, decrease from 7.99 (FTE/year)/MW to 7.02 (FTE/year)/MW for PV-installation, whereas they remain constant at 0.39 FTE/MW for the PV-O&M sectors[91]. Simple employment multipliers reported by GSE for PV-system installation ranged from 6 (FTE/year)/M EUR in 2012 to 7 (FTE/year)/M EUR in 2014, whereas for PV-system O&M, the same multiplier hovered around 12 FTE/M EUR during the same period.

Lehr and Ulrich (2017) estimated gross employment (including direct and indirect effects) generated by RE diffusion in Germany from 2004 to 2014 with an I-O

---

[91] The employment-factor values for 2015 derived from GSE data are significantly lower than those estimated by Rutovitz et al. (2015) for Greenpeace's *Energy [R]Evolution* report published in 2015.

model extended to additional sectors covering production of RE technologies and O&M activities. In 2014, gross employment in RE and linked sectors was estimated at about 350,000 FTE, a level more than twice higher than 2004, but 11% lower than 2012. Lehr and Ulrich argue that market dynamics in the PV sector were largely responsible for the marked increase until 2012 and for the following decline. PV installations and investments in Germany grew exponentially until 2009, and hovered around an annual level of around 7 GW until 2012, before starting to decline in 2013 as a result of the introduction of a cap in annual installations and a reduction in feed-in tariffs (FITs).

## 6.3 Creation of PV-related I-O vectors, Technical-Coefficient Matrix, and Leontief-Inverse Matrix

In order to comprehensively assess the economic impacts of PV deployment in Italy in the two scenarios, a static I-O model-based approach is applied with integration of dynamic employment multipliers. As a first step, this methodological approach requires the construction of specific column vectors including intermediate inputs of all those economic sectors stepping up their production as a result of increased final demand for the installation of new PV systems and O&M of existing capacity. In general, the construction of these vectors – which will be included in an expanded SIOT – requires, in turn, that each cost component (input) be allocated to specific economic sectors, as classified by the System of National Accounts (SNA) used in specific regional or country contexts.

Two new column vectors are needed for the economic sub-sectors chosen for the economic impact analysis (EIA), namely “Construction and installation of PV system" (hereinafter also referred to as PV-C&I) and "Operation and maintenance of PV systems" (hereinafter also referred to as PV-O&M). These two column vectors represent the input structure of the two PV sectors that also need to be represented by a new row characterizing output (e.g., to which sectors output is sold). The new columns and rows are then incorporated into the expanded SIOT for Italy.

A third, or even fourth, vector for other PV-related industries, like production of silicon ingots and PV cells, were not included in the impact analysis, since Italy had virtually no production of either in 2010, and almost complete import dependency for PV cells continued to 2016. Dependence on module imports gradually decreased from its peak in 2011 (when only 4.5% of demand was met by domestic production), to the extent that in 2016, domestic industries had a production equivalent to 89% of demand (Castello et al., 2012; Tilli et al., 2016). Considering the ultimate objective of the analysis, however, having a dedicated column vector for PV-module production was deemed irrelevant, as this industry production is already included in the so-called *first-round effect* of an increase in demand for PV systems. Had Italy been a net exporter of PV modules, the introduction of a new vector for this industry would have been necessary.

As aforementioned, in order to construct the two new vectors, the cost-structure for the PV-C&I and PV-O&M industries with shares for main cost components was estimated for the year 2010. The main cost components of these two PV sectors were then allocated to economic sectors in the I-O tables for Italy, based on the NACE Rev 2 classification of the European System of Accounts (ESA) (Tables 6.3, 6.4).

The main cost component (or intermediate input) for the PV-C&I industry in 2010 in Italy was “PV modules” (42.5% of average PV-system cost), followed by installation (including planning and permitting – with 29% of total average PV-system costs), inverters (9.5%), support structures (7%), electrical components (7%), and wholesale trade margins (5%). The *domestic footprint* of the PV-C&I industry in Italy was about 66% of total turnover in 2010.

Table 6.3 Shares of Cost Components in PV-C&I Industry in 2010 and Allocation to NACE Rev 2 Sectors

| **Cost component** | **Share on total installation cost 2010 (%)** | **Share of domestic industry (%)** | **Allocation to Economic Sector (NACE rev 2 classification)** |
|---|---|---|---|
| PV modules | 42% | 23% | 26. Manufacture of computer, electronic and optical prod. |
| Inverters | 10% | 100% | 27. Manufacture of electrical equipment |
| Other electrical components | 7% | 95% | 27. Manufacture of electrical equipment |
| Other structural components | 7% | 85% | 25. Manufacture of fabricated metal products |
| Project engineering and installation | 29% | 99% | 43. Specialised construction activities |
| Wholesale trade margin | 5% | 99% | 46. Wholesale Trade |
| Share of domestic economic activity on total installation cost = | | | **65.70%** |

Source: Author’s elaboration from Castello et al., 2010; 2012; Politecnico di Milano, 2011, and Ragwlitz et al., 2009.

Table 6.4 Main Cost Components of PV-O&M Industry in 2010 and Allocation to NACE REV 2 Sectors

| **Cost Component** | **Share on total O&M cost (%)** | **Share domestic (%)** | **Allocation to Economic Sector (NACE rev 2 classification)** |
|---|---|---|---|
| Maintenance - labor | 35% | 100% | 74. Other professional activities |
| Maintenance -hardware | 35% | 92% | 27. Manufacture of electrical equipment |
| Insurance | 10% | 100% | 65. Insurance |
| Administrative costs | 15% | 100% | 74. Other professional activities |
| Bank costs | 5% | 100% | 64. Financial Service Activities |
| Share of domestic economic activity on total installation cost = | | | **97.20%** |

Source: Author’s elaboration from Castello et al., 2010; 2012; Politecnico di Milano, 2011; and Ragwlitz et al., 2009.

Labor costs for maintenance and hardware costs had the highest shares (35% each) of PV-O&M expenditures in 2010, followed by administration costs (15%), insurance (10%), and costs for financial services (5%). The domestic share of these inputs on PV-O&M expenditures was as high as 98%.

The next step in developing a revised SIOT table with the two new PV sectors is that of further disaggregating the shares of the different cost components by domestic and external inputs, and allocating these sub-components to either the "Intermediate-Input" category or the two "Payment" categories in the I-O Table: Imports, and Value Added (Tables 6.5, 6.6).

Table 6.5 Allocation of Cost Components in PV-C&I Sector to Main Categories in I-O Table, 2010

| Economic Sector (NACE rev 2 classification) | Share (%) on PV-installation investment | PV-installation Cost component | Category in I-O Table |
|---|---|---|---|
| 25. Manuf. of fabricated metal products - DOMESTIC | 5.95% | Other structural components | Intermediate inputs |
| 25. Manuf. of fabricated metal products - FOREIGN | 1.05% | Other structural components | Imports |
| 26. Manuf. Of computer, electronic products - DOMESTIC | 9.87% | Modules | Intermediate inputs |
| 26. Manuf. Of computer, electronic products - FOREIGN | 32.56% | Modules | Imports |
| 27. Manuf. of electrical equipment - DOMESTIC | 16.15% | Inverters | Intermediate inputs |
| 27. Manuf. of electrical equipment - EXTERNAL | 0.35% | Inverters | Imports |
| 43. Specialised construction activities - DOMESTIC | 28.78% | Project engineering and installation | Value Added |
| 43. Specialised construction activities - FOREIGN | 0.29% | Project engineering and installation | Imports |
| 46. Wholesale trade - DOMESTIC | 4.95% | Wholesale trade margin | Value added |
| 46. Wholesale trade - EXTERNAL | 0.05% | Wholesale trade margin | Imports |
| TOTAL | 100% | | |
| Share of domestic intermediate inputs | 31.97% | | Intermediate Inputs |
| Share of foreign intermediate inputs | 33.96% | | Imports |
| Share of value added | 34% | | Value added |
| Share of Final Imports | 0.34% | | Imports |
| TOTAL | 100% | | |

Source: Author's elaboration

In 2010, foreign intermediate inputs had the highest share (34%) of costs in PV-C&I, followed by domestic intermediate inputs (32%), value added (34%), and a very small share for final imports (about 0.5%). This share accounts for foreign companies acting in engineering, procurement, and construction (EPC) or foreign system integrators that installed PV systems in Italy without creating a subsidiary.

Table 6.6 Allocation of Cost Components in PV-O&M Sector to Main Categories in I-O Table, 2010

| Economic Sector (NACE rev 2 classification) | Share (%) on PV O&M Expenditures | PV-O&M Cost component | Category in I-O Table |
|---|---|---|---|
| 27. Manuf. of electrical equipment - DOMESTIC | 32.20% | Maintenance - hardware | Intermediate inputs |
| 27. Manuf. of electrical equipment - FOREIGN | 2.80% | Maintenance - hardware | Imports |
| 64. Financial Service Activities | 5% | Bank costs | Intermediate inputs |
| 65. Insurance | 10% | Insurance | Intermediate inputs |
| 74. Other professional activities | 50% | Maintenance - labor; Administrative costs | Value added |
| TOTAL | 100% | | |
| Share of domestic intermediate inputs | 47.20% | | Intermediate inputs |
| Share of foreign intermediate inputs | 2.80% | | Imports |
| Share of value added on total output | 50% | | Value added |
| TOTAL | 100% | | |

Source: Author’s elaboration

Cost components classified as “Value Added” (e.g., labor costs for personnel in charge of O&M activities, administrative costs, etc.) had the highest share on PV O&M expenditures in 2010, followed by “Domestic Intermediate Inputs” (47.20%) and a small residual for “Foreign Intermediate Inputs”.

With values of PV-related transactions for each cost component allocated to economic sectors and to main categories in the I-O Table, the two new column vectors for PV-C&I and PV-O&M were constructed (Tables 6.7 and 6.8).

The last step before constructing the technical-coefficient matrix is to identify the sectors where the transactions for the two PV sectors were originally reported in the 63x63 SIOT. This is necessary in order to subtract the transactions for the two PV sectors and avoid double-counting. An analysis of the Supply and Use Tables (SUTs) an Imports Tables (ISTAT, 2013) suggested that investments in PV-C&I are embedded in NACE Rev 2 Sector 43 “Specialized Construction Activities”[92]. An analysis of the literature indicated that activities for the PV-O&M sector are likely to fall under sector 74 “Other Professional Activities”.

Table 6.7 I-O Vector for PV-C&I Sector in Italy, 2010 (EUR[nominal] million)

| **Sectorial Inputs to PV Construction &Installation by economic sector/category** | **Value of Transactions** (M EUR) |
|---|---|
| 25. Manufacture of fabricated metal products | 474 |
| 26. Manufacture of computer, electronic and optical products | 786 |
| 27. Manufacture of electrical equipment | 1,286 |
| Total Domestic Intermediate Inputs | 2,547 |
| Total Value Added | 2,686 |
| Intermediate imports | 2,705 |
| Final imports | 27 |
| Total Payments | 5,418 |
| TOTAL | 7,965 |

Source: Author’s elaboration

Next, the row vectors for the PV-C&I and PV-O&M sectors were developed with estimates on demand from sectors purchasing PV systems and PV-O&M services in 2010. Demand for output of these two PV sectors was allocated among the three main sectoral groups and final demand (e.g., households and public sector; Table 6.9).

---

[92] The value of Imports of the “Specialized Construction” sector shows a significant spike in the Imports Table for 2011, when PV installations reached their peak of 9.3 GW associated with a significant import of modules.

Table 6.8 I-O Vector for PV-O&M Sector in Italy, 2010 (EUR[nominal] million)

| **Sectorial inputs to PV Operation & Maintenance by economic sector / category** | **Value of Transactions** (M EUR) |
|---|---|
| 27. Manufacture of electrical equipment | 57 |
| 64. Financial Service Activities | 9 |
| 65. Insurance | 18 |
| Total Intermediate Inputs | 83 |
| Total Value Added | 88 |
| Intermediate Imports | 5 |
| Final Imports | |
| Total Payments | |
| TOTAL | 176 |

Source: Author's elaboration

Table 6.9 Demand for PV Systems and O&M Services by Sector in 2010

| **Selling Sector** | **Buying Sector** | | | **Final Demand** | **Total** |
|---|---|---|---|---|---|
| | Agriculture | Industry | Services | | |
| PV C&I | 610 | 5462 | 819 | 1074 | 7965 |
| PV O&M | 18 | 102 | 18 | 39 | 176 |

Source: Author's analysis based on GSE, 2011; 2012.

In order to simplify the process of developing the new **A** matrix with the two new PV sectors, a new 12x12 transactions table was constructed from the 63x63 SIOT made available by ISTAT (2013) for the year 2010 and the two PV-related column and row vectors. The new 12x12 sector SOIT includes the following economic sectors: PV-C&I, PV O&M, and the seven sectors linked or embedding the two PV sectors (24, 25, 27, 43, 46, 65, and 74). All other sectors were grouped under the three sectoral groups "Agriculture", "Rest of Industry", and "Rest of Services". As intermediate inputs in the 63x63 I-O table for the Italian economy include foreign intermediate imports, the latter had to be “scrubbed out” by difference (Miller & Blair, 2009) using a table with imports by sector (ISTAT, 2013).

With all PV-related transaction values estimated (the zs in equation [6.1] as well as value added, imports, and final demand), both the **A** matrix (Table 6.10) and the Leontief inverse matrix (Table 6.11) were constructed using equations (6.1–6.9).

With the Leontief inverse matrix developed, before evaluating the actual estimation of employment and output effects of PV deployment in the two scenarios, the final step is to construct two new column vectors for final demand for new PV systems ($\mathbf{f'}_{\text{PV-INST}}$) and O&M services ($\mathbf{f'}_{\text{PV-O\&M}}$), incorporating investments in the PV-C&I sector and PV-O&M expenditures. These two new column vectors need to be post-multiplied by **L** to estimate the increased output as per equation (6.10).

## Table 6.10 Matrix A of Technical Coefficients for the Italian Economy with Inclusion of PV-related Sub-sectors, 2010

| **Sector** | AGRICULTURE | 25. Manuf. of Fabricated Metal Products | 26. Manuf. of Computer and Electronic Products | 27. Manuf. of Electrical Equipment | PV Installation | 43. Specialised Construction Activities | (rest of) INDUSTRY | 64. Financial Services Activities | 65. Insurance | PV O&M | 74. Other professional activities | (rest of) SERVICES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AGRICULTURE | 0.0805 | 0.0009 | 0.0001 | 0.0004 | 0.0000 | 0.0005 | 0.0164 | 0.0000 | 0.0000 | 0.0000 | 0.0006 | 0.0031 |
| 25. Manufacturing of Fabricated Metal Products | 0.0049 | 0.1471 | 0.0042 | 0.0274 | 0.0575 | 0.0422 | 0.0251 | 0.0002 | 0.0003 | 0.0000 | 0.0033 | 0.0024 |
| 26. Manufacturing of Computer and Electronic Products | 0.0012 | 0.0024 | 0.0224 | 0.0076 | 0.0690 | 0.0014 | 0.0021 | 0.0009 | 0.0009 | 0.0000 | 0.0019 | 0.0023 |
| 27. Manufacturing of Electrical Equipment | 0.0026 | 0.0095 | 0.0043 | 0.0378 | 0.1596 | 0.0090 | 0.0051 | 0.0001 | 0.0002 | 0.3169 | 0.0000 | 0.0017 |
| PV Installation | 0.0101 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0045 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0005 |
| Specialised Construction Activities[a] | 0.0007 | 0.0061 | 0.0036 | 0.0081 | 0.0000 | 0.1974 | 0.0008 | 0.0111 | 0.0061 | 0.0000 | 0.0084 | 0.0109 |
| (rest of) INDUSTRY[b] | 0.1613 | 0.1771 | 0.0391 | 0.1520 | 0.0000 | 0.1739 | 0.1755 | 0.0126 | 0.0142 | 0.0000 | 0.0615 | 0.0793 |
| 64. Financial Services Activities | 0.0086 | 0.0154 | 0.0061 | 0.0101 | 0.0000 | 0.0151 | 0.0106 | 0.0981 | 0.1264 | 0.0491 | 0.0135 | 0.0227 |
| 65. Insurance | 0.0018 | 0.0008 | 0.0002 | 0.0006 | 0.0000 | 0.0011 | 0.0005 | 0.0026 | 0.0010 | 0.0982 | 0.0001 | 0.0011 |
| PV O&M | 0.0003 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 74. Other professional activities[c] | 0.0023 | 0.0039 | 0.0029 | 0.0040 | 0.0000 | 0.0049 | 0.0030 | 0.0024 | 0.0047 | 0.0000 | 0.0227 | 0.0067 |
| (rest of) SERVICES[d] | 0.0645 | 0.1383 | 0.1015 | 0.1344 | 0.0000 | 0.1288 | 0.1377 | 0.1525 | 0.3744 | 0.0000 | 0.2123 | 0.2191 |
| TOTAL Intermediate Inputs | **0.34** | **0.50** | **0.18** | **0.38** | **0.29** | **0.57** | **0.38** | **0.28** | **0.53** | **0.46** | **0.32** | **0.35** |

Note: (a) Excludes value of transactions estimated for 'PV-installation' sub-sector; (b) Excludes transaction values for sectors 25, 26, 27, PV-installation, and Specialized Construction Activities; (c) Excludes estimated value of transactions for the PV O&M sub-sector.

Source: Author's elaboration based on ISTAT, 2017

Table 6.11 Leontief Inverse Matrix for the Italian Economy, 2010

| **Sector** | AGRICULTURE | 25. Manuf. of Fabricated Metal Products | 26. Manuf. of Computer and Electronic products | 27. Manuf. of Electrical Equipment | PV installation | 43. Specialized Construction Activities[a] | (rest of) INDUSTRY[b] | 64. Financial Services Activities | 65. Insurance | PV O&M | 74. Other professional activities[c] | (rest of) SERVICES[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AGRICULTURE | 1.0922 | 0.0072 | 0.0019 | 0.0054 | 0.0018 | 0.0073 | 0.0232 | 0.0016 | 0.0032 | 0.0021 | 0.0038 | 0.0069 |
| 25. Manufacturing of fabricated metal products | 0.0150 | 1.1830 | 0.0080 | 0.0417 | 0.0923 | 0.0719 | 0.0387 | 0.0032 | 0.0052 | 0.0139 | 0.0091 | 0.0090 |
| 26. Manufacturing of Computer and Electronic Products | 0.0036 | 0.0044 | 1.0236 | 0.0094 | 0.1116 | 0.0020 | 0.0041 | 0.0017 | 0.0026 | 0.0033 | 0.0031 | 0.0037 |
| 27. Manufacturing of Electrical Equipment | 0.0071 | 0.0142 | 0.0055 | 1.0418 | 0.2055 | 0.0135 | 0.0087 | 0.0010 | 0.0019 | 0.3296 | 0.0016 | 0.0036 |
| PV Installation | 0.0116 | 0.0014 | 0.0004 | 0.0011 | 1.0004 | 0.0015 | 0.0057 | 0.0003 | 0.0006 | 0.0004 | 0.0007 | 0.0013 |
| 43. Specialised Construction Activities[a] | 0.0043 | 0.0138 | 0.0071 | 0.0148 | 0.0046 | 1.2510 | 0.0057 | 0.0188 | 0.0173 | 0.0073 | 0.0156 | 0.0189 |
| (rest of) INDUSTRY[b] | 0.2335 | 0.2888 | 0.0683 | 0.2294 | 0.0726 | 0.3117 | 1.2525 | 0.0450 | 0.0773 | 0.0823 | 0.1130 | 0.1364 |
| 64. Financial Services Activities | 0.0176 | 0.0314 | 0.0121 | 0.0217 | 0.0078 | 0.0338 | 0.0221 | 1.1160 | 0.1553 | 0.0769 | 0.0251 | 0.0358 |
| 65. Insurance | 0.0023 | 0.0015 | 0.0005 | 0.0011 | 0.0004 | 0.0020 | 0.0010 | 0.0032 | 1.0020 | 0.0989 | 0.0006 | 0.0016 |
| PV O&M | 0.0003 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 1.0000 | 0.0000 | 0.0000 |
| 74. Other Professional Activities[c] | 0.0044 | 0.0078 | 0.0044 | 0.0069 | 0.0024 | 0.0097 | 0.0058 | 0.0046 | 0.0092 | 0.0033 | 1.0258 | 0.0097 |
| (rest of) SERVICES[d] | 0.1422 | 0.2753 | 0.1525 | 0.2379 | 0.0823 | 0.2870 | 0.2389 | 0.2329 | 0.5316 | 0.1388 | 0.3091 | 1.3214 |

Note: (a) Excludes values of transactions estimated for the 'PV Installation' sub-sector; (b) Excludes transaction values for transactions of sectors 25, 26, 27, PV Installation and 43; (c) Excludes estimated value of transactions for 'PV O&M' sub-sector; (d) Excludes transaction values for sectors 64, 65, PV O&M, and 74.

Source: Author's elaboration based on ISTAT (2017)

## 6.4 Estimation of Output Impacts in the Reference Scenario

Direct and indirect output effects deriving from the increase in demand modeled in the reference scenario (RS) between 2010 and 2020 are shown in Table 6.12[93].

Table 6.12 Output Effects in the Reference Scenario, 2010-2020

| Year | **PV C&I** | | **PV O&M** | |
|---|---|---|---|---|
| | Increased Demand **f'** M EUR(2010) | Direct+Indirect Output effects **x'** M EUR(2010) | Increased Demand **f'** M EUR(2010) | Direct+Indirect Output effects **x'** M EUR(2010) |
| 2010 | 7,963 | 12,592 | 165 | 290 |
| 2011 | 20,794 | 32,880 | 480 | 844 |
| 2012 | 6,969 | 11,020 | 817 | 1,436 |
| 2013 | 2,315 | 3,661 | 969 | 1,703 |
| 2014 | 684 | 1,081 | 1,019 | 1,790 |
| 2015 | 505 | 799 | 880 | 1,547 |
| 2016 | 497 | 786 | 808 | 1,419 |
| 2017 | 564 | 891 | 802 | 1,410 |
| 2018 | 669 | 1,057 | 816 | 1,433 |
| 2019 | 828 | 1,309 | 835 | 1,466 |
| 2020 | 1,067 | 1,687 | 862 | 1,514 |
| Cum. 2010-2016 | 39,729 | 62,820 | 5,138 | 9,028 |
| Average 2010-2016 | 3,612 | 5,711 | 467 | 821 |
| Cum. 2010-2020 | 42,856 | 67,765 | 8,452 | 14,851 |
| Average 2010-2020 | 3,896 | 6,160 | 768 | 1,350 |
| | Output multiplier = | 1.58 | Output multiplier = | 1.76 |

Source: Author's analysis.

---

[93] The final-demand vectors for the reference scenario include historical data from 2010 to 2016 and projections from 2017 to 2020.

Historical PV deployment between 2010 and 2016 resulted in an average annual (total) gross output effect (not including induced effects) of about EUR 6,100 million[94] for PV-C&I and about EUR 600 million for PV-O&M. The estimated simple output multipliers are 1.58 for PV-C&I and 1.76 for PV-O&M[95].

## 6.5 Estimation of Employment Impacts in the Reference Scenario

The calculation of employment impacts resulting from increased demand for the PV-C&I and PV-O&M sectors from 2010 to 2020 in the RS is carried out through the estimation of employment multipliers as per equation 6.12 (Miller & Blair, 2009). One of the elements of this equation is the employment coefficient (the number of jobs per unit of output in an economic sector), which were in turn estimated from employment factors. The latter are expressed by the ratio of total jobs divided by the relevant metric determining the scale of economic activity in each sector, which, in the case of the two PV sectors examined, are Megawatts (MW) of PV installations and MWs PV capacity under O&M. The methodology to estimate employment impacts for the PV-C&I sector is summarized graphically in Figure 6.1.

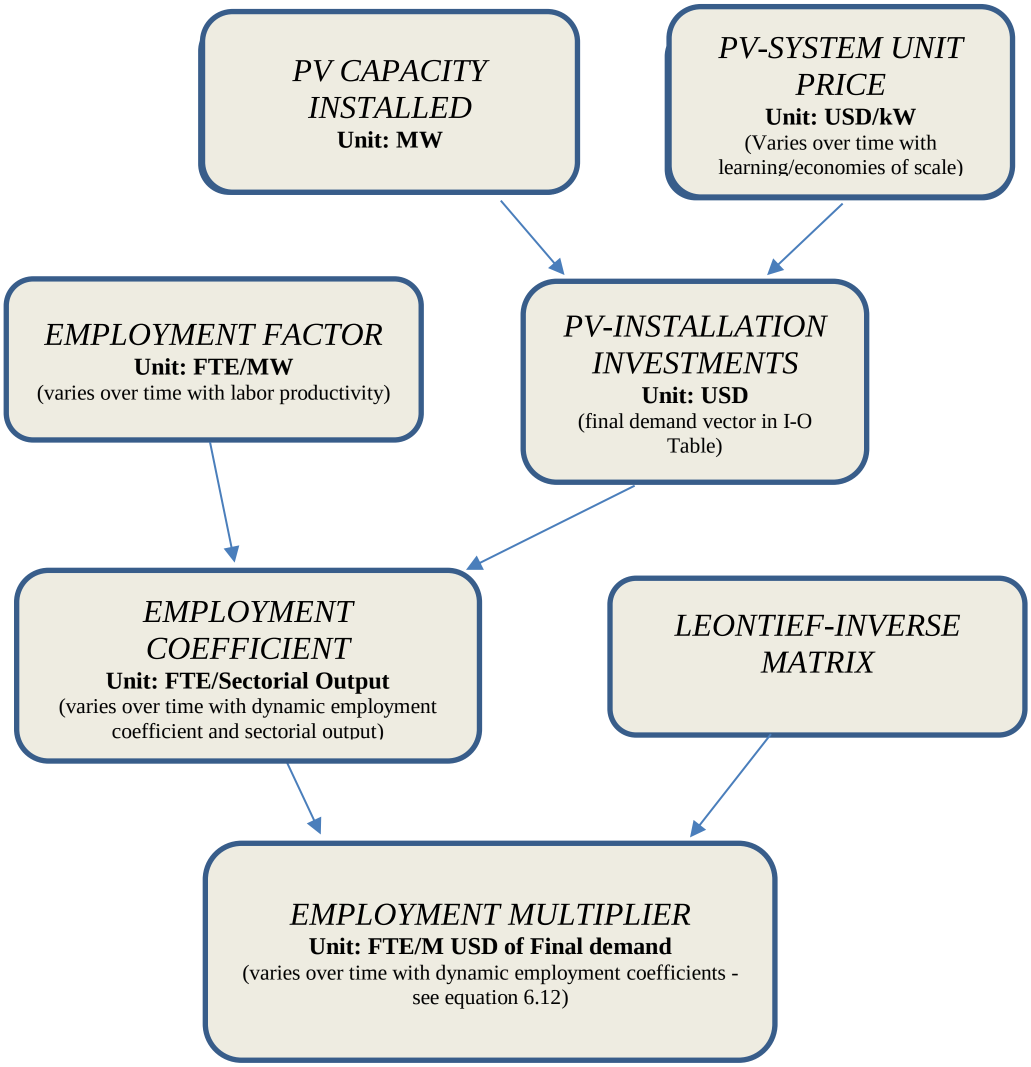
Employment factors for PV-C&I and PV-O&M were estimated using available historical data (Castello et al., 2009–15; GSE, 2016b) and equation (3.1) (with

---

[94] Unless stated differently, all values in this chapter are in constant 2010 Euros.

[95] The output multiplier is constant throughout the whole time frame 2010-20, a finding that is consistent with I-O theory as the $l_{ij}$ values (parameters) in Table 6.11 (Leontief Inverse Matrix) are constant.

employment factors replacing prices in the experience-curve equation) for years in which historical values are not available or are inconsistent (Tables 6.13 and 6.14).



Source: Author's elaboration.

Figure 6.1 Description of Methodology Followed to Estimate Employment Multipliers for the PV-C&I Sector in Year *t*

Table 6.13 Employment Factors, Employment Coefficients, and Employment Multipliers for PV-C&I Sector in the Reference Scenario

| Year | **Employment factors** | **Employment coefficients** | **Employment multipliers** |
|---|---|---|---|
| | ([FTE/year]/MW installed) | ([FTE/year]/M EUR[2010]Output) | ([FTE/year]/M EUR[2010] demand) |
| 2010 | 7.70 | 2.24 | 5.04 |
| 2011 | 7.03 | 3.15 | 5.94 |
| 2012 | 6.91 | 4.19 | 6.99 |
| 2013 | 6.86 | 4.54 | 7.34 |
| 2014 | 6.85 | 4.25 | 7.05 |
| 2015 | 6.84 | 4.27 | 7.07 |
| 2016 | 6.83 | 5.34 | 8.14 |
| 2017 | 6.83 | 5.56 | 8.36 |
| 2018 | 6.82 | 5.85 | 8.65 |
| 2019 | 6.80 | 6.12 | 8.92 |
| 2020 | 6.78 | 6.39 | 9.19 |

Note: Employment factors were estimated by author with the Experience-index equation using the value for year 2007 (9.97 FTE/MW) from Castello et al. (2008) and the 2014 value (6.85 FTE/MW) from GSE (2016b). Cumulative PV capacity is used as metric for 'experience'. The estimated experience index used to estimate employment-factor values from 2008 to 2013 and from 2015 to 2020 is 0.07. Employment multipliers were estimated by author based on methodology from Miller & Blair (2009).

Data sources: Castello et al. 2009-2015; Tilli et al., 2016-2017; GSE, 2016b; Politecnico di Milano, 2010-2017.

Employment in the PV-C&I sector has a different nature than that in the PV-O&M sector: while jobs in the former can fluctuate significantly with annual installations, employment in O&M is longer-term and increases linearly with PV cumulative capacity. Hence, employment in the PV-O&M sector might be considered more “valuable” to policymakers, given its more permanent or longer-term nature. As a result, two different metrics will be used in the following analysis to measure employment in these two sectors: “FTE” (equivalent to person-year) for the PV-C&I sector, and “jobs” for the PV-C&I sector. This approach is consistent with methodologies adopted or suggested in the relevant literature (e.g., Breitschopf et al, 2013; Cameron & van der Zwann, 2015).

Table 6.14 Employment Factors, Employment Coefficients, and Employment Multipliers for PV-O&M Sector in the Reference Scenario

| Year | **Employment factors** | **Employment coefficients** | **Employment multipliers** |
|---|---|---|---|
| | (FTE/MW under O&M) | (FTE/M EUR[2010] output) | (FTE/M EUR[2010] demand) |
| 2010 | 0.4479 | 6.30 | 9.80 |
| 2011 | 0.4124 | 7.20 | 10.71 |
| 2012 | 0.3964 | 7.45 | 10.96 |
| 2013 | 0.3931 | 7.16 | 10.66 |
| 2014 | 0.3927 | 6.93 | 10.44 |
| 2015 | 0.3916 | 8.34 | 11.84 |
| 2016 | 0.3911 | 9.26 | 12.76 |
| 2017 | 0.3911 | 9.35 | 12.85 |
| 2018 | 0.3904 | 9.42 | 12.93 |
| 2019 | 0.3896 | 9.50 | 13.00 |
| 2020 | 0.3885 | 9.57 | 13.07 |

Note: Employment factors were estimated by author with the Experience-index equation assuming 0.48 FTE/MW in 2009 (the value reported for Germany in 2007 and used by Rutovitz & Atherton [2009]) and 0.39 FTE/MW in 2014 (GSE, 2016b). The estimated experience index is 0.0642. Employment multipliers were estimated by author based on methodology from Miller & Blair (2009).

Data sources: Castello et al. 2009-2015; Tilli et al., 2016-2017; GSE, 2016b; Politecnico di Milano, 2010-2017.

While output multipliers are constant during the time frame considered, employment multipliers vary over time since they are derived from employment coefficients, themselves calculated from employment factors. The latter showed a general decreasing trend as the number of employees required to perform a specific task (be it the installation of new PV systems or their O&M) is also subject to learning effects, as was found in Chapter 3.

Historical PV deployment between 2010 and 2016 embedded in the RS resulted in the creation of (cumulative) direct employment impacts amounting to about 130,000 FTEs in the PV-C&I sector and about 39,000 jobs in the PV O&M sector. Indirect employment effects of investments in PV-C&I between 2010 and 2016 were estimated at 112,000 FTEs, whereas expenditures in O&M of PV systems resulted in the creation of 18,000 jobs in linked sectors (Table 6.15).

Table 6.15 Employment Impacts in the Reference Scenario, 2010-2020

| Year | PV C&I | | PV O&M | |
|---|---|---|---|---|
| | Direct employment (FTE/year) | Indirect employment (FTE/year) | Direct Employment (FTE) | Indirect employment (FTE) |
| 2010 | 17,862 | 22,290 | 1,038 | 578 |
| 2011 | 65,416 | 58,205 | 3,460 | 1,683 |
| 2012 | 29,206 | 19,508 | 6,090 | 2,864 |
| 2013 | 10,512 | 7,581 | 6,940 | 3,397 |
| 2014 | 2,904 | 1,914 | 7,063 | 3,570 |
| 2015 | 2,156 | 1,415 | 7,342 | 3,086 |
| 2016 | 2,654 | 1,392 | 7,474 | 2,830 |
| 2017 | 3,134 | 1,578 | 7,498 | 2,812 |
| 2018 | 3,909 | 1,872 | 7,687 | 2,859 |
| 2019 | 5,069 | 2,317 | 7,928 | 2,925 |
| 2020 | 6,821 | 2,986 | 8,247 | 3,020 |
| Cum. 2010-2016 | 130,710 | 112,305 | 39,407 | 18,008 |
| Cum. 2010-2020 | 149,643 | 121,058 | 70,767 | 29,624 |

Source: Author's analysis.

As expected, between 2010 and 2016, employment in the PV-C&I sector had been fluctuating significantly in parallel with the irregular trends of installations (peaking in 2011, reaching a bottom in 2015, and showing a possible rebound in 2016), while jobs in the PV-O&M sector increased linearly with the PV capacity in operation.

## 6.6 Comparison of Economic-impact Results in 2010-2016 with Studies in Literature

As mentioned in the literature review, at least three studies have looked at the economic impacts of photovoltaic deployment in Italy in recent years (Barbarella et.

al, 2009; GSE, 2016; Cai et al., 2016). While Cai et al. (2016) do not show individual data for output and employment effects of PV technology (but rather for the renewable-energy sector on the whole), it was possible to extract data on employment multipliers from the two other studies in order to compare results (Table 6.16).

Table 6.16 Comparison of Estimated Employment Multipliers with Values Reported in the Relevant Literature (FTE / M EUR[2016] of final demand)

| Sector | **PV C&I** | | | **PV O&M** | | |
|---|---|---|---|---|---|---|
| Year | Barbarella et al. | GSE | Own estimation | Barbarella et al. | GSE | Own estimation |
| 2009 | 12.85 | | | 20.11 | | |
| 2010 | | | 5.04 | | | 9.80 |
| 2011 | | | 5.94 | | | 10.71 |
| 2012 | | 6.32 | 6.99 | | 11.89 | 10.96 |
| 2013 | | 6.91 | 7.34 | | 11.89 | 10.66 |
| 2014 | | 6.94 | 7.05 | | 11.89 | 10.44 |
| 2015 | | 6.95 | 7.07 | | 11.89 | 11.84 |
| 2016 | | | 8.14 | | | 12.76 |

Data sources: Barbarella et al., 2016b; GSE, 2016b; Author's estimation.

The estimated employment multipliers from 2012 to 2015 are closely aligned with those reported by GSE (2016b) for both the PV C&I and PV-O&M sectors. It should be pointed out that the GSE study on economic impacts from which the multiplier values were extracted was also a source of data for employment factors and PV system prices from 2012 to 2015 used for this work, so this alignment of results should not be surprising (see Figure 6.1). However, this alignment might also suggest that values from the Leontief-inverse matrix in the two analyses (the GSE study using 2011 values for the Matrix) are not too divergent from each other. Notably, the multiplier for the PV-O&M sector from the GSE study is constant from 2012 to 2015, suggesting that authors used fixed employment factors and did not incorporate learning effects in their analysis.

Employment multiplier values from the Barbarella et al. (2009) study are, on the other hand, significantly different from those estimated in the present work. This is also not surprising since the former study used the SIUT for year 2006 to estimate employment impacts from 2009 onwards, while the two industries underwent a significant transformation in scale from 2006 to 2010.

Comparing multiplier results with those of studies carried out in other countries presents two kinds of problems. First, there is limited literature on the application of I-O methodology to estimate economic impacts of PV deployment at a national level in recent years. Secondly, cross-country comparisons of multipliers may be of limited analytical value for the sake of "validating" results of EIAs, since the degree of maturity and interindustry links could vary significantly within different national contexts (Cameron & van der Zwann, 2015).

### 6.7 Estimation of Output Impacts in the Counterfactual Scenario

The estimation of output impacts of PV deployment in the counterfactual scenario (CS) is carried out with two different **f'** vectors than in the RS, given that the patterns of investments in PV installation and expenditures for O&M in the two scenarios are different. However, the output multipliers for the two scenarios are the same, given that the **x'** vectors (the output impacts) are obtained from the same Leontief-inverse matrix (see equation [6.10]).

Between 2010 and 2020, PV deployment in the counterfactual scenario generates, on average, an annual total (excluding induced effects) output impact of about EUR 3,500 million for the PV-installation sector and about EUR 650 million for the PV-O&M sector, respectively (vs. EUR 6,160 and 1,500 million in the reference scenario; Table 6.17).

Table 6.17 Output Impacts in the Counterfactual Scenario, 2010-2020

| Year | **PV C&I** | | **PV O&M** | | **Energy efficiency** | |
|---|---|---|---|---|---|---|
| | Increased Demand **f'** M EUR(2010) | Direct+Indirect Output effects **x'** M EUR(2010) | Increased Demand **f'** M EUR(2010) | Direct+Indirect Output effets **x'** M EUR(2010) | Increased demand **f'** M EUR(2010) | Direct+Indirect Output effets **x'** M EUR(2010) |
| 2010 | 2,548 | 4,029 | 71 | 125 | 310 | 535 |
| 2011 | 2,104 | 3,327 | 111 | 196 | 310 | 535 |
| 2012 | 1,904 | 3,011 | 137 | 242 | 310 | 535 |
| 2013 | 1,821 | 2,879 | 184 | 323 | 310 | 535 |
| 2014 | 1,958 | 3,097 | 239 | 421 | 310 | 535 |
| 2015 | 2,085 | 3,297 | 301 | 529 | 310 | 535 |
| 2016 | 2,210 | 3,495 | 313 | 550 | 310 | 535 |
| 2017 | 2,285 | 3,613 | 339 | 595 | 310 | 535 |
| 2018 | 2,374 | 3,753 | 397 | 698 | 310 | 535 |
| 2019 | 2,475 | 3,914 | 461 | 809 | 310 | 535 |
| 2020 | 2,704 | 4,276 | 529 | 930 | 310 | 535 |
| Cum. 2010-2016 | 14,631 | 23,135 | 1,357 | 2,384 | 2,169 | 3,743 |
| Average 2010-2016 | 1,330 | 2,103 | 123 | 217 | 197 | 340 |
| Cum. 2010-2020 | 24,469 | 38,691 | 3,083 | 5,417 | 3,409 | 5,882 |
| Average 2010-2020 | 2,224 | 3,517 | 280 | 492 | 310 | 535 |
| | Output multiplier = | 1.58 | Output multiplier = | 1.76 | Output multiplier = | 1.73 |

Source: Author’s elaboration.

Estimation of output impacts from the additional EE investments in the counterfactual scenario is based on multiplier values derived from the analysis done by Beccarello (2011). The (average) multiplier for the mix of EE measures included in the CS is 1.73 (Table C.1 in Appendix C), higher than the one for PV installation (1.58) and slightly lower than the one for PV O&M (1.76). The counterfactual scenario assumes EE investments take place at a constant annual flow of EUR 311 million per year from 2010 and 2020; hence, the (constant) annual output effect is estimated by multiplying the annual-investment value by the EE output multiplier, resulting in an annual output-impact of about EUR 540 million (EUR[2010]) per year.

A summing up of output effects for the three sectors between 2010 and 2020 results in an average annual (aggregate) output impact in the CS of about EUR 4,700 million in the CS, versus EUR 7,670 million in the reference case. The average multiplier (obtained by averaging output effects of the three sectors) in the CS is 1.61, only slightly higher than the RS (1.60). This finding might seem to suggest that adding EE investments to the CS does not have a significant impact on increasing the total indirect output effects relative to the RS. However, this limited effect of additional EE on the scenario multiplier actually has to do with the much lower scale of EE investments (yearly average of EUR 311 million) versus PV-installation (about EUR 3,900 million in the RS and EUR 2,200 million in the CS). Had the scale of EE investments been similar to that of the PV-installation sector, the average multiplier of the CS would have obviously been higher.

## 6.8 Estimation of Employment Impacts in the Counterfactual Scenario

The estimation of employment impacts from PV deployment in the CS is based on the same methodology used to calculate employment factors in the RS (the application of the experience curve equation to employment multipliers). Despite use of the same experience indexes in the two scenarios, employment multipliers are obviously different in the CS, as a result of the different evolution in scale of the two industries between 2010 and 2016. Employment coefficients and employment multipliers are also different than in the CS as a result of the relatively lower PV-system prices and unit O&M costs (Tables 6.18 and 6.19).

Table 6.18 Employment Factors, Employment Coefficients, and Employment Multipliers for PV-C&I Sector in the Counterfactual Scenario

| Year | Employment factors | Employment coefficients | Employment multipliers |
|---|---|---|---|
| | ([FTE/year]/MW installed) | ([FTE/year]/M EUR[2010]Output) | (FTE[year]/M EUR[2010] demand) |
| 2010 | 8.26 | 2.58 | 5.38 |
| 2011 | 8.20 | 3.41 | 6.21 |
| 2012 | 8.15 | 4.12 | 6.92 |
| 2013 | 8.09 | 4.71 | 7.51 |
| 2014 | 8.04 | 4.78 | 7.58 |
| 2015 | 7.99 | 4.91 | 7.71 |
| 2016 | 7.93 | 5.06 | 7.86 |
| 2017 | 7.88 | 5.35 | 8.15 |
| 2018 | 7.83 | 5.63 | 8.43 |
| 2019 | 7.78 | 5.90 | 8.70 |
| 2020 | 7.70 | 6.15 | 8.95 |

Note: Employment factors were estimated by author with the Experience-index equation using the same experience index (0.07) as in the reference scenario with 2009 as base year. Cumulative PV capacity is used as metric for "experience" with 2009 as base year. Employment multipliers were estimated by author based on methodology from Miller & Blair (2009).

Data sources: Castello et al. 2009-2015; Tilli et al., 2016-2017; GSE, 2016b; Politecnico di Milano, 2010-2017.

Table 6.19 Employment Factors, Employment Coefficients, and Employment Multipliers for PV-O&M Sector in the Counterfactual Scenario

| Year | Employment factors | Employment coefficients | Employment multipliers |
|---|---|---|---|
| | (FTE/MW under O&M) | (FTE/M EUR[2010] Output) | (FTE/M EUR[2010] demand) |
| 2010 | 0.4593 | 10.12 | 13.63 |
| 2011 | 0.4468 | 9.63 | 13.14 |
| 2012 | 0.4376 | 10.57 | 14.08 |
| 2013 | 0.4302 | 10.15 | 13.66 |
| 2014 | 0.4240 | 9.64 | 13.14 |
| 2015 | 0.4185 | 9.27 | 12.77 |
| 2016 | 0.4136 | 10.59 | 14.09 |
| 2017 | 0.4091 | 11.47 | 14.97 |
| 2018 | 0.4050 | 11.34 | 14.84 |
| 2019 | 0.4011 | 11.24 | 14.75 |
| 2020 | 0.3974 | 11.20 | 14.71 |

Note: Employment factors were estimated by author with the Experience-index equation using the same assumptions on base-year value (0.48 FTE/MW in 2009) and the same experience index calculated for the RS. Employment multipliers were estimated by author based on methodology from Miller & Blair (2009).

Data sources: Castello et al. 2009-2015; Tilli et al., 2016-2017; GSE, 2016b; Politecnico di Milano, 2010-2017.

The cumulative employment impact of the CS between 2010 and 2020 is about 186,000 FTEs in the PV-C&I sector and 43,000 jobs in the PV O&M sector (Table 6.20).

Table 6.20 Employment Impacts from PV Deployment in the Counterfactual Scenario, 2010-2020

| Year | PV C&I | | PV O&M | |
|---|---|---|---|---|
| | Direct employment (FTE/year) | Indirect employment (FTE/year) | Direct Employment (FTE) | Indirect employment (FTE) |
| 2010 | 6,569 | 7,131 | 719 | 249 |
| 2011 | 7,178 | 5,890 | 1,073 | 390 |
| 2012 | 7,844 | 5,331 | 1,453 | 482 |
| 2013 | 8,572 | 5,097 | 1,864 | 643 |
| 2014 | 9,367 | 5,482 | 2,308 | 839 |
| 2015 | 10,236 | 5,836 | 2,790 | 1,055 |
| 2016 | 11,185 | 6,187 | 3,314 | 1,097 |
| 2017 | 12,223 | 6,396 | 3,884 | 1,187 |
| 2018 | 13,357 | 6,644 | 4,504 | 1,392 |
| 2019 | 14,596 | 6,928 | 5,179 | 1,614 |
| 2020 | 16,623 | 7,569 | 5,933 | 1,856 |
| Cum. 2010-2016 | 60,950 | 40,954 | 13,522 | 4,756 |
| Cum. 2010-2020 | 117,749 | 68,492 | 33,021 | 10,805 |

Source: Author's analysis

The methodology used to estimate employment impacts of EE investments in the CS is slightly different from that used for the two PV sectors. Total employment impacts are estimated using the employment-multiplier value derived from the Beccarello (2011), while direct employment is calculated from the ratio of total to direct impacts taken from the same source (2011) as well. The assumptions used to estimate the employment factor and the employment multiplier are shown in Table C.2 (Appendix C).

Based on the 16.55 FTE/M EUR multiplier derived from Beccarello, the results of the EE employment assessment for the additional EE investments indicate a total employment impact of about 2,000 FTE per year, with direct employment effects amounting to about 600 FTE per year (Table 6.21).

Table 6.21 Employment Impacts from Additional EE Investments in the Counterfactual Scenario

| Year / Time frame | Direct Employment (FTE) | Indirect Employment (FTE) | Total (direct+indirect) Employment (FTE) |
|---|---|---|---|
| Yearly average 2010-2020 | 1,609 | 3,519 | 5,128 |
| Cumulative 2010-2020 | 17,696 | 38,710 | 56,406 |

Source: Author's analysis based on Beccarello (2011).

## 6.9 Comparison of Impacts in Reference and Counterfactual Scenario

Comparing the economic impacts of the historical PV-deployment path embedded in the RS with the alternative technology-support route conceptualized in the CS can provide useful insight on the comparative economic efficiency and trade-offs of policies for achieving the same energy sustainability objectives.

The absolute level of economic impacts (output and employment effects) is not a suitable metric to compare the *efficiency* or *cost-effectiveness*[96] of the two scenarios, as the magnitude of final demand mobilized by incentives in the two

---

[96] In the context of this analysis, *cost effectiveness* is intended as the degree to which inputs or efforts of economic or financial nature (e.g., RD&D investments, subsidies) are translated into outputs (e.g., output or employment effects, increases in productivity, technology-cost reductions).

scenarios is significantly different. Between 2010 and 2020, the RS has a policy-induced cumulative increase in final demand of about EUR 51 billion, while the exogenous increase in final demand in the CS amounts to EUR 32 billion. However, the value of the average output multiplier in the two scenarios is almost the same. EE investments in the CS have a much higher output multiplier than PV installation (1.73 vs 1.58), but the relative low volume of EE investments in the CS does not produce a significant impact on increasing the overall scenario output multiplier (1.61 in the CS vs. 1.60 in the RS). Hence, comparing the two scenarios on the basis of the average output multiplier does not bring significant analytical insight.

Consequently, the only metric left to compare the two scenarios on the basis of cost-effectiveness is the employment multiplier. First, as a result of the different evolution of employment coefficients (in turn, the result of different growth rates in employment and investments), the CS has higher employment multipliers for both the PV-C&I and PV-O&M sectors. Second, the employment multiplier from the additional EE investments in the CS (16.55) is significantly higher than the employment multiplier for PV-installation installations (6.32 in the RS). As a result, the CS achieves a higher (+20%) overall employment multiplier than does the RS (8.73 vs. 7.23)[97]. This difference in creating employment in the scenarios is non-negligible, even considering the fact that EE investments are, in absolute levels, not significant in the CS. Had the share of EE investments in the CS been higher, the difference in employment multipliers between the two scenarios would have been

---

[97] This scenario multiplier is calculated “ex-post” from scenario results. Its numerator is obtained by summing employment in the three sectors and using “FTE” as the common metric.

even more evident (Table 6.22 summarizes the average output and employment multipliers for the two scenarios).

Table 6.22 Output and Employment Multipliers in the Two Scenarios

<table>
<tr><th>Multiplier</th><th>Reference Scenario</th><th>Counterfactual Scenario</th></tr>
<tr><td>Output multiplier PV Installation</td><td colspan="2">1.58</td></tr>
<tr><td>Output multiplier PV O&M</td><td colspan="2">1.76</td></tr>
<tr><td>Output multiplier EE</td><td>-</td><td>1.73</td></tr>
<tr><td>Scenario Output multiplier</td><td>1.60</td><td>1.61</td></tr>
<tr><td>Average Employment multiplier PV installation</td><td>6.32</td><td>7.61</td></tr>
<tr><td>Average Employment multiplier PV O&M</td><td>11.88</td><td>14.22</td></tr>
<tr><td>Average Employment multiplier EE</td><td>-</td><td>16.55</td></tr>
<tr><td>Scenario Employment multiplier</td><td>7.23</td><td>9.25</td></tr>
</table>

Source: Author’s elaboration

Another way to assess the cost-effectiveness of the two scenarios is by using subsidies in place of increased final demand as denominator of the employment multiplier (a metric that can be defined as “ratio of employment impact to subsidies”). The results indicate a marked difference between the two scenarios: the RS has a ratio of employment impacts to subsidies of 5, while the same ratio for the CS is 15.8. This differential links with findings in chapter 4 that highlighted the high subsidization costs of the Conto Energia program, which supported PV deployment from 2006 to 2013, underlying the RS. Even if subsidies for EE measures in the CS were to cover 100% of the upfront investment costs (an assumption that can only be used for conceptual analysis on boundary conditions), the ratio would only decrease to 14.9, still almost three times higher than in the RS.

In conclusion, findings from this economic-impact analysis suggest that monetary incentives provided under Conto Energia supporting PV deployment, as reflected in the RS, resulted in a significant opportunity cost to Italian policymakers. Had part of the financial resources been used for additional EE incentives, the same impact on achieving the objective of the EU's Renewable Energy Directive for Italy by 2020 could have been had at much lower costs.

## 6.10 Summary

A methodological framework based on symmetric input-output tables was developed to estimate the gross economic and employment effects of historical deployment of PV technology in Italy in the frame of a reference scenario including projections to 2020. Economic impacts were also estimated for a counterfactual scenario based on lower PV deployment and higher energy-efficiency investments.

Two new vectors for the sectors "PV-system Construction & Installation" and "PV-system Operation & Maintenance" were constructed based on the cost-distribution of these two industries in 2010. These vectors were then incorporated into the 63x63 SIOT for Italy, from which 12x12-sector technical-coefficient and Leontief Inverse matrices were constructed. Historical data and scenario projections for investments in the construction and installation of PV-systems and expenditures for O&M were then incorporated into two new final-demand vectors necessary for economic-impact analysis.

Gross output effects were estimated by post-multiplication of the new final demand vectors by the Leontief-inverse matrix. The estimated output multiplier for PV C&I in 2010 is 1.58, and 1.75 for PV O&M, while the output multiplier for the additional energy-efficiency investments in the counterfactual scenario is 1.73. The small share of energy-efficiency investments in the latter scenario on total clean-energy investments results in the two scenarios having almost the same average output multiplier.

PV deployment between 2010 and 2016, largely supported by the Conto Energia program, resulted in cumulative employment impacts amounting to 144,000 FTEs in the PV-C&I sector, with 112,000 FTEs in the linked sectors. Employment impacts in the PV-O&M sector were estimated at 7,500 jobs in 2016, with 3,500 jobs in linked sectors.

Employment multipliers showed more meaningful differences among sectors and between the two scenarios. During the historical time frame of 2010–16 that was analyzed, the estimated average employment multiplier is about 7 (FTE/year)/M EUR (of final demand) for the PV-C&I sector and about 11 FTE/M EUR for the PV-O&M sector. The much higher employment multiplier (16.55 FTE/M EUR) of the additional energy-efficiency investments in the counterfactual scenario makes this scenario more efficient in terms of employment impacts. Averaging impacts in the three sectors, the employment multiplier for the counterfactual scenario is about 15% higher than in the reference scenario.

The overall cost-effectiveness of the two scenarios was also assessed, by dividing employment impacts by subsidies estimated (for installations under Conto Energia) and assumed (for scenario projections) for PV deployment and the additional EE investments. The strategy underlying the counterfactual scenario – to dilute support for PV technology over time and to accelerate energy-efficiency investments – results in a ratio of employment impacts to subsidies more than three times higher than in the reference scenario. This finding suggests that at least part of the incentives disbursed to support PV deployment under Conto Energia could have had a significantly more efficient use in terms of employment impacts, while still having the same effect on contributing to energy-sustainability objectives.

# Chapter 7

# CONCLUSIONS, POLICY RECOMMENDATIONS AND FUTURE RESEARCH

## 7.1 Conclusions

Thanks to the Conto Energia program, PV installations in Italy grew from 12 MW in 2006 to about 3,600 MW in 2013, with a total of about 17,800 MW of PV capacity being installed over the 2006-16 timespan. PV is now the fourth largest source of electricity generation in Italy, holding a share of about 7% of the electricity mix (the third largest share in the world). This significant deployment of PV technology largely contributed to Italy's achievement of the 2020 target of the European Union "Renewable Energy Directive" 2009/28/CE (a 17% share of renewables on gross internal energy consumption) by as early as 2016. These results, however, came with a hefty cost: cumulative payments from 2006 to 2038 for feed-in tariffs (FIT) under the Conto Energia program are estimated to total EUR 132 billion. Despite this notable financial burden, the question of whether or not the Conto Energia program was cost-effective has been left largely unaddressed by peer-reviewed literature since its last batch of incentivized installations took place in 2016.

The present work has attempted to assess the cost-effectiveness of the Conto Energia program by applying an integrated methodological framework. The economic impact analysis of PV deployment under the Conto Energia program – the central research focus of this dissertation – provided enough quantitative evidence to conclude that this incentive regime was indeed far from being a cost-effective way to promote clean-energy deployment. The rationale for this research was not only to carry out an ex-post assessment of “sunken costs” (given that the Conto Energia program was discontinued in 2016), but also to provide useful insights and analysis that can help policymakers develop more efficient clean-energy policies in the future. In fact, the methodological framework tested can prove useful to Italian policymakers as they define the measures necessary to achieve the 2030 ambitious decarbonization goals set out in the National Energy Strategy. This concluding part of the dissertation intends to offer policymakers further considerations and recommendations that can help fine-tune current and future energy policies in order to increase their cost-effectiveness.

This chapter is comprised of three sections. Section 1 summarizes the most important research findings. Section 2 draws some general conclusions on the need for governments to increase efforts to integrate clean-energy and industrial policy frameworks. Section 3 discusses the limitations of this study and identifies some possible venues for future analytical work.

## 7.2 Research Findings

### 7.2.1 Results from Learning Process Analysis

Prices of PV systems in Italy have undergone a significant reduction since the early 2000’s. From 2002 to 2016, prices decreased by 80%, and much of this reduction took place in parallel with the exponential market growth spurred by the Conto Energia program. To what extent this reduction was caused by domestic market dynamics versus global learning effects and economies of scale is a relevant question for both comprehensively assessing the benefits of the Conto Energia program and for developing PV-system price projections to be used in scenario analysis.

Drawing on the many available sources reporting price data broken down by component, it was estimated that about 75% of PV-system price reduction over 2002-16 was due to manufactured components that are traded globally (PV modules, inverters, and other BOS components like cables and support structures). During the same period, installations in the Italian PV market accounted for only about 6% of global PV demand, so the effect of the domestic market was not significant in spurring the global learning effects and economies of scale of manufactured components traded globally.

Local learning effects, on the other hand, may have played a role in reducing the so-called *soft costs* (planning, project engineering, installation, and administrative costs), accounting for 25% of the PV-system price reduction between 2006 and 2016. Learning rates observed in the Italian PV market between 2006 and 2016 were 22% for soft costs. Based on global PV market projections available in the literature and the estimated learning rates for modules (21%), inverters (20%), and other BOS costs (17%), the cost of these three components was estimated to reach EUR 620/kW by 2035 (assuming an average global market growth of 7.5%).

### 7.2.2 Results from Subsidization Cost Analysis

The estimated total cumulative cost of FIT payments through 2038 for PV plants installed under the Conto Energia program amounts to EUR 130 billion, with a net present cost of EUR 62 billion (using 2006 as a base year and a nominal social discount rate of 5%)[98]. In order to gauge the extent of subsidization of PV capacity installed in each of the eleven years of implementation of the Conto Energia program, twenty-year FIT payments for capacity installed in a given year were discounted to obtain the so-called *capital-grant equivalent* (per unit of capacity installed). Results of the subsidization analysis based on the net-present cost methodology indicate that the capital grant equivalent values of FIT payments were higher than the estimated average PV-system prices throughout the entire 2006-16 time frame. The estimated capital-grant equivalent value for the year 2011 exceeds 200% of the average PV-system price estimated for the same year. These findings suggest that a different incentive framework (e.g., an investment tax credit combined with a production tax credit for non-residential systems, and a tax deduction combined with net metering for residential systems) might have been less onerous in supporting PV deployment in Italy.

### 7.2.3 Results from Scenario Analysis

A first economic-impact assessment of the Conto Energia program was conducted in the frame of a comparative scenario analysis. The reference scenario was built on historical PV deployment from 2006 to 2016 and on a projected market diffusion that would allow PV to reach the objective set by the National Energy Strategy of 70 TWh of generation by 2030. The counterfactual scenario was built on an alternative path of PV deployment, having much lower PV installations (with respect to the reference case) from 2010 to 2013 that were, however, compensated by higher deployment from 2017 to 2030, so that PV technology would meet the same 70

---

[98] Equivalent to about EUR[2016] 71 billion.

TWh National Energy Strategy objective. The counterfactual scenario also assumed additional energy-efficiency investments in order to have the same impact as the reference case on reducing natural gas demand and $CO_2$ emissions by 2020.

Findings show that total investments for construction and installation (C&I) of PV systems between 2006 and 2035 in the two scenarios are not significantly different, with EUR(2016) 106 billion in the reference scenario and EUR(2016) 101 billion in the aligned at about EUR(2016). This might suggest that a hypothetical strategy of delaying support for PV deployment in order to take advantage of global price-reduction dynamics would not have had significant effects in terms of reducing the investment costs for the construction and installation of PV systems.

There is, however, a striking difference between the two scenarios when it comes to subsidization costs. The reference scenario is almost five times more onerous than the counterfactual one in the subsidization of PV deployment. The difference in total subsidization costs between the two scenarios is of EUR(2016) 54 billion, which, had it been used to mobilize additional EE investments between 2020 and 2030, would have instead resulted in an extra 20 M toe of reductions in natural gas demand and 47 M toe of additional carbon emissions reduction in the counterfactual scenario.

### 7.2.4 Results from LCOE and Cash-flow Analysis

PV reached “market parity” in the niche of utility-scale plants in 2017, when a 1 MW PV power plant was installed in Central Italy. This PV power plant will sell generated electricity to the grid without the support of any incentive scheme (Qualenergia.it, 2017a). While the levelized cost of electricity (LCOE) of both residential and commercial PV systems was below the retail electricity price in 2016, PV installations in the distributed PV market[99] were, with 316 MW, significantly lower than the level achieved in 2012 (about 1,800 MW). This might suggest that grid parity, as measured by the equivalence of the LCOE to retail electricity prices, is not a significant analytical “watershed” for PV market development.

Financial performance indicators like payback time or internal rate of return (IRR) can be considered as alternative grid-parity metrics to forecast or project market development. Estimated IRR values of residential and commercial systems in Central Italy in 2016 are in the 8-9.5% range, taking into account the effects of the residential tax deduction and the net-metering scheme. Without the tax deduction, the IRR for residential systems would still be below the 4% value considered a possible threshold for market viability without incentives. Yet, cash flow analysis reinforces the LCOE analysis findings: the market development of distributed PV systems is not accelerating significantly after grid-parity – as measured by financial performance metrics – is achieved. Even taking into account the relatively high IRR values resulting from the incentives currently in place, distributed PV installations in 2016 were significantly below 2012 levels. Overall, this points to two possible issues that make grid-parity analysis quite a complex undertaking: the saturation of “sweet spots” (e.g., the niche of “early adopters” more prone to install PV systems), and the presence of market failures (e.g., lack of information, the use of very high implicit discount rates by prospective adopters, etc.). This suggests that reaching the National Energy Strategy target of about 70 TWh generation from solar PV by 2030 (vs. 22 TWh in 2016) could be challenging without adequate market-support mechanisms.

---

[99] In the context of the present work, *distributed PV systems* are defined as systems with rated power of up to 200 kW.

### 7.2.5 Results from Economic-impact Analysis

The Input-Output (I-O) methodology framework was used to estimate the output and employment effects of the two scenarios between 2010 and 2020, building on the 2010 Symmetric I-O table for the Italian economy.

The estimated output multiplier for the PV-C&I sector in 2010 is 1.58, and 1.76 for the PV operation and maintenance (O&M) sector, while the output multiplier for the additional energy-efficiency investments assumed in the counterfactual scenario is 1.73. The two scenarios have roughly the same average output multiplier (calculated by summing up the investments and output effects of the three sectors). This is largely due to the relatively low share of energy-efficiency investments in the counterfactual scenario.

Employment multipliers show more marked differences among sectors in the two scenarios. Energy-efficiency investments modeled in the counterfactual scenario have, between 2010 and 2016, the highest average employment multiplier, with almost 17 FTE/M Eur (of final demand), followed by the PV-O&M sector with 11 FTE/M Eur, and finally the PV-C&I sector with 7 FTE(year)/M Eur. Overall, the employment multiplier of the counterfactual scenario is 15% higher than that of the reference scenario. This finding suggests that the relatively more balanced clean-energy mix that is embedded in the counterfactual scenario is more effective in creating jobs.

Finally, the cost-effectiveness of the two scenarios was assessed by looking at the ratio of employment generated to subsidies. The calculation of these ratios revealed a striking difference between the two scenarios, with the counterfactual scenario showing an employment to subsidy ratio of 15.8 FTE/M EUR (of subsidy), almost three times higher than that in the reference scenario (estimated at 5 FTE/M Eur). Since the reference scenario incorporates PV installation under the Conto

Energia program, this finding suggests that this incentive scheme had a significant opportunity cost. Policymakers could possibly have reached the same clean-energy targets by 2020 at lower subsidization costs and with higher employment impacts.

## 7.3 Policy Assessment of the Conto Energia Program

While there is general agreement over the effectiveness of FITs vs. other incentive schemes in supporting the deployment of renewable energy sources (Jacobs an Sovacool, 2012; Dijkgraaf et al., 2018), critiques have been raised on the cost-effectiveness of FIT programs in Germany and Italy (e.g., Frondel et. al., 2010; Antonelli & Desideri, 2014).

As far as Italy is concerned, the finding that the capital-grant equivalent of FIT incentives systematically exceeded the estimated average PV system prices from 2006 to 2016 points to an "over-incentivization" of PV systems during the implementation of the Conto Energia program. Evidence that PV systems were over-incentivized comes not only from the calculation of capital-grant equivalent values, but also from the simple estimation of return rates of investments of PV systems, which, for non-residential systems, reached levels as high as 25% (Antonelli & Desideri, 2014). Had more effective caps on annual installed capacity as well as more flexible FITs (e.g., adapting quickly to the rapid downturn of PV module costs in 2010-11) been put in place, the costs to government and taxpayers could have been lower. The evidence for sub-optimal cost-effectiveness lies in the findings of the present work, which indicate that part of the "budget envelope" used for the Conto Energia program could have been used to support clean-energy deployment in a more efficient way, resulting in higher economic impacts.

There are other aspects to consider in assessing the Conto Energia program. One of these aspects is the kind of diffusion model that the Conto Energia program enabled to support PV deployment. Giannuzzi, Valori & Basosi (2013) pointed to the over-proliferation of ground-mounted plants, which resulted from a lack of adequate regulation. In fact, between 2008 and 2011, more than 6 GW of centralized PV power plants (almost 50% of total PV installations) were installed on the ground. Antonelli and Desideri (2014) stress that the much more favorable support for large PV power plants contradicts one of the widely agreed-upon missions of FIT programs, namely, that they should support a distributed model of PV diffusion rather than a centralized one that is based on large installations on the ground. One can argue that investments in centralized PV power plants could have been channeled towards industrial and commercial building roofs instead, helping small and medium enterprises reduce their electricity bills.

Furthermore, economic impact analysis pointed to a broader policy issue, that is, the need to integrate clean-energy policies with industrial policies. *Cost-effectiveness*, in the frame of designing clean-energy policies, can be interpreted by policymakers as the reaching of a specific target (e.g., in terms of share of renewables on energy supply, decrease of energy intensity, or reduction in energy-related carbon emissions at the lowest possible cost to government and taxpayers). This can be done through the use of methodological tools like marginal abatement cost curves, energy supply curves, etc. However, a specific clean-energy option (either a renewable energy technology or an energy-efficiency measure including infrastructure investments promoting low-carbon behavioral changes) can have relatively low costs (and be at the lower end of the marginal cost curve), but can also be relatively inefficient in terms of creating added value and employment effects for the domestic economy. Towards the end of 2011, for example, solar PV was probably the cheapest renewable-electricity generating option in Italy (together with wind, on sites having particularly favorable wind speed), however its employment multiplier was significantly lower than the "bundle" of energy-efficiency investments analyzed in the counterfactual scenario.

Another aspect of intersectoral policy integration relevant to the implementation of the Conto Energia program is whether and how policymakers can better align market-pull mechanisms with the objective of promoting the growth of domestic high-tech industries with export potential. As the history of the German and Italian FIT programs shows, domestic PV manufacturing industries were not able to scale up quickly enough to stand competition from foreign companies. In fact, as has already been pointed out (Frondel et al., 2010; Cai et al., 2016), generous support for renewable energy deployment in Germany and Italy coincided instead, in both countries, with a massive scaling down, if not disappearance, of their solar PV cell and module manufacturing industries. While at the onset of Conto Energia in 2006, domestic production of PV cells and market demand in Italy were almost equivalent, the degree of technology independence decreased abruptly to less than 6% in 2010, and then declined to almost zero in 2015 (Table 7.1). In other words, while the Italian domestic PV market was booming, the Italian PV cell manufacturing industry experienced its demise.

Whether it could have been possible to maintain a viable domestic PV cell production capacity in the face of the exponential growth of foreign producers (notably China) is a question that extends beyond the scope of this analysis. This question should probably receive greater attention, as it is likely to be of significant interest to policymakers seeking to find ways to optimize the two aforementioned strategic objectives: promotion of clean energy and job growth. This issue will be addressed in the policy recommendations.

Table 7.1 Share of Domestic PV cell and Module Production on Italian PV market, 2006-2015

| Year | Domestic PV cell production MW | Amporphous silicon PV module production MW | Annual PV installations MW | Share of domestic PV cell production on PV annual installations % | Share of domestic PV cell and a-si module production on on PV annual installations % |
|---|---|---|---|---|---|
| 2006 | 11 | 0 | 12 | 91.67% | 91.67% |
| 2007 | 13 | 0 | 70.2 | 18.52% | 18.52% |
| 2008 | 28.4 | 0 | 337.9 | 8.40% | 8.40% |
| 2009 | 66.1 | 0 | 723.38 | 9.14% | 9.14% |
| 2010 | 130 | 0 | 2,320.93 | 5.60% | 5.60% |
| 2011 | 118 | 0 | 9,303.59 | 1.27% | 1.27% |
| 2012 | 20 | 160 | 3,654.00 | 0.55% | 4.93% |
| 2013 | 0 | 190 | 1,400.00 | 0.00% | 13.57% |
| 2014 | 0 | 190 | 409.00 | 0.00% | 46.45% |
| 2015 | 3 | 190 | 307.00 | 0.98% | 62.87% |

Note: PV module production in 2013-15 estimated by author

Data sources: Castello et al., 2007-2014; Tilli et al., 2016-2017; Politecnico di Milano, 2009-2016.

Factors that could explain the lack of cost-effectiveness of the Conto Energia program can be manifold, ranging from a lack of vision, planning capacity, or simple foresight on the part of policymakers when embarking on costly subsidization projects, to the degree to which the political decision-making process is influenced by political lobbying.

While an investigation of the “political economy” of the Italian Conto Energia program is beyond the analytical scope of the present work, there is some evidence that would suggest that political decision-making processes may have played a role in significantly increasing the program's costs. A case in point for an investigation of the role of lobbying is the so-called *Salva Alcoa* Decree, which extended the tariffs of the second Conto Energia scheme (tariffs that were supposed to end in 2010) to plants installed during the first semester of 2011 (Agnoli, 2014). As a result of the Salva Alcoa Decree (converted into law by the Italian Parliament), an additional 3,700 MW were installed in 2011 under a FIT scheme that had been designed at a time when market conditions were significantly different. For example, average selling prices of PV modules more than halved from 2008 to 2011, decreasing from 3.25 to 1.37 USD/$W_p$ (Mints, 2012). Partly as a result of the Salva Alcoa Decree, the annual costs of this FIT program increased from around EUR 0.7 million in 2010 to approximately EUR 3.8 billion in 2011. It should be noted that the Italian Conto Energia program may not be an isolated case among European countries when it comes to a lack of cost-effectiveness resulting from political decisions in legislative bodies. Frondel et al., for example, criticize the German FIT program as an "unsound energy policy that is highly prone to political lobbyism" (Frondel et al, 2010: 4055).

The findings of the present work suggest that the Conto Energia program was, in fact, not a cost-effective instrument for supporting market deployment of PV technology. Political decision making processes were probably crucial in rendering this incentive scheme a case of sub-optimal clean-energy policymaking, if not an outright "policy failure". The next section will aim to feed the findings of this work into policy recommendations to decision makers in order to contribute toward improving the cost-effectiveness of current and future clean-energy policies.

### 7.4 Policy Recommendations

Results from this analysis can inform the future clean-energy policies that Italian policymakers will need to design in order to achieve, *in a way that is cost-effective,* the objectives for renewable energy and energy efficiency set forth in the National Energy Strategy by 2030. The six main policy recommendations for the Italian government are as follows:

- First: to develop cost projections to 2030 (both for capital cost and levelized cost of energy) for the main renewable-energy and energy-efficiency technologies (e.g., heat pumps) based on global and local learning-curve analysis, as developed in Chapter 3 herein;
- Second: to develop marginal “clean-energy” (comprising renewable-energy technologies and energy efficiency options) and carbon abatement cost curves through 2030. This framework could be derived from engineering bottom-up analysis as illustrated for PV and energy-efficiency in Chapter 4. This would, in theory, allow for the identification of the cheapest mix of solutions necessary to achieve clean-energy supply and decarbonization targets, taking technical potentials into account;
- Third: to develop a range of alternative scenarios, all achieving the same objectives by 2030, but through different technological routes, in a way similar to that done in the scenario analysis through 2030 in Chapter 4;
- Fourth: to develop a framework of dynamic employment indicators that include employment factors (taking learning rates into account), employment

coefficients, and employment multipliers. These indicators will serve the purpose of projecting employment impacts in each of the scenarios constructed, in a way similar to that done in the economic-impact analysis in Chapter 6;

- Fifth: to estimate the degree of subsidies needed to drive clean-energy deployment in each scenario. Different methodologies can be used to estimate the degree of subsidization of an energy scenario; for example, one can estimate the "elasticities" of market diffusion to financial performance (e.g., as measured by IRR values or payback rates). With projections on capital cost prices of clean-energy technologies, it is possible to calculate the degree of subsidization that would allow market deployment to reach desired targets;
- Sixth and final: to identify the most cost-effective scenario in terms of ratio of employment effects to either subsidies or investment costs, and finally, to design a policy framework consistent with the clean-energy policy mix identified in this scenario.

One further step that policymakers could consider, in order to attempt to align the two objectives of cost minimization and employment maximization, would be to use a composite indicator or index, in which each clean-energy technology could be ranked based on the two dimensions of *cost* (through an indicator like "cost per Mtoe generated or saved") and *economic impact* (with "employment multiplier" as an indicator).

## 7.5 Directions for Future Research

This dissertation research had some limitations, which are worth considering for the development of future analytical work. At the same time, the literature review and exploratory analyses completed also touched upon aspects which, while being beyond the analytical scope of the present work, could, in the future, provide useful insight to policymakers and complement the data collection and methodological approach of this dissertation.

### 7.5.1 Limitations related to Dissertation Research

The first limitation regards the role that local learning effects have in driving down the prices of PV systems. The literature reviewed did not include analysis on the factors that could explain the observed reduction in soft costs of PV systems. In particular, it was noted that there is no data available to investigate whether this reduction was largely due to a greater experience of installers, the increased size of companies active in the PV-C&I sector, or simply the reduction in profit margins due to a more competitive market. Addressing this question would require a dedicated survey or, possibly, a series interviews with PV-system installers. Unfortunately, during the first stage of the research, it was not possible to secure the support of Italian PV industry associations in this regard.

The second limitation regards data availability on the investment costs, techno-economic potential values, and employment-impact metrics (output, value-added, and employment multipliers) of energy-efficiency measures in Italy. Despite a literature review that was quite extensive, it was only possible to identify a single study (Beccarello, 2011) having the granularity of data required to create and assess the counterfactual scenario. A constraint of this part of the research was the need to source data published within a specific time frame (e.g., between 2008 and 2012) in order to feed this into the counterfactual scenario. The reason for this time-related constraint is the fact that the counterfactual scenario, whose base year is 2010, attempts to "simulate" an alternative policy pathway that policymakers could have chosen during the very first stage of the Conto Energia program, before the 2010-12 PV installation boom. In other words, even if more recent studies had been available, their data on energy-efficiency investments and techno-economic potential would not have been useful in building the counterfactual scenario, as these indicators vary significantly over time. That being said, the fact is that there is a critical lack of data even for more recent years, which would warrant dedicated research work.

The third limitation relates to the metrics used to measure the cost-effectiveness of Conto Energia. The ratio of employment impacts to subsidy is a novel metric that was created for the purpose of this analysis and which could be used for ex-post assessments. However, its use in ex-ante analyses (e.g., the period 2020-35 that was not included in the impact analysis) is problematic, as it would require the estimation of subsidies needed to achieve a given level of clean-energy deployment. As mentioned in the previous section, one route for carrying out this estimation could be the use of technology-diffusion curves, with financial-performance metrics (e.g., payback) included as one of the variables in the market diffusion equation. This, in turn, would require the prior estimation of the “elasticity” of market diffusion to financial performance, which can be done econometrically, provided there is enough data available. In fact, the major challenge in pursuing this analytical path is that of data availability. An alternative could be, as was also mentioned in the previous section, that of developing an index that incorporates indicators related to costs of clean-energy technologies as well as their employment or value added multipliers. A methodology that combines multiple, single indicators into a composite indicator is used by the European Commission for the *European Innovation Scoreboard* report (European Commission, 2018).

## 7.6 Additional Venues for Future Research

An interesting venue for future research that emerged during the scoping analysis relates to the question of whether and to what extent it is possible to balance technology push and market pull policies. For example, while the market pull for PV technologies in Italy was ramping up quickly with the Conto Energia program, increasing from EUR 18 million in 2007 to about EUR 6,500 million in 2013, over the same period, public research, development, and demonstration (RD&D) expenditures for solar energy[100] only increased from EUR 45 to EUR 56 million (IEA, 2018). While RD&D expenditures in solar energy in 2007 were 250% higher than FIT payments under the Conto Energia program, in 2013, they were a mere 0.9%.

It can be argued that, had Italian policy makers opted for a more balanced approach to increase public RD&D expenditures in parallel with a less ambitious and generous FIT program, Italian PV cell and module manufacturers might have been more resilient in the face of foreign competition. This might have been the case

---

[100] Broken down data for RD&D expenditures in solar photovoltaics is only available until 2009.

particularly if increased public RD&D budgets had supported public-private partnerships with the Italian PV industry, and expressly to develop automated and innovative production processes of solar PV cells and modules. The project *AMPERE*, for example, funded by the European Commission's Framework Research Programme, now sees the participation of the Italian module manufacturer 3SUN with public research labs to develop and operate an innovative production process of high-efficiency, bifacial heterojunction PV modules (ENEA, 2018). However, this project was not launched until 2017, and the extreme degree of "foreign footprint" on PV cells and modules installed under the Conto Energia program (Table 7.1) could have at least been prevented by earlier action on this front.

The case for drawing a balance between market pull and technology push incentive frameworks in order to better align clean-energy policies with industrial policies becomes even more compelling if one considers the impacts of innovation spillovers. In Germany, the debate on the domestic FIT program has also touched upon the issue of whether this market pull scheme had positive impacts in terms of boosting domestic innovative capacity, as measured by innovation outputs like patents. Peters et al. point that while Germany was "founding the learning curve of the world" (Peters et al, 2012: 1296), China and other Asian producers were able to capture increasing shares of the global PV cell and module demand. IEA's analysis (IEA, 2015) shows a strong correlation between exports and patents in the Chinese PV sector, meaning that Chinese manufacturers were able to intercept foreign demand for PV modules while, simultaneously, building up their innovation capacity.

The broad question that warrants discussion is whether and to what extent policymakers should subsidize technologies when policies are likely to cause innovation spillovers. Evidence from Germany and Italy shows that strong market-pull incentives do not necessarily result per se in improvements in innovative capacity and competitiveness of domestic industries. A possible reason for this "policy failure" is the absence of an integrated policy framework. Hence, while supporting clean-energy deployment and at the same time fostering a viable and innovative domestic industry may be possible, to do so would require, on the part of policymakers, a more holistic vision and more strategic planning.

# REFERENCES

Alesina, A., & Giavazzi, F. (2013). *Troppe Illusioni sull'Innovazione.* Retrieved from Corriere della Sera: 05/09/2013 http://www.corriere.it/editoriali/13_febbraio_03/troppe-illusioni-su-innovazione-alberto-alesina-francesco-giavazzi_0b6216f4-6dd1-11e2-ad59-736471fe2e30.shtml

Althesys Strategic Consultants. (2014). *Irex Annual Report 2014. Il consolidamento del settore italiano delle rinnovabili tra internazionalizzazione e trasformazione del sistema elettrico. Executive Summary.* Milan, Italy: Althesys.

Alvarez, G., Merion Jara, R., & Rallo Julian, J. (2009). *Study of the Effects on Employment of Public Aid to Renewable Energy Sources.* King Juan Carlos University. March 2009.

Arora, V. (2013). *An Evaluation of Macroeconomic Models for Use at EIA.* U.S. Energy Information Administration, Working Paper.

Arrow, K. (1962). The economic impliations of learning by doing. *Review of Economic Studies*, (29): 155-173.

Autorità per l'energia elettrica il gas e il sistema idrico (ARERA). (2017). *Relazione annuale sullo stato dei servizi e sull'attività svolta.* Rome: ARERA. Available at https://www.arera.it/it/relaz_ann/17/17.htm.

Barbarella, A., Liberatore, P., & Galli, G. (2009). *Indagine sull'Impatto delle Politiche di Mitigazione dei Cambiamenti Climatici sul Sistema Produttivo e sull'Occupazione in Italia.* Rome, Italy: Consiglio Nazionale dell'Economia e del Lavoro.

Barbose, G., Darghouth, N., Weaver, S., & Wiser, R. (2013). *Tracking the Sun VI - An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998 to 2012.* Available at http://emp.lbl.gov/publications/tracking-sun-vi-historical-summary-installed-price-photovoltaics-united-states-1998-201: Lawrence Berkeley National Laboratory.

Barnham, K., Knorr, K., & Mazzer, M. (2013). Benefits of photovoltaic power in supplying national electricity demand. *Energy Policy*, (54): 385-390.

Beccarelllo, M. (2011). Valutazione degli impatti socio-economici delle politiche per l'efficienza energetica. *L'Industria*, 223-243.

Bellini, E. (2017, November 10). *Four takeaways on Italian PV from Key Solar Event.* Retrieved from PV-Magazine: https://www.pv-magazine.com/2017/11/10/four-key-takeaways-on-italian-pv-from-key-solar-event/

Bhandari, R., & Stadler, I. (2009). Grid parity analysis of solar photovoltaics systems in Germany using experience curves. *Solar Energy*, 83: 1634-1644.

Bosetti, V., Carraro, C., Duval, R., Sgobbi, A., & Tavoni, M. (2009). *The Role of R&D and Technology Diffusion in Climate Change Mitigation: New Perspectives Using the Witch Model.* Fondazione ENI Enrico Mattei (FEEM): http://www.feem.it/Feem/Pub/Publications/WPapers/default.htm.

Breitschopf, B., Nathani, C., & Resch, G. (2011). *Overview of impact assessment approaches; Interim report for the IEA in the framework of "Economic and Industrial Development" - EID* - . October 2011: EMPLOY Project.

Breitschopf, B., Nathani, C., & Resch, G. (2013). *Methodological guidelines for estimating the employment impacts of using renewable energies for electricity generation.* Fraunhoder ISI, Rutter+Partner, Energy Economics Group: http://iea-retd.org/wp-content/uploads/2012/07/RETD-2012_Ecomod_final_Barbara.pdf.

Breitschopf, B., Nathani, C., & Resch, G. (2013). *Methodological guidelines for estimating the employment impacts of using renewable energies for electricity generation.* http:: Fraunhoder ISI, Rutter + Partner, Energy Economics Group.

Burfisher, M. E. (2011). *Introduction to Computable General Equilbrium Models.* New York: Cambridge University Press.

Byrne, J., & Kurdgelashvili, L. (2011). The Role of Policy in PV Industry Growth: Past, Present, and Future. In A. Luque, & S. Hegedus, *Handbook of Photovoltaic Science and Engineering, Second Edition* (pp. 39-81). John Wiley & Sons.

Cai, M., Cusumano, N., Lorenzoni, A., & Pontoni, F. (2016). *A comprehensive ex-post assessment of the Italian RES policy: deployment, jobs, value added and import leakages.* Milan, Italy.: IEFE (Istituto di Economia delle Fonti di Energia).

Cameron, L., & van der Zwaan, B. (2015). Employment factors for wind and solar technologies: A literature review. *Renewable and Sustainable Energy Reviews*, 160-72.

Candelise, C., Winskel, M., & Gross, R. (2013). the dynamics of solar PV costs and prices as a challenge for technology forecasting. *Renewable and Sustainable Energy Reviews*, 26: 96-107.

Castello, S., De Lillo, A., & Guastella, S. (2003). *National Survery Report on PV Power Applications in Italy 2002.* International Energy Agency Photovoltaic Power Systems Programme: http://www.iea-pvps.org/?id=93.

Castello, S., De Lillo, A., & Guastella, S. (2004). *National Survey Report on PV Power Applications in Italy 2003.* International Energy Agency Photovoltaic Power Systems Programme: http://www.iea-pvps.org/?id=93.

Castello, S., De Lillo, A., & Guastella, S. (2007). *National Survey Report on PV Power Applications in Italy 2006.* International Energy Agency Photovoltaic Power Systems Programme: http://www.iea-pvps.org/?id=93.

Castello, S., De Lillo, A., Guastella, S., & Paletta, F. (2008). *National Survey Report on PV Power Applications in Italy 2007.* International Energy Agency Co-Operative Programme on Photovoltaic Power Systems: http://www.iea-pvps.org/?id=93.

Castello, S., De Lillo, A., Guastella, S., & Paletta, F. (2009). *National Survey Report of PV Power Applications in Italy 2008.* International Energy Agency Co-Operative Programme on Photovoltaic Power Systems: http://www.iea-pvps.org/?id=93.

Castello, S., De Lillo, A., Guastella, S., & Paletta, F. (2010). *National Survey Report of PV Power Applications in Italy 2009.* International Energy Agency Co-Operative Programme on Photovoltaic Power Systems: http://www.iea-pvps.org/?id=93.

Castello, S., De Lillo, A., Guastella, S., & Paletta, F. (2012). *National Survey Report of PV Power Applications in Italy 2011.* International Energy Agency Co-Operative Programme on Photovoltaic Power Systems: http://www.iea-pvps.org/?id=93.

Castello, S., De Lillo, A., Guastella, S., & Paletta, F. (2013). *National Survey Report of PV Power Applications in Italy 2012.* International Energy Agency Co-Operative Programme on Photovoltaic Power Systems: http://www.iea-pvps.org/?id=93.

Castello, S., Tilli, F., & Guastella, S. (2014). *National Survey Report of PV Power Applications In Italy 2013.* International Energy Agency Photovoltaic Power Systems Programme: http://www.iea-pvps.org/?id=93.

Castello, S., Tilli, F., & Guastella, S. (2015). *National Survey Report of PV Power Applications in Italy 2014.* http://www.iea-pvps.org/?id=93: International Energy Agency Photovoltaic Power Systems Programme.

Ciorba, U., Pauli, F., & Menna, P. (2004). Technical and economical analysis of an induced demand in the photovoltaic sector. *Energy Policy,* 32: 949-960.

Codegoni, A. (2014, July 1). *FV, quando e come si possono sfruttare i certificati bianchi.* Retrieved September 14, 2014, from Qualenergia.it: http://www.qualenergia.it/articoli/20140630-fotovoltaico-quando-e-come-si-possono-sfruttare-i-certificati-bianchi

Crooks, E., & Samson, A. (2017). GE cuts 12,000 jobs in power equipment division . *Financial Times,* December 7, 2017: https://www.ft.com/content/02f11fd8-db59-11e7-a039-c64b1c09b482.

Daly, H., & Cobb, J. (1989). *For the Common Good.* Boston: Beacon Press.

Diamandis, P. (2014). *Solar Energy Revolution: A Massive Opportunity.* Retrieved November 2, 2014, from Forbes: http://www.forbes.com/sites/peterdiamandis/2014/09/02/solar-energy-revolution-a-massive-opportunity/

Dijkgraaf, E., van Dorp, T., & Maasland, E. (2018). On the Effectiveness of Feed-in Tariffs in the Development of Solar Photovoltaics. *The Energy Journal,* 81-99.

D'Orazio, A. (2009). *Prospettive di Sviluppo delle Energie Rinnovabili per La Produzione di Energia Elettrica. Opportunità per il Sistema Industriale Nazionale.* Milan, Italy.: IEFE.

ENEA. (2017, March 30). *Fotovoltaico, al via progetto da 14 milioni per filiera industriale in Italia* . Retrieved from http://www.enea.it/it/Stampa/news/energia-fotovoltaico-al-via-progetto-da-14-milioni-per-filiera-industriale-in-italia

ENEA. (2017). *Rapporto Annuale sull'Efficienza Energetica 2017.* http://www.enea.it/it/seguici/pubblicazioni/pdf-volumi/raee-2017.pdf.

EPIA - European Photovoltaic Industry Association. (2011). *Solar Photovoltaic. On the road to competitiveness.* Available at http://www.epia.org/news/publications/.

EUFORES. (2018, March 22). *Monitoring & Modelling Initiative on the Targets for Renewable Energy.* Retrieved from http://www.eufores.org/index.php?id=39

Feldman, D. e. (2005). *Photovoltaic System Pricing Trends.* https://www.nrel.gov/docs/fy15osti/64898.pdf. US Department of Energy.

Ferioli, F., Schoots, K., & van der Zwaan, B. (2009). Use and limitations of learning curves for energy technology policy: A component-learning hypothesis. *Energy Policy*, 2525-2535.

Ferrazza, F., De Lillo, A., & Farinelli, U. (2002). The Italian PV R&D Programme: Status and Perspectives. *Photovoltaic Specialists Conference, 2002. Conference Record of the Twenty-Ninth IEEE.* DOI: 10.1109/PVSC.2002.1190446.

Frondel, M., Ritter, N., Schmidt, C., & Vance, C. (2010). Economic impacts from the promotion of renewable energy technologies: the German experience. *Energy Policy*, 38: 4048-4056.

Giannuzzi, G., Valori, L., & Basosi, R. (2013). *Lo Chiamavano il Paese del Sole.* Roma, Italy: Aracne Editrice.

Greenpeace International; Global Wind Energy Council; SolarPowerEurope . (2015). *Energy [R]evolution. A Sustainable World Energy Outlook.* https://www.greenpeace.org/archive-international/en/publications/Campaign-reports/Climate-Reports/Energy-Revolution-2015/.

Grubler, A. (2010). The costs of the French nuclear scale-up: A case of negative learning by doing. *Energy Policy*, 38(9): 5174-5188.

GSE (Gestore dei Servizi Energetici). (2009). *Il Solare. Dati Statistici al 31 dicembre 2008.* Retrieved from Rapporti Statistici: http://www.gse.it/it/Statistiche/RapportiStatistici/Pagine/default.aspx

GSE. (2010). *Rapporto Statistico 2009. Solare Fotovoltaico.* http://www.gse.it/it/Statistiche/RapportiStatistici/Pagine/default.aspx. Retrieved from Rapporti Statistici.

GSE. (2011). *Rapporto Statistico 2010. Solare Fotovoltaico.* http://www.gse.it/it/Statistiche/RapportiStatistici/Pagine/default.aspx. Retrieved from Rapporti Statistici.

GSE. (2012). *Rapporto Statistico 2011. Solare Fotovoltaico.* GSE: http://www.gse.it/it/Statistiche/RapportiStatistici/Pagine/default.aspx. Retrieved from Rapporti Statistici.

GSE. (2013). *Rapporto Statistico 2012. Solare Fotovoltaico.* http://www.gse.it/it/Statistiche/RapportiStatistici/Pagine/default.aspx.

GSE. (2014). *Rapporto Statistico 2013. Solare Fotovoltaico.* GSE: http://www.gse.it/it/Statistiche/RapportiStatistici/Pagine/default.aspx.

GSE. (2014a). *Data and Financial Statements.* Retrieved May 25, 2013, from GSE: http://www.gse.it/en/dataandfinancialstatement/Pages/default.aspx

GSE. (2014b). *Fotovoltaico.* Retrieved January 26, 2014, from GSE: http://www.gse.it/it/Conto%20Energia/Fotovoltaico/QuintoContoEnergia/Fotovoltaico/Pagine/default.aspx

GSE. (2014b). *Risultati Incentivazione.* Retrieved January 26, 2014, from GSE: http://www.gse.it/it/Conto%20Energia/Risultati%20incentivazione/Pages/default.aspx

GSE. (2015). *Rapporto Statistico 2014. Solare Fotovoltaico.* GSE: http://www.gse.it/it/Statistiche/RapportiStatistici/Pagine/default.aspx.

GSE. (2016a). *Rapporto Statistico 2015. Solare Fotovoltaico.* . GSE: http://www.gse.it/it/Statistiche/RapportiStatistici/Pagine/default.aspx.

GSE. (2016b, July 11). *La valutazione delle ricadute economiche e occupazionali dello sviluppo delle fonti energetiche rinnovabili in Italia.* Retrieved from https://www.gse.it/dati-e-scenari/studi-e-scenari

GSE. (2017a). *Rapporto 2016 delle attività del Gestore dei Servizi Energetici.* GSE: https://www.gse.it/dati-e-scenari/rapporti.

GSE. (2017b). *Rapporto Statistico 2016. Solare Fotovoltaico.* GSE: https://www.gse.it/dati-e-scenari/statistiche.

GSE. (2017c). *Scenari oneri lungo periodo Rapporto Annuale 2016.* GSE: personal communication.

Hall, R., & Liebermann, M. (2012). *Microeconomics: Principles and Applications.* Google Ebook.

Harmon, C. (2000). *Experiences Curves of Photovoltaic Technology.* Laxenburg, Austria: International Institute for Applied System Analysis. Interim Report IR-00-014.

Hertel, T. W. (1997). *Global Trade Analysis. Modeling and Applications.* Cambridge, UK: Cambridge University Press.

Hillebrand, B., Buttermann, H., Behringer, J., & Bluel, M. (2006). The expansion of renewable energies and the employment effects in Germany. *Energy Policy,* (34): 3484-3494.

Hudson, E., & Jorgenson, D. (1978). Energy Prices and the U.S. Economy, 1972-1976. *Natural Resources Journal*, vol. 18 (4): 877-97.

Hurtado Munoz, L., Huijben, J., Verhees, B., & Verbong, G. (2014). The power of grid parity: A discursive approach. *Technological Forecasting and Social Change*, Article in press, http://dx.doi.org/10.1016/j.techfore.2013.12.012.

Hutchinson, A. (2009, February 26). *Solar Panel Drops to $1 per Watt: Is this a Milestone or the Bottom for Silicon-Based Panels?* Retrieved February 3, 2014, from http://www.popularmechanics.com/science/energy/solar-wind/4306443

IEA (International Energy Agency). (2000). *Experience Curves for Energy Technology Policy, Parigi.* Paris: OECD/IEA.

IEA. (2012). *World Energy Outlook 2012.* Paris, France: OECD/IEA.

IEA. (2014a). *Capturing the Multiple Benefits of Energy Efficiency.* Paris: OECD/IEA.

IEA. (2014b). *Energy Technology Perspectives 2014.* http://www.iea.org/publications/freepublications/publication/EnergyTechnologyPerspectives2014.pdf.: IEA/OECD.

IEA. (2014c). *Technology Roadmap. Solar photovoltaic energy.* https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapSolarPhotovoltaicEnergy_2014edition.pdf.: IEA/OECD.

IEA. (2014d). *The Power of Transformation. Wind, Sun, and the Economics of Flexible Power Systems.* Paris, France: OECD/IEA.

IEA. (2015). *Energy Technology Perspectives 2015.* Paris, France: IEA/OECD.

IEA. (2017, 10 29). *Statistics*. Retrieved from http://www.iea.org/statistics/statisticssearch/

IEA. (2017a). *Energy Technology Perspectives 2017 - Catalysing Energy Systems Transformations.* Paris, France: IEA/OECD.

IEA. (2018, June 17). *RD&D Statistics - Energy Technology RD&D Budgets online data service.* Retrieved from http://www.iea.org/statistics/RDDonlinedataservice/

IEA and NEA (Nuclear Energy Agency). (2010). *Projecting costs of generating electricity.* Paris, France: OECD/IEA.

IEA-PVPS (International Energy Agency Photovoltaic Power Systems Programme). (2002). *Potential for Building Integrated Photovoltaics. Summary.* www.iea-pvps.org: Report IEA-PVPS T7-4 : 2002.

IEA-PVPS. (2006). *Trends in Photovoltaic Applications.* http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/tr_2005.pdf (accessed 19 April 2017): IEA-PVPS.

IEA-PVPS. (2013). *Trends 2013 in Photovoltaic Applications.* Available at www.iea-pvps.org: Report IEA-PVPS T1-23: 2013.

IEA-PVPS. (2016). *Trends 2016 in Photovoltaic Applications.* Report IEA PVPS T1-30: 2016. http://iea-pvps.org/fileadmin/dam/public/report/national/Trends_2016_-_mr.pdf.

IEA-PVPS. (2017a). *Annual Report 2016.* http://iea-pvps.org/index.php?id=6&eID=dam_frontend_push&docID=3951: IEA-PVPS.

IEA-PVPS. (2017b). *Trends in Photovoltaic Applications 2017.* www.iea-pvps.org.

IMF (International Monetary Fund). (2017, March 8). *World Economic Outlook 2016 Database.* Retrieved from https://www.imf.org/external/pubs/ft/weo/2016/02/weodata/index.aspx

ISE - Fraunhofer Institute for Solar Energy Systems. (2013). *Levelized Cost of Electricity Renewable Energy Technologies* . Freiburg, Germany.

Isoard, S., & Soria, A. (2001). Technical change dynamics; evidence from the emerging renewable energy technologies. *Energy Economics*, 23: 69-636.

ISTAT. (2014, 13 5). *Popolazione.* Retrieved from http://www.istat.it/it/popolazione

Istituto Nazionale di Statistica (ISTAT). (2013). *Il Sistema di Tavole Input-Output.* Retrieved from https://www.istat.it/it/archivio/108705. Accessed 17 April 2017.

Jacobs, D., & Sovacool, B. (2012). Feed-in tariffs and other support mechanisms for solar PV promotion. *Compr. Renew. Energy*, 385-401.

Jager-Waldau, A. (2016). *PV Status Report 2016.* EUR 28159 EN: European Commission, Joint Research Centre.

Joint Research Centre. (2014, May 14). *Solar resource data and tools for an assessment of photovoltaic systems.* Retrieved from http://re.jrc.ec.europa.eu/pvgis/solrad/index.htm

JRC (Joint Research Centre). (n.d.). *Photovoltaic Geographical Information System*. Retrieved March 21, 2014, from JRC's Institute for Energy and Transport: http://re.jrc.ec.europa.eu/pvgis/

Lantz, E., & Tegen, S. (2009). *NREL Responses to the Report 'Study of the Effects on Employment of Public Aid to Renewable Energy Sources' from King Juan Carlos University (Spain).* National Renewable Energy Laboratory. NREL/TP-6A2-46261: https://www.nrel.gov/docs/fy09osti/46261.pdf.

Lehr, U., & Ulrich, P. (2017). Economic Impacts of Renewable Energy Increase in Germany. In T. (. Uyar, *Towards 100% Renewable Energy* (pp. 263-272). Springer International Publishing Switzerland .

Lehr, U., Lutz, C., & Edler, D. (2012). Green Jobs? Economic Impacts of Renewable Energy in Germany. *Energy Policy*, 47: 358-364.

Lehr, U., Nitsh, J., Kratzat, M., Lutz, C., & Edler, D. (2008). Renewable energy and employment in Germany. *Energy Policy*, 36: 108-117.

Linares, P., & Labandeira, X. (2010 ). Energy efficiency: economics and policy. *Journal of Economic Surveis*, (24): 573-592.

Marchetti, C., & Nakicenovic, N. (1979). *The dynamics of energy sstems and the logistic substitution model.* Vienna: IIASA.

Mauleón, I. (2016). Photovoltaic learning rate estimation: Issues and implications. *Renewable and Sustainable Energy Reviews*, (65): 507-524.

Maycock, P. (2002). *The World Photovoltaic Market.* Warrenton, VA: PV Energy Systems, Inc.

Miller, R., & Blair, P. (2009). *Input Output Analysis. Foundations and Extensions.* New York: Cambridge University Press.

Miller, R., Polenske, K., & Rose, A. (1989). *Frontiers of Input-output analysis.* New York, NY: Oxford University Press.

Ministero dello Sviluppo Economico (MSE). (2017). *Strategia Energetica Nazionale.* http://www.sviluppoeconomico.gov.it/images/stories/documenti/testo_della_StrategiaEnergeticaNazionale_2017.pdf.

Mints, P. (2012, November 20). *The Solar PV Ecosystem, A Brief History and a Look Ahead.* Retrieved from Renewable Energy World: http://www.renewableenergyworld.com/rea/news/article/2012/11/the-solar-pv-ecosystem-a-brief-history-and-a-look-ahead

Mission Innovation. (2017, March 22). Retrieved from About Mission Innovation: http://mission-innovation.net/about/

Mission Innovation. (2017). Retrieved from Baseline and Doubling Plans 22 October 2017: http://mission-innovation.net/participating-countries/italy/

MSE (Ministero dello Sviluppo Economico). (2017, March 1). Retrieved from Strategia Energetica Nazionale 2017. Audizione Parlamentare: http://www.sviluppoeconomico.gov.it/images/stories/documenti/SEN_Audizione_Parlamentare_1marzo2017.pdf

Nakicenovic, N., Grubler, A., & McDonald, a. A. (1998). *Global Energy Perspectives.* Cambridge, United Kingdom: Cambridge University Press.

National Renewable Energy Laboratory (NREL). (2015). *JEDI: Jobs and Economic Development Impact Model (Factsheet).* NREL/FS-5000-64129. NREL, Golden, CO (US).

Nauclér, T., & Enkvist, P. (2009). *Pathways to a Low-Carbon Economy - Version 2 of the Global Greenhouse Gas Abatement Cost Curve.* New York: McKinsey & Company.

Neij, L. (2008). Cost development of future technologies for power generation—A study. *Energy Policy*, 36: 2200-2211.

Nicholson, W. (1998). *Microeconomic Theory. Basic Principles and Extensions.* Orlando, FL: Hartcourt College Publishers.

NREL - National Renewable Energy Laboratory. (2014, 5 13). *How to Change Parameters in Legacy Calculators.* Retrieved from http://www.nrel.gov/rredc/pvwatts/changing_parameters.html

NREL. (2018, April 1). *JEDI Publications.* Retrieved from https://www.nrel.gov/analysis/jedi/publications.html

Olivier, D., Miall, H., Nectoux, F., & Opperman, M. (1983). *Energy-efficient Futures: Opening the Solar Option.* London: Blackrose Press.

Paidipati, J., Frantzis, L., Sawyer, H., & Kurrasc, A. (2008, February). *Rooftop Photovoltaics Market Penetration Scenarios.* Golden, Colorado: National Renewable Energy Laboratory. Retrieved from http://www.nrel.gov/docs/fy08osti/42306.pdf

Peters, M., Schneider, M., Griesshaber, T., & Hoffmann, V. (2012). The impact of technology-push and demand-pull policies on technical change - Does the locus of policies matter? *Research Policy*, 41: 1296-1308.

Peterson, E. B., Schleich, J., & Duscha, V. (2011). Environmental and economic effects of the Copenaghen pledges and more ambitious emission reduction targets. *Energy Policy*, 3697-3708.

Photon. (2014, January 24). *Photon Newsletter.* Retrieved February 2, 2014, from http://www.photon.info/newsletter/document/83758.pdf

Polenske, K., & Skolka, J. (1976). *Advances in Input-output analysis.* Cambridge, MA: HarperCollins Distribution Services .

Politecnico di Milano. (2009). *Solar Energy Report. Edizione 2008.* Milano, Italy: Politecnico di Milano.

Politecnico di Milano. (2010). *Solar Energy Report. Edizione 2009.* Milano, Italy: Politecnico di Milano. Energy & Strategy Group.

Politecnico di Milano. (2011). *Solar Energy Report. Aprile 2011.* Milano, Italy: Politecnico di Milano. Energy & Strategy Group.

Politecnico di Milano. (2012). *Solar Energy Report. Aprile 2012.* Milano, Italy: Politecnico di Milano. Energy & Strategy Group.

Politecnico di Milano. (2013). *Solar Energy Report. Aprile 2013.* Milano, Italy.: Politecnico di Milano. Energy & Strategy Group.

Politecnico di Milano. (2014). *Solar Energy Report. Aprile 2014.* Milano, Italy: Politecnico di Milano. Energy & Strategy Group.

Politecnico di Milano. (2015). *Renewable Energy Report 2014.* www.energystrategy.it: Energy & Strategy Group.

Politecnico di Milano. (2016). *Renewable Energy Report.* http://: Energy & Strategy Group.

Poponi, D. (2003). Analysis of diffusion pathsfor photovoltaic technology based on experience curves. *Solar Energy,* (74): 331-340.

Poponi, D., & Byrne, J. &. (2005). Breakeven Price Estimates for Residential PV Applications in OECD Countries with an Analysis of Prospective Cost Reductions . *Energy Studies Review*, 14 (1): 104-117.

Qualenergia. (2014). *Ecobonus e capacity payment. Il testo della legge di Stabilita'.* Retrieved January 21, 2014, from http://qualenergia.it/articoli/20140102-ecobonus-e-capacity-payment-il-testo-della-legge-di-stabilit%C3%A0-vigore-da-ieri

Qualenergia.it. (2015a, November 17). *Sistemi di Distribuzione Chiusi, RIU e Reti Private, Nuove Regole dall'Autorità.* Retrieved from Qualenergia.it: http://www.qualenergia.it/articoli/20151117-sistemi-di-distribuzione-chisu-riu-e-reti-private-nuove-regole-dall-aeegsi

Qualenergia.it. (2017a, June 30). *Fotovoltaico in Market Parity: Il Caso dei 63 MW a Montalto di Castro.* Retrieved from http://www.qualenergia.it/articoli/20170630-fotovoltaico-market-parity-il-caso-dei-63-mw-montalto-di-castro

R.W. Beck. (2009). *Distributed Renewable Energy Operating Impacts and Valuation Study.* Arizona Public Service.

Ragwitz, M., Schade, W., Breitschpf, B., Walz, R., Helfrich, N., Rathman, M., . . . Konstantinaviciute, I. (2009). *The impact of renewable energy policy on economic growth and employment in teh European Union.* Published for the European Commission DG Energy and Transport.

Rao, K., & Kishore, V. (2010). A review of technology diffusion models with special reference to renewable energy technologies. *Renewable and Sustainable Energy Reviews*, 14: 1070-1078.

Redazione di Qualenergia. (2013, April 18). *Quei 50 miliardi che le rinnovabili farebbero guadagnare all'Italia*. Retrieved September 2, 2014, from Qualenergia.it: http://www.qualenergia.it/articoli/20130418-quei-50-miliardi-che-le-rinnovabili-farebbero-guadagnare-a-italia

Redazione di Qualenergia.it. (2017a, November 15). *Obiettivo fotovoltaico nella SEN, le proposte di Italia Solare.* Retrieved from Qualenergia.it: http://www.qualenergia.it/articoli/20171115-obiettivo-fotovoltaico-nella-sen-le-proposte-di-italia-solare

REMI. (2018, March 22). *Models.* Retrieved from http://www.remi.com/models/

Rizzani Associati. (n.d.). *Realizzazione impianto fotovoltaico S.B.E. di Monfalcone*. Retrieved March 26, 2014, from http://www.rizzani.it/Progetti/Industriale/2006-Impianto-fotovoltaico-S.B.E.-Spa

Rogers, E. (2003). *Diffusion of Innovations.* New York, NY: Free Press.

Romer, D. (2012). *Advanced Macroeconomics.* New York, NY: McGraw Hill.

Rutovitz, J., & Atherton, A. (2009). *Energy sector jobs to 2030: a global analysis.* Sydney: Institute for Sustainable Futures.

Rutovitz, J., Dominish, E., & and Downes, J. (2015). *Calculating global energy sector jobs: 2015 methodology*. Prepared for Greenpeace International by the Institute for Sustainable Futures, University of Technology Sydney: https://opus.lib.uts.edu.au/bitstream/10453/43718/1/Rutovitzetal2015Calculatingglobalenergysectorjobsmethodology.pdf.

Sagar, A. D., & van der Zwaan, B. (2006). Technological innovation in the energy sector: R&D, deployment, and learning-by-doing. *Energy Policy,* 2601-2608.

SEII. (2010). *Solar Europe Industry Initiative Implementation Plan 2010-2012.* Retrieved from <http://ec.europa.eu/energy/technology/initiatives/ on May 6, 2014.

Shum, K., & Watanabe, C. (2008). Towards a local learning (innovation) model of solar photovoltaic deployment. *Energy Policy*, 36(2): 508-521.

Silvestrini, G. (2014, July 25). *Quel timore di una tumultuosa crescita del fotovoltaico.* Retrieved August 26, 2014, from Qualenergia.it: http://www.qualenergia.it/articoli/20140725-quel-timore-di-una-tumultuosa-crescita-del-fotovoltaico

Solow, R. (1957). Technical change and the aggregate production function. *Review of Economics and Statistics*, 39: 312-320.

Terna. (2017, August 19). *Dati Statistici.* Retrieved from https://www.terna.it/it-it/sistemaelettrico/statisticheeprevisioni/datistatistici.aspx

Terna. (2017). *Scenari della Domanda Elettrica in Italia 2016-2026.* Terna: http://download.terna.it/terna/0000/0925/46.PDF.

Terna. (2018, March 3). *Dati Statistici - Produzione 2016.* Retrieved from http://www.terna.it/it-it/sistemaelettrico/statisticheeprevisioni/datistatistici.aspx

The Economist. (2018, February 3). A new type of solar cell is coming to market. *https://www.economist.com/news/science-and-technology/21736122-perovskites-have-potential-outshine-silicon-solar-panels-new-type*.

Tilli, F., Guastella, S., & Castello, S. (2016). *National Survey Report of PV Power Applications in Italy 2015.* Intenrational Energy Agency Photovoltaic Power Systems Programme: http://www.iea-pvps.org/?id=93.

Tilli, F., Maugeri, G., & Castello, S. (2017). *National Survey of PV Power Applications in Italy 2016.* International Energy Agency Photovoltaic Power Systems Programme: http://www.iea-pvps.org/?id=93.

Trappey, A., Trappey, C., Tan, H., Liu, P., Li, S., & Lin, L. (2016). The determinants of photovoltaic system costs: an evaluation using a hierarchical learning curve model. *Journal of Cleaner Production*, 1709-1716.

Van der Zwaan, B., & Rabl, A. (2003). Prospects for PV: A Learning Curve Analysis. *Solar Energy*, 74: 19-31.

Walmsley, T., Aguiar, A., & Narayanan, B. (2012). *Introduction to the Global Trade Analysis Project and GTAP Data Base.* Center for Global Trade Analysis, Purdue University.

Weisbrod, G., & Weisbrod, B. (1997). *Measuring Economic Impacts of Projects and Programs.* http://www.edrgroup.com/images/stories/Transportation/econ-impact-primer.pdf (accessed 18 April 2017): Economic Development Research Group.

Williams, R., & Terzian, G. (1993). *A Benefit/Cost Analysis of Accelerated Deployment of Photovoltaic Technology*. PU/CEES Report No. 281. Center for Energy and Environmental Studies, Princenton University.

Yang, C. (2010). Reconsidering solar grid parity. *Energy Policy*, 38: 3270-3273.

Zuccaro, C. (2013, July 14). *Personal Communication*. Rome, Italy.

## Appendix A

# METHODOLOGY FOR ESTIMATING CAPITAL-GRANT EQUIVALENT VALUES OF FEED-IN TARIFF PAYMENTS IN CONTO ENERGIA PROGRAM

The capital-grant equivalent of feed-in tariffs (FITs) paid for photovoltaic (PV) capacity installed under the Conto Energia program in a given year *t* (from 2006 to 2016) is calculated by discounting (with a [nominal] social discount rate of 5%) the twenty-year flow of FIT payments accruing to the owners of PV systems. For the sake of calculating the capital-grant equivalent of FIT payments, it is necessary to breakdown annual FIT payments by PV capacity installed in each of the eleven years of the program’s validity. The methodological "hurdle" stands in the fact that data on annual FIT payments is only reported according to each Conto Energia implementation phase or *scheme* (cf. ch. II, § 2.5), but there is no further breakdown of data on FIT payments per year of PV capacity installed (GSE, 2017a). For example, annual FIT payments in 2016 for PV capacity installed under the second scheme (6,840 MW between 2007 and 2010) totaled EUR 2.94 billion (see Table A.1), but the data reported do not specify what part of these payments were for PV capacity installed under the second scheme in 2007 or 2008.

The estimation of capital-grant equivalent values is not a straightforward exercise, since during six of the eleven years of the program’s validity (2007, 2008, 2009, 2011, 2012, 2013), the total PV capacity installed was the result of installations that actually took place under different schemes of the Conto Energia program (see

Table A.2). In 2011, for example, 3.6 GW of PV systems were installed under three different schemes (the second, third, and fourth, respectively).

Table A.1 Annual FIT Payments (M Eur) for PV Systems Installed, Broken Down by Conto Energia Scheme, 2006-2016

| Year | First Conto-Energia scheme (M Eur) | Second Conto-Energia scheme (M Eur) | Third Conto-Energia scheme (M Eur) | Fourth Conto-Energia scheme (M Eur) | Fifth Conto-Energia scheme (M Eur) | TOTAL (M Eur) |
|---|---|---|---|---|---|---|
| 2006 | 1 | - | - | - | - | 1 |
| 2007 | 17 | 1 | - | - | - | 18 |
| 2008 | 55 | 34 | - | - | - | 89 |
| 2009 | 97 | 208 | - | - | - | 305 |
| 2010 | 99 | 639 | - | - | - | 738 |
| 2011 | 107 | 2,915 | 438 | 332 | - | 3,792 |
| 2012 | 106 | 3,394 | 669 | 1,916 | 4 | 6,089 |
| 2013 | 95 | 3,220 | 637 | 2,389 | 167 | 6,508 |
| 2014 | 92 | 3,156 | 626 | 2,388 | 226 | 6,488 |
| 2015 | 87 | 3,033 | 597 | 2,296 | 223 | 6,236 |
| 2016 | 89 | 2,940 | 569 | 2,213 | 207 | 6,018 |

Data source: GSE, 2017a

Table A.2 Annual PV Installations by Conto Energia Scheme and Year (MW)

| Year | First Conto-Energia scheme (MW) | Second Conto-Energia scheme (MW) | Third Conto-Energia scheme (MW) | Fourth Conto-Energia scheme (MW) | Fifth Conto-Energia scheme (MW) | TOTAL (MW) |
|---|---|---|---|---|---|---|
| 2006 | 9 | - | - | - | - | 9 |
| 2007 | 52 | 18 | - | - | - | 70 |
| 2008 | 65 | 273 | - | - | - | 338 |
| 2009 | 38 | 681 | - | - | - | 718 |
| 2010 | - | 2,321 | - | - | - | 2,321 |
| 2011 | - | 3,546 | 1,555 | 4,375 | - | 9,475 |
| 2012 | - | - | - | 3,082 | 498 | 3,580 |
| 2013 | - | - | - | 316 | 787 | 1,103 |
| 2014 | - | - | - | - | 92 | 92 |
| 2015 | - | - | - | - | 7 | 7 |
| 2016 | - | - | - | - | 20 | 20 |
| TOTAL | 163 | 6,840 | 1,555 | 7,772 | 1,404 | 17,734 |

Data source: GSE, 2017a

The methodology used to estimate the capital-grant equivalent of FIT payments for PV capacity installed annually between 2006 and 2016 consists of eight steps. The first four of these eight steps apply to so-called *capacity cohorts*, namely PV capacity installed under each of the five schemes per year of installation (for a total of n. 18 cohorts, which correspond to the values in the first five columns of Table A.2). These eight steps consist of estimating:

(1) the normalized *full-hour equivalent value* of PV capacity installed from $t_1$ (the year in which a capacity cohort is installed) to $t_{20}$ (the last year of its incentivization). For example, the 18 MW of PV capacity installed in year 2007 under the second Conto Energia scheme (capacity cohort n. 5) are estimated to have a normalized full-hour equivalent value lower than "1" in that same year 2007, to account for the obvious fact that PV installations physically take place gradually, over the course of the year, so their capacity factor is lower than what would have been achieved had capacity been fully operational from January 1st. The same capacity cohort n. 5 has a normalized full-hour equivalent of 1 in 2008, etc. A correction factor is then applied after year ten of operations to account for a 0.5% output decay;

(2) the amount of electricity generated by each capacity cohort from $t_1$ to $t_{20}$, based on the aforementioned full-hour equivalent values. For example, capacity cohort no. 5 is estimated to generate 22 GWh in 2007 and 19 GWh in 2026;

(3) the share of electricity generated by each capacity cohort on total electricity generated by PV systems installed under a specific Conto Energia scheme from year $t_1$ to year $t_{20}$. For example, the electricity generated by the 18 MW of capacity cohort no. 5 in 2010 is estimated to be about 1.5% of total electricity generated by all five cohorts of the second Conto Energia scheme that same year;

(4) the incentives paid to each capacity cohort from year $t_1$ to year $t_{20}$ based on the shares of electricity generated estimated in (3). FIT payments from 2006 to 2016 are reported by GSE (2017a) and those from 2017 to 2019 were estimated by the author, while data on projected FIT payments from 2020 to

2038 were provided by GSE (2017c) and already incorporate the effects of the retroactive measures introduced in 2014;

(5) the breakdown of annual FIT payments (reported in the last column of Table A.2) by capacity per “year of installation” from 2006 to 2036, based on (4). For example, FIT payments in 2016 for PV capacity installed in 2007 (under the first and second Conto Energia schemes) were estimated at about EUR 36 million;

(6) the total cumulative cost of FIT incentives for annual PV capacity installed from 2006 to 2016 (for a total of eleven data points). For example, the estimated cumulative cost of FIT payments for PV capacity installed in 2008 is about EUR 3.1 billion;

(7) the present value (using a nominal social discount rate of 5%) of cumulative FIT payments for annual PV capacity installed from 2006 to 2016 (for a total of eleven data points). For example, the estimated present value of FIT payments for PV capacity installed in 2008 is about EUR 2 billion;
the “capital-grant equivalent”, by dividing (7) by capacity installed in the same year (Table 4.3).

# Appendix B

## SCENARIO RESULTS

Table B.1 PV Market Projections in the Reference Scenario

| Year | CAGR % | Annual PV installations MW | Cumulative PV capacity MW | PV Electricity generated GWh |
|---|---|---|---|---|
| 2017 | 20% | 459 | 19,404 | 23,489 |
| 2018 | 25% | 574 | 19,978 | 24,121 |
| 2019 | 30% | 746 | 20,723 | 24,929 |
| 2020 | 35% | 1,007 | 21,730 | 26,003 |
| 2021 | 40% | 1,409 | 23,139 | 27,482 |
| 2022 | 35% | 1,903 | 25,042 | 29,511 |
| 2023 | 30% | 2,473 | 27,515 | 32,191 |
| 2024 | 25% | 3,092 | 30,607 | 35,600 |
| 2025 | 21% | 3,736 | 34,343 | 39,782 |
| 2026 | 17% | 4,358 | 38,701 | 44,740 |
| 2027 | 13% | 4,903 | 43,605 | 50,412 |
| 2028 | 8% | 5,312 | 48,916 | 56,669 |
| 2029 | 4% | 5,533 | 54,450 | 63,312 |
| 2030 | 0% | 5,533 | 59,983 | 70,090 |
| 2031 | 0% | 5,533 | 65,504 | 76,868 |
| 2032 | 0% | 5,533 | 70,967 | 83,632 |
| 2033 | 0% | 5,533 | 76,163 | 90,324 |
| 2034 | 0% | 5,533 | 80,973 | 96,689 |
| 2035 | 0% | 5,533 | 84,185 | 102,581 |

Source: Author's elaboration

Table B. 2 PV Market Projections in the Counterfactual Scenario

| Year | CAGR % | Annual PV installations MW | Cumulative PV capacity MW | PV Electricity generated GWh |
|---|---|---|---|---|
| 2010 | 10% | 796 | 1,964 | 1,919 |
| 2011 | 10% | 875 | 2,839 | 2,942 |
| 2012 | 10% | 963 | 3,802 | 4,068 |
| 2013 | 10% | 1,059 | 4,861 | 5,306 |
| 2014 | 10% | 1,165 | 6,026 | 6,669 |
| 2015 | 10% | 1,282 | 7,308 | 8,167 |
| 2016 | 10% | 1,410 | 8,717 | 9,816 |
| 2017 | 10% | 1,551 | 10,268 | 11,629 |
| 2018 | 10% | 1,706 | 11,974 | 13,623 |
| 2019 | 10% | 1,876 | 13,850 | 15,817 |
| 2020 | 15% | 2,158 | 16,008 | 18,288 |
| 2021 | 20% | 2,589 | 18,597 | 21,195 |
| 2022 | 18% | 3,050 | 21,647 | 24,649 |
| 2023 | 16% | 3,524 | 25,170 | 28,675 |
| 2024 | 13% | 3,994 | 29,164 | 33,280 |
| 2025 | 11% | 4,438 | 33,602 | 38,444 |
| 2026 | 9% | 4,832 | 38,434 | 44,122 |
| 2027 | 7% | 5,154 | 43,588 | 50,238 |
| 2028 | 4% | 5,383 | 48,971 | 56,692 |
| 2029 | 2% | 5,503 | 54,474 | 63,360 |
| 2030 | 0% | 5,503 | 59,977 | 70,101 |
| 2031 | 0% | 5,503 | 65,468 | 76,842 |
| 2032 | 0% | 5,503 | 70,900 | 83,568 |
| 2033 | 0% | 5,503 | 76,065 | 90,224 |
| 2034 | 0% | 5,503 | 80,845 | 96,551 |
| 2035 | 0% | 5,503 | 85,552 | 102,405 |

Source: Author’s elaboration

Table B.3 Projections on Soft Costs, Total PV System Prices, C&I Investments and O&M Expenditures in the Reference Scenario

| Year | Soft costs Eur(2016)/kW | PV system price Eur(2016)/kW | PV C&I Investments M Eur(2016) | PV O&M Expenditures M Eur(2016) |
|---|---|---|---|---|
| 2016 | 186 | 1385 | 530 | 860 |
| 2017 | 184 | 1308 | 600 | 854 |
| 2018 | 182 | 1241 | 712 | 868 |
| 2019 | 180 | 1182 | 882 | 889 |
| 2020 | 177 | 1128 | 1,136 | 918 |
| 2021 | 174 | 1081 | 1,523 | 970 |
| 2022 | 169 | 1038 | 1,975 | 1,041 |
| 2023 | 164 | 999 | 2,470 | 1,136 |
| 2024 | 158 | 962 | 2,973 | 1,256 |
| 2025 | 152 | 927 | 3,464 | 1,404 |
| 2026 | 146 | 896 | 3,904 | 1,579 |
| 2027 | 140 | 867 | 4,251 | 1,779 |
| 2028 | 135 | 840 | 4,464 | 2,000 |
| 2029 | 130 | 816 | 4,515 | 2,234 |
| 2030 | 126 | 793 | 4,391 | 2,473 |
| 2031 | 122 | 777 | 4,302 | 2,712 |
| 2032 | 119 | 763 | 4,222 | 2,951 |
| 2033 | 116 | 750 | 4,151 | 3,187 |
| 2034 | 114 | 739 | 4,087 | 3,412 |
| 2035 | 112 | 729 | 4,032 | 3,620 |

Source: Author’s elaboration

Table B. 4 Projections on Soft Costs, Total PV System Prices, C&I Investments, and O&M Expenditures in the Counterfactual Scenario

| Year | Soft costs Eur(2016)/kW | PV system price Eur(2016)/kW | PV C&I Investments M Eur(2016) | PV O&M Expenditures M Eur(2016) |
|---|---|---|---|---|
| 2009 | 926 | 4,094 | 2,962 | 76 |
| 2010 | 778 | 3,409 | 2,713 | 119 |
| 2011 | 687 | 2,560 | 2,240 | 146 |
| 2012 | 622 | 2,106 | 2,028 | 195 |
| 2013 | 573 | 1,831 | 1,939 | 255 |
| 2014 | 533 | 1,790 | 2,085 | 321 |
| 2015 | 499 | 1,732 | 2,220 | 333 |
| 2016 | 470 | 1,670 | 2,354 | 361 |
| 2017 | 445 | 1,569 | 2,433 | 423 |
| 2018 | 423 | 1,482 | 2,527 | 490 |
| 2019 | 402 | 1,405 | 2,635 | 564 |
| 2020 | 383 | 1,334 | 2,879 | 645 |
| 2021 | 364 | 1,272 | 3,293 | 748 |
| 2022 | 346 | 1,215 | 3,706 | 870 |
| 2023 | 329 | 1,164 | 4,102 | 1,012 |
| 2024 | 313 | 1,117 | 4,461 | 1,174 |
| 2025 | 299 | 1,074 | 4,765 | 1,357 |
| 2026 | 285 | 1,035 | 5,002 | 1,557 |
| 2027 | 273 | 1,000 | 5,155 | 1,773 |
| 2028 | 263 | 969 | 5,214 | 2,001 |
| 2029 | 254 | 940 | 5,170 | 2,236 |
| 2030 | 246 | 913 | 5,025 | 2,474 |
| 2031 | 238 | 894 | 4,918 | 2,712 |
| 2032 | 232 | 876 | 4,822 | 2,949 |
| 2033 | 227 | 861 | 4,736 | 3,184 |
| 2034 | 222 | 847 | 4,660 | 3,407 |
| 2035 | 218 | 834 | 4,591 | 3,614 |

Source: Author's elaboration

# Appendix C

## ASSUMPTIONS ON ENERGY-EFFICIENCY IMPACT ANALYSIS

Table C.1 Input Assumptions Used for Estimating EE Output Multiplier in the Counterfactual Scenario

| EE Measure | Increased demand(f')[a] Cum. 2010-2020 M Euros[2010] | Direct+Indirect Output (x') Cum. 2010-2020 M Euros[2010] | Output multiplier |
|---|---|---|---|
| Lighting | 3333 | 3405 | 1.02 |
| Heat pumps | 383 | 922 | 2.41 |
| Condensing boilers | 2448 | 6310 | 2.58 |
| Cum. 2010-2020 | 6164 | 10637 | 1.73 |

Note: (a) Values of increased final demand assumed by Beccarello (2011) that are different from values assumed in the counterfactual scenario

Data source: Beccarello, 2011

Table C.2 Assumptions Used to Calculate Employment Factor and Multiplier of Additional EE Investments in the Counterfactual Scenario

| EE Measure | Increased demand $f^i$ 2010-2020 M Euros[2010] | Direct Employment 2010-2020 FTE | Employment Coefficient FTE/M Euros | Indirect Employment 2010-2020 FTE | Total Employment 2010-2020 FTE | Employment multiplier FTE /M Euros |
|---|---|---|---|---|---|---|
| Lighting | 3333 | 18,000 | 5.40 | 38,000 | 56,000 | 16.80 |
| Heat pumps | 383 | 2,000 | 5.22 | 5,000 | 7,000 | 18.28 |
| Condensing boilers | 2448 | 12,000 | 4.90 | 27,000 | 39,000 | 15.93 |
| Total | 6164 | 32,000 | 5.19 | 70,000 | 102,000 | 16.55 |

Data source: Beccarello, 2011