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China and the future of the EU's Solar Tech Industry

CoSEM Master Thesis TU Delft

Energy Transition:

China and the future of the EU Solar Tech Industry

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Preface

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Dear reader,

This report presents the findings of my MSc Thesis. I have been working on the research for the last six months. The report can be interesting for people dealing with the field of solar energy.

Working with my thesis committee was sincerely enjoyable. I particularly thank Daniel Scholten for his support throughout the research, Ivo Bouwmans for the valuable advice and Rolf Kunneke for taking the role as first supervisor.

I also would like to thank my family and friends for their support during the entire process.

Elena Marabini

Abstract

With the 2019 European Green Deal, the EU has set an ambitious roadmap to enable European citizens to benefit from a Green Transition. One of the main goal of the Green Deal is the deployment of renewable energy sources. Within these, solar power has been identified as the fastest growing source. Within solar technologies, crystalline-silicon (c-Si) based account for a market share of 95%. Nevertheless, large-scale production of solar PVs encounters many challenges, due to the current solar industry design. Countries that aim at developing solar technology on a significant scale, have to face China's current market dominance. China is the largest producer, exporter, and installer of solar panels, on a worldwide scale.

The final goal of the research is to evaluate if and how could China impede the competitiveness or market expansion of Member States in the c-Si solar-tech industry. The main research question therefore is:

What is China's market dominance when compared to the European Union in the solar panels global industry?

The analysis is structured by following the application of a novel Analytical Framework that takes into account all the significant factors that are able to influence the solar market dynamics. From the application of Analytical Framework to the EU-China case-study emerges the Market Dominance Assessment, that analyses the actual market dominance of China, with respect to the European Union, in the commercialization of c-Si technologies.

Three are the main takeaways that can be drawn from the Market Dominance Assessment. Firstly, China, technically, controls over 80% of the worldwide c-Si solar market; each variable of the Analytical Framework confirms the predominance of Chinese companies along the global solar supply chain, creating a situation where European parties cannot have access to those resources that allowed China to reach its current status. Secondly, the European Union is dependent on imports of Chinese c-Si panels, at the point that 90% of the current PV installations in the European territory come from China and few other Asian countries; at the same time, the EU is China's number one trading partner. C-si panels trading, therefore, over years, created a situation of mutual dependency among the two market parties, where the EU is dependent of Chinese export rates, while China, to avoid over-supply, is dependent on European import rates. Thirdly, the best market strategy that Member States can apply is to accept and recognize the market dominance of China, and work to strengthen the domestic solar industry by tackling local weaknesses. As outlined in

the policy options, the European Union, on my advice, should work, in the first place, towards the implementation of a European electricity market.

In conclusion, the European Union, therefore, remains highly dependent on Chinese c-Si panels, and this dependency is expected to rise in the coming years, due to future European plans to foster solar energy. Anyhow, with the right policies and an adequate degree of investments in the solar industry, European countries will easily be able to reach the goals set in the European Green Deal.

Contents

List of Figures

List of Tables

List of Graphs

Abbrevations

EU	European Union
FYP	Five-Year-Plan
c-Si	Crystalline-silicon
PV(s)	Photovoltaic(s)
O&M	Operation and Maintenance
HHI	Herfindahl-Hirschman Index
RES	Renewable Energy Sources
CRMs	Critical Raw Materials
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
WTO	World Trade Organization
RRF	Recovery and Resilience Facility
EPO	European Patent Office
NECP	National Energy and Climate Plan

1 Introduction

The European Union aims at becoming the world's first climate-neutral continent by 2050 [1]. With the 2019 European Green Deal [2], the EU has set an ambitious roadmap to enable European citizens and businesses to benefit from a Green Transition.

Main goals of the Green Transition are: a considerable reduction in the dependency on fossil fuels; the lowering of GHG emissions; and the creation of jobs in the Green-Tech industry [2]. The growth of renewable energy sources, indeed, is expected to stimulate employment throughout the whole EU: implementing the Paris Agreement, in full worldwide, could create 18 million net additional jobs by 2030 due to changes in the production and use of energy [3]. In the EU, the Green Transition was expected to create 1.2 million additional jobs before the outbreak of COVID-19 [4].

In the EU, three are the main renewable energy sources that, during the period from 2009 to 2019, peaked as electricity generation sources. These are solar power, wind power and solid biofuels. Within these, solar power has been identified as the fastest growing source [5]. As of 2019, electricity generated from solar power reached 125.7 TWh, compared to just 7.4 TWh in 2008 [5].

Nevertheless, large-scale production of solar PVs does not come without challenges for the EU [6]. There are, in fact, many characteristics of the solar-tech supply chain that complicate the access to this industry [7]. These characteristics have a twofold socio-technical nature [7]. Social, since countries that aim at developing solar technology on a significant scale, have to face China's current market dominance [8]. Worldwide, out of the 25 main solar PV panels manufacturing companies, 12 are Chinese, and they make up for more than 50 [9]. And technical, since large-scale production of solar PV panels requires adequate clean-tech know-how and industrial resources [7].

A first characteristic of the solar PVs technology manufacturing chain is the usage of rare earth materials [10]. One single PV panel requires, on average, the use of 19 metals and mineral products [10]. Out of these, 8 metals face supply challenges, due to geopolitical risks and the low number of suppliers [10]. Rare earth materials, in addition, are not only used in the production of solar PV panels, but also in other forms of clean technologies [11]. Given the high demand and China's control for over 80 % of global supply [12], there exists a risk for European Countries to incur in the scarcity of these materials.

Secondly, rights to commercialise specific solar PVs for pre-established periods, are assigned with

patents [13]. Patents are therefore a key part of the solar tech supply chain [14]. In the last decade, patenting rates in clean energy technologies have peaked, surpassing rates of traditional energy fields such as fossil fuels and nuclear [15]. In the EU, Germany accounts for almost 31.000 energy patents by 2017 [15]. In the global solar chain, however, it is China that leads the way [13]. Since patents guarantee commercial rights to enter a market with a specific product, European PV panels could face limitations given by patents hold by other economic actors [16].

In addition to the availability of rare earth materials and to the control over commercial rights, solar power requires an adequate production capacity, in order to have a significant impact on the solar power industry growth [17]. If the EU wants to increase the degree of deployment of solar technology and reach the goals set in the European Green Deal [1], countries must be equipped with the necessary infrastructures.

1.1 Problem Statement

Reaching the greenhouse gas emissions targets sought in the Paris Climate Agreement means that the availability of rare earth minerals must increase by 12 times by 2050 [18]. There is a concrete risk, therefore, for shortages of these materials to happen, potentially causing damages to the worldwide solar-tech industry [18]. In this "Green Tech Race", countries that have access to natural reserves position themselves in an advantageous position [19]. When looking at the actual state of the solar supply chain, China, in particular, accounts for over 95 % of the world's production of rare earths [12]. Also, in the past, the Chinese government was not afraid to use control over rare earths extraction and distribution as a means of exerting geopolitical dominance over other countries [20]. China leads the world in terms of renewable energy patents [15], and moreover it is now the world's largest producer, exporter and installer of solar panels, wind turbines, batteries and electric vehicle [15].

The existing literature tends to analyse these characteristics individually, excluding from the discussion the broader context where China's and the EU's market strategy take place. Framing the latter, three main topics have been reviewed for the scope of this Thesis. These are European and Chinese competition laws [21] [22] [23] [24] [25] [26] [27] [28], the impacts on geopolitics due to the Energy Transition [15] [29] [30] [31] [32], and international trade policies [33] [34] [35] [36] [37] [38] [39] [40]. The papers all contribute to address part of the issue, as outlined later in the literature review. However, none truly delves deep enough in the solar-tech supply chain to explore the vulnerabilities of the EU's solar industry strategy, especially if associated with China's market dominance. This aspects is the one that represents the main contribution of this research to the existing literature. The research, indeed, analyses the market dominance of China through an novel Analytical Framework that considers all significant aspects that shape the dynamics of the solar industry, with a specific focus on the c-Si technology. These aspects are not only evaluated per se, but also compared to each other through a thorough discussion. The solar supply chain is studied from different perspectives, that are economic, socio-institutional, and technical, and at different levels, that are global, national, and European. Thus, the Market Dominance Assessment of China in the c-Si solar industry is evaluated as a complex process that evolved during years, impacted by both internal factors (such as: subsidies, number of patents applications, or the ability to cut down production costs), and external factors (such as: trade policies, international competition, rate of technological change), that altogether affect interstate relations among countries, and therefore national market strategies. The final outcome corresponds to an in-depth analysis that gives a concrete overview about the actual state of the c-Si solar supply chain, narrowed to the Chinese and European level, and that highlights where strengths and weaknesses, for both market parties, lay. Also, a significant added value of the research resides in the EU's policy recommendations that naturally emerge from the analysis.

Summing up, while developing a structured and concrete plan towards a Green Transition will surely enhance EU's chances to become the world's first energy neutral continent [41], there exist external factors that could slow down the Great Shift from fossil fuels to renewable energy sources [21].

1.2 Research Objective and Main Research Question

The research objective of this Thesis is to assess the real degree of China's dominance in the global market of solar technology, given the established control that the country has on mineral materials, patents, and production capacity in the solar panels industry [42]. The final goal is to evaluate if and how could China impede the competitiveness or market expansion of European Member States in the solar-tech industry.

This is done by evaluating the EU's options in terms of access to supply of PV panels that are not of Chinese competence (Substitution), the concentration and dynamics between companies in the solar-tech market (Competition), the pace of technological developments in the solar-tech industry (Technological Change), the degree of freedom of China in exerting its solar-tech market dominance without causing commercial drawbacks (Reputation Damage), the existence of Counter Monopolies in other parts of the solar-tech value chain, and the Potential Market Entries in the solar-tech industry by new players. Alongside, quantitative data, namely Patents, Production Capacity, Raw Materials, Subsidies, Labour, Production Costs, and Solar Power Potential, all contribute to the Market Dominance Assessment. These variables have been selected from literature, and narrowed down to the scope of this Thesis. Following chapters explain how the Market Dominance Assessment is done, the process of selection of the variables, and their division into **static** and **dynamic**.

The main research question of this Thesis emerges naturally from the previous observation, and is as following:

What is China's market dominance when compared to the European Union in the solar panels global industry?

1.3 Sub-questions

The following research sub-questions are formulated in order to answer the main research question:

- **SQ1**: How to assess market dominance in solar PV markets?
- **SQ2**: What are the EU's and China's future energy and industrial policies, with respect to solar power?
- **SQ3**: What is the actual market dominance of China?
- **SQ4**: How can the EU circumvent China's market dominance?

1.4 Scoping

Every type of renewable energy technology has different requirements in terms of supply chain infrastructure, rare earth materials (if needed), or patents, between others [43]. In any case, there is no other renewable energy technology that is relatable to one specific country such as solar power to China [44]. For the purpose of this Thesis, other renewable energy technologies apart from solar power are left out of scope. In addition, the focus of this Thesis is on c-Si solar technologies, since c-Si alone accounts for 95% of the global PV production, distribution, installation, and usage of solar panels [45].

The same reasoning remains valid for technological patents: logically, patents that are not related to the c-Si solar technology, and that don't belong to European Member States or China, are also left out of scope.

Also, ore bodies or metals / elements that are not required for the construction of a c-Si PV panel are left out of scope. In particular, the focus will be on silicon metal, since it represent the main critical material needed for the production of c-Si based technologies [46].

1.5 Fit to CoSEM Program

While the Thesis main field of research falls under Political and Economics Sciences, it also includes Technological elements. The technological component is mainly given by solar technology, its supply chain and the materials needed to construct solar PV panels. The thesis does not exclude the economic aspects of solar technology as well as the current state of solar tech industry, since they both have a stake in influencing the policy options of a country. In this way, in the Thesis energy infrastructures are considered as socio-technical systems where the adoption of a specific technology for energy production has repercussions not only on the technical design of the infrastructure, but also on politics, international relations, energy geopolitics and energy security. The Thesis addresses the complexity of the energy system and, by focusing on a specific renewable energy technology, tries to systematically analyse the implications of its adoption. The research objective of the Thesis is thus strictly related with the Complex Systems Engineering and Management, Energy track MSc program, in the way explained above.

1.6 General Approach

The basis of this Thesis relies on extensive research in the existing literature and on the use of available databases.

Chapter 2 establishes a global overview of the solar PV industry over the last decade and analyses the transformation of the solar supply chain, until its current design. It then elaborates on the key insights found through Documentary Analysis, to shape the structure of the Analytical Framework used later in Chapter 4 to assess China's market dominance.

In Chapter 3 there is a discussion of the EU and China energy and industrial policies. The outcome is a brief System Analysis that describes the institutional environment where the EU and Chinese solar-tech policies develops, useful for the application of the Analytical Framework later in Chapter 4.

Next, Chapter 4 sets the application of the Analytical Framework outlined in Chapter 2, and consequently it develops the actual Market Dominance Assessment of the European and Chinese submarkets throughout the whole solar supply chain. This Chapter sees a consistent use of databases.

The use of databases gives a quantitative contribution to the Thesis, and this allows for a numerical comparison between the Chinese and European realities, in terms of availability of resources.

Chapter 5 highlights the main risks for the EU's solar industry strategy that emerge from the analysis developed in the previous chapters. Follows the identification of European policy options in handling vulnerabilities in solar PVs production.

Chapter 6 develops the conclusion and possibilities for further research.

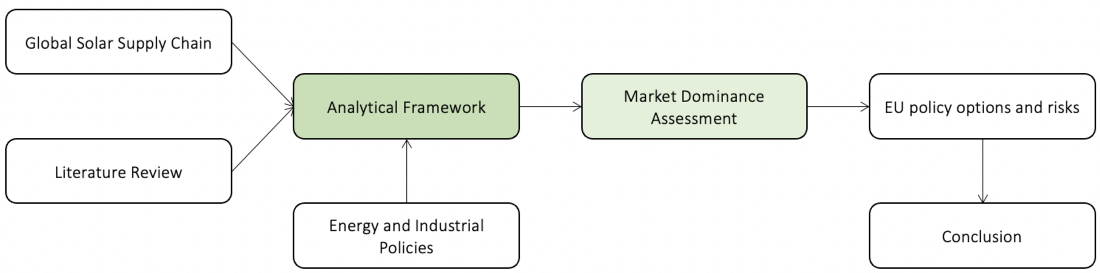


Figure 1: *Research Approach*

1.7 Methods

Main methods used in the Thesis comprehend Documentary Analysis and Data Analysis.

Documentary Analysis is used in Chapter 2 and 4. In the former, an overview of the solar PV industry over the last decade is given, to assess how its design developed and transformed worldwide.

Documentary Analysis continues in Chapter 3. Here, European and Chinese energy and industrial policies are analysed, to create a system analysis that clearly sets future goals in terms of solar-tech development. This is done by evaluating the European Green Deal and China's 14th Five Year Plan, since these are the key documents where countries express their intentions in terms of solar power evolution [2] [18]. Alongside, is an overview of the past and current European and Chinese incentives in the solar-tech industry. Incentives are, indeed, an useful tool to evaluate countries' intention to foster a specific industrial area by giving financial support or tax reduction to economic actors [47]. The outcomes of the analysis is then merged with the findings of the literature review, to evaluate where the EU and Chinese policies place with respect to broader institutional settings and agreements. The system analysis is used to answer SQ2.

The Market Dominance Assessment of China and the EU solar-tech industries in the global solar market is done through Data Analysis. Data are needed to fulfil the Analytical Framework previously drawn up.

The Analytical Framework, in turn, sets and describes the variables identified as significant to assess the market dominance of a country in a specific industrial area. All of them are framed to solar PVs requirements. The Analytical Framework evaluates market dominance on two levels. The first level is defined as "static", since variables investigated are objective and mainly numerical. These are: control over raw materials, number and distribution of patents, production rates, labour. The second level is instead more "dynamic", since variables are not valued as objective data, but emerge from a comparison between EU's and China's status. Variables discussed here are competition, substitution, technological change, reputation damage, counter monopolies, and potential market entry, all of them related to the solar PVs market. The development and application of the Analytical Framework to the EU's and China's sub-markets answers SQ1 and SQ3.

The findings of the Data and Documentary Analysis are then merged to create an overview of China's current market dominance in the solar tech industry through a Discursive Analysis. The Discursive Analysis allows to develop EU-specific policy advices to mitigate China's pressure, answering SQ4.

1.8 Planning

Annex A reports the Planning of the Research.

2 Chapter 2: Outlining the Analytical Framework

The Chapter starts with a brief recap of the history of solar cells, and then focuses on the study of the broader solar value chain during more recent years. Next, is the literature review. The literature review addresses the topics of regulation, competition, and international trade. These topics are then narrowed down to the EU and Chinese levels. In addition, a brief overview of the main geopolitical implications expected from the development of renewable energy technologies on interstate energy relations is given. The Chapter concludes with the outline of the Analytical Framework, that will be applied to the EU-Chinese case-study later in Chapter 4.

Each section (and the related subsections) of the global solar industry overview is included to highlights specific characteristics of it that will be further discussed in the Market Dominance Assessment. Also, the individual sections are useful to outline how the variables of the Analytical Framework were derived from the Documentary Analysis. In particular, section 2.1.1 (A Brief History of Solar Power) highlights how solar power emerged in the market, and how single countries, over time, became leaders in its commercialization; main outcome from this sections is the importance of national support in the deployment of a niche technology, and the potential of subsidies in driving investments (later included in the Analytical Framework). Following, section 2.1.2 (Production of a Solar Cell), by outlining the different phases of the manufacturing process of a c-Si solar cell, shows the needs for highly specialized infrastructures for its production; at the same time, it shows how the ability of Chinese companies in vertically integrating these production phases allowed the country to cut down productions costs and overturn the global solar industry. Production capacity and production costs, as well, are later included in the Analytical Framework.

2.1 Global Solar Industry

To understand the process that allowed China, over the years, to reach its current position in the global market of PV panels, it is useful, if not necessary, to give an overview of the transformation of the solar supply chain over the last decade [42].

This Section focuses on getting insight about who are the main actors involved in the global solar industry, and how they contributed, or failed, in shaping its current design.

2.1.1 A Brief History of Solar Power

Solar PV panels were first produced in 1954, in the United States [48]. The silicon PV cell, the first solar cell capable of converting enough sun's energy into power to run everyday electrical equipment, was born at Bell Labs. [49]. Until the 1960's, solar PVs were mainly used to power various parts of spacecraft, especially by NASA [50].

However, given the high cost compared to the relatively low efficiency (around 4%) [49], solar power installations almost stopped until the late 1990's, when Public Incentives started spreading in various countries throughout the world [48]. Investments in research allowed the price per Watt produced with solar energy to reduce from €350 per Wp at its initial stage, to the current price of €0.25 per Wp, with an average efficiency of 18% [51].

Solar power remained a niche market until 1991, when Germany introduced a new subsidy scheme to promote the production of electricity from renewable energy sources [52]. These new Feed in Tariffs allowed small-scale producers to benefit from an above-market price (up to four times the market rate) for what they deliver to the grid, for 20 years [53]. Up to now, in Germany, over 1.6 million solar projects have been installed; at peak levels, solar power can generate over 40% of Germany's power [54]. In the following years, many countries adopted the FiT scheme: Italy in 1992, Denmark and India in 1993, Sweden in 1998, and others followed [55]. Japan, as well, introduced FiTs in 2009 [55]; utilities were required to buy excess electricity produced by homes and businesses at a doubled market price [55]. By the end of 2017, cumulative capacity reached 50 GWp, the world's second largest solar PV installed capacity, behind China [56]. In the US, the expansion of solar power started in 2008, with the introduction of policy tools such as the Investment Tax Credit [57]. Nationwide, there are today more than 100 GWp of solar capacity installed [57].

Until 2005, Japan, the US, and Germany represented the global leaders of the solar PVs production, distribution, and installation [58]. They had the best tech know-how, the highest efficiencies, competition was relatively low, and public incentives were supporting the introduction of solar power in the energy market [59]. The situation remained stable until 2010, when China aggressively entered the global solar market, marking the end of the status quo, and causing major drawbacks for European companies [58].

From this brief analysis of the evolution, during years, of solar power, it is remarkable already how **subsidies** affected the deployment of the solar technology. Germany, with the introduction of a single type of incentive (FiT), created the demand, in the European market, for solar PVs, enabling smaller economic actors to access the solar power market and solar PVs to diffuse [58]. The guaranteed profits enhanced private investments, that furthermore reduced the price of this technology. The German case, and the countries that followed, highlights the importance of public financial support in the initial stages of a technology, whose high costs would reduce the attractiveness of the investment. Solar power **subsidies**, as later outlined, are therefore included in the Market Dominance Assessment, since they reflect the public support for private investors, and the intentions of a state (or a conglomerate of states) towards the deployment of a technology.

2.1.2 Production of a Solar Cell

There exist different families of Solar PV cells, depending on how they are produced and the materials they are composed of [60]. The most diffuse categories in the market are mono-crystalline, poly-crystalline, and thin-film. The first two categories alone account for 95% of land-based PV systems [45]. Crystalline-based cells have the highest share of the market thanks to their relatively low-cost, with an average efficiency of 18% [61].

Type	Cost per Watt	Pros	Cons
Mono-crystalline	1 – 1.50 $ / Watt	Long lifespan High efficiency	High cost
Poly-crystalline	0.90 – 1 $ / Watt	Low cost Good efficiency	Short lifespan
Thin-film	0.70 to 1 $ / Watt	Low cost Flexible	High space needs Short lifespan

Table 1: *Main types of solar cells*

source: Aurora Solar Inc.

The production process of a c-Si PV cell involves different phases, that can be carried out by one single company, or split up between different actors [62]. It starts with the silicon (Si) purification [63]. The use of silicon in manufacturing of solar cells requires Si to be almost free from impurities [63]. First, silicon is converted into a compound; next, it undergoes a distillation process. The end product is a material that is 99.9999999% pure [63].

The next phase involves the manufacturing of silicon wafers [63]. A silicon wafer is a thin slice of a crystalline silicon, that act as a substrate to integrate electrical devices in the cell [63]. The most reliable and used method to produce silicon wafers is the Czochralski (CZ) method [64]: pure silicon is melt and solidified into a cylindrical shape; the shape is then sliced into 100 to 200 mm squares with a width of 100 to 500 micrometres, that will be used in solar power applications [65].

Chinese companies, after a few years since they entered the global solar market, opted for a strategy of vertical integration of these two phases [63]. This allowed them to increase their control over the solar value chain, to cut down costs along the manufacturing chain, and to bring the rates of production to levels that have easily overtaken the European capacity. Due to the strict requirements in terms of both purity for silicon and thinness for wafers, these companies, also, are equipped with specific know-how and expensive adequate infrastructures [63]; the production costs of a c-Si solar cell, en fact, are concentrated into these two manufacturing steps [66].

The third phase is the cell production [63]. Two silicon wafers are assembled together to form a p-n junction, which allows the photovoltaic effect [63]. Then, metal contacts are applied at the top and the rear of the junction [63]. Metal contacts carry electricity to of from the device, and they prevent sunlight from reaching the silicon semiconductor [63]. Next, is the module assembling [63]. Different cells are soldered together and encapsulated in glass sheets through high temperatures to create a module [63]. Last, is the combination of solar modules with complementary equipment, such as batteries or inverters, to deliver electricity to the loads, that is the electricity grid or the consumption devices [63].

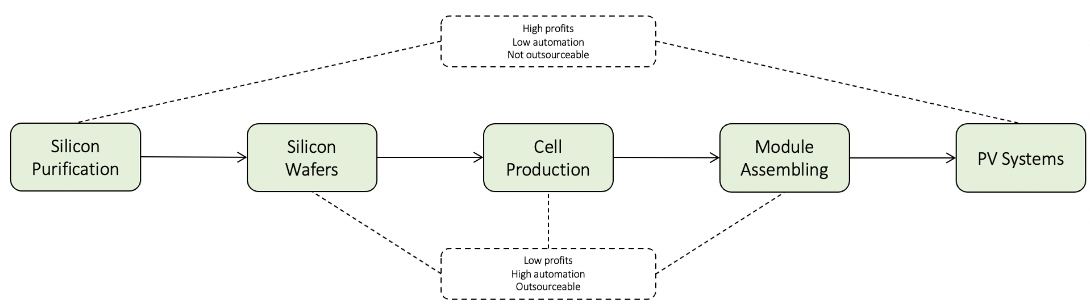


Figure 2: *Production process of a c-Si solar cell*
source: Ranjan, Balaji, Panella, Rocco, Ydstie, Erik [63]

The design of the production process of a c-Si solar cell highlights how the degree of vertical integration, the ability to access advanced know-how and to cut down **production costs**, and the access to **production capacity** have a stake in determining the potential of a country, or a union of countries, in the deployment of this technology. Data about the two latter factors are consequently included in the Market Dominance Assessment, and analysed as *static* variables.

2.1.3 Critical Raw Materials

The elemental requirements of the specific c-Si solar technology comprehend silver (Ag), nickel (Ni), aluminium (Al), copper (Cu), and iron (Fe) [57]. These metals, in turn, are derived from a set of six ore bodies, namely nickel ore, chromium ore, gold ore, iron ore, copper ore and aluminium ore [67]. In terms of minerals, a c-Si PV panel requires silicon metal, indium, selenium, gallium, germanium, silver, and tin [57]. Between these, the EU includes in the list of *Critical Raw Materials* silicon metal, indium, gallium, and germanium [41].

Earth materials that are defined as "rare" or owe this classification to the availability of economically extractable concentrations [68]. China produces 80% of the global supply of gallium and germanium, 48% of indium, and 66% of silicon metal [41]. However, other countries as well are intertwined in the global rare earths supply chain; there are, en fact, various countries that act as intermediaries between the nation / continent where the material is extracted, and the country where it is further used in the industry [67]. The main EU sourcing countries for Gallium, for example, are Germany (35%) and the UK (28%); China accounts for 27% [41].

To monitor the import and export trends of raw materials, the EU has developed the Raw Materials Information System (RMIS), that is an open-source database with state-of-the-art information about economics, trades, and policies about Europe's raw materials sphere [69]. In addition, the EU aims at cooperating with international agreements to enhance the life-cycle management of these materials, giving new life to used electronic devices, and therefore creating new post-consumption markets [69].

From these observations, and considering the predominance of the c-Si technology over other solar options (with a market share of 95%), it is remarkable how the trade of raw materials is crucial for the business continuity of the global solar industry [67]. Currently, based on how it is designed, the specific c-Si technology could not function without the usage of these materials [67]. Also, the c-Si technology has reached a certain level of maturity, meaning that there are no forecasts about further significant technological development in the coming years that could lead to a shift towards the use of other materials not classified as "critical" or produced domestically [70]. It is therefore necessary to include data about the trade of raw materials in the Market Dominance Assessment. As already remarked, for the purpose of this Thesis, only the market of **silicon metal** will be included in the Market Dominance Assessment, given its higher concentration with respect to other ore and minerals used to produce c-Si solar cells [46]. While the current trends of **Technological change**, with regards to the c-Si solar-tech, do not leave room to significant improvements, as above explained, this variable is nevertheless included in the Market Dominance Assessment, as a dynamic variable; more promising results, instead (as explained later with the application of the Analytical Framework), reside in other types of solar technologies (such as thin-film solar panels or perovskite cells) [70]. These options are evaluated more in detail in section 4.5 (**Substitution**).

2.1.4 Solar Power Value Chain

Different parts of the solar power value chain are in the hands of different niche companies [71]. Smaller companies tend to specialize in a single phase of the supply chain, or in post-installation services [71]. At the bottom of the value chain, system integrators and solar utilities profit from the sell of the generated electricity [72]. The solar value chain can be visualized as a pyramid, where, at the top, a handful number of companies, geographically concentrated, control the silicon extraction and the production of silicon wafers, while, at the bottom, companies spread worldwide, especially companies whose core business deals with the installation and the O&M processes [73].

In the solar power value chain, companies that benefit from the highest profits are companies at the end and at the beginning of the chain, namely companies whose core business deals with the installation or usage of solar PVs, or with the extraction, production, and distribution of rare earth materials [74]. On the other side, companies actually manufacturing solar cells and modules make the least profit out of the industry [72]. The reason for this is that, from the wafer production onwards, the supply chain is generally quite automated; however, labour cost remains significant [75]. Solar cells and modules production can be outsourced to countries where the labour cost is cheaper [15]; on the contrary, installation and maintenance of solar PVs have to take place locally, and processes like the silicon purification requires specialized and unique know-how [15]. The manufacturing and installation of solar PV systems, therefore, represent processes that require a certain availability of labour, with more or less specialized skills, depending on the task that must be carried out during the different production phases. **Labour**, therefore, is a significant factor that influences the potential for a country to keep up with the demand for a product (in this case specifically, c-Si panels). A lack of workers in the solar supply chain would imply a drawback in the industry. Labour data, for the reasons just explained, are included as a static variable in the Market Dominance Assessment.

2.1.5 Companies

With the expansion of the PVs market, the solar supply chain started a process of vertical integration [63]. Companies, before the advent of China, were mainly specialized in one or two phases of the solar PVs production process, such as modules assembly or silicon wafers production [76]. Chinese companies, instead, pointed on a strategy that encompasses the overall value chain, consequently being able to cut down production costs and dramatically expand their outputs [63].

Below is a recap of today's biggest companies in the solar silicon market industry, and the respective production capacity [77]. Noticeable, 8 out of 10 companies have Chinese headquarters [77].

Silicon Wafer Manufacturers		
Company	Country	Production Capacity
Ja Solar Holdings	China	40 GW
Tongwei Co., Ltd.	China	55 GW
Trina Solar	China	50 GW
Hanwha Q-CELLS	China	11.3 GW
JinkoSolar	China	30 GW
LONGi	China	38 GW
Shunfeng (Wuxi Suntech)	South Korea, Malaysia	5 GW
Canadian Solar	China	30 GW
Aiko Solar	USA	36 GW
First Solar	China	5 GW

Table 2: *Main silicon wafers manufacturers*
source: Bernreuter Research [77]

These companies, while being leaders in the global silicon wafers production, have diversified core businesses [77]. Some companies mainly produce solar panels, while others sell PV-complementary components (such as storage batteries, cables, and wires), or are involved in other industrial sectors (such as the automotive industry) [77]. Depending on their market strategy, they can be clustered by the degree of vertical integration and the degree of products diversification [66], as shown in the matrix below. Higher vertical integration allows players to have a higher market share and the possibility to outsource some phases of the supply chain, and therefore to better control final prices and production costs [76]. However, low degrees of diversification expose companies to market fluctuation: should the solar PV market collapse, these companies would suffer from major drawbacks [76].

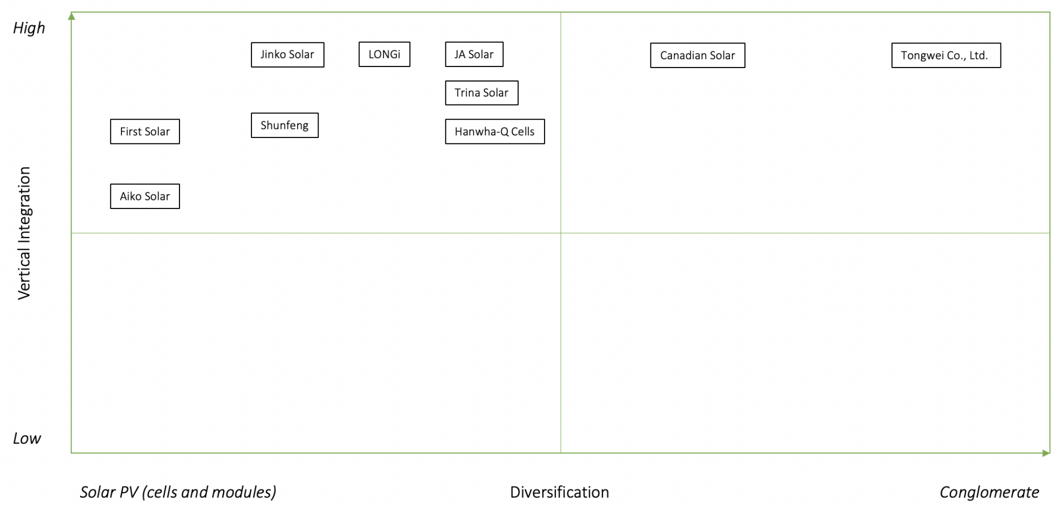


Figure 3: *Clustering of silicon panels manufacturers by "diversification" and "vertical integration";* source: Bernreuter Research, Green Rhino Energy [77] [66]

2.2 Literature Review

The literature review has been conducted after framing the research objective and the main research question, reason why it is placed after section 1.2. For each topic, different keywords were used and combined in different ways, to project a better overview of the existing literature. Keywords used in the research were "Geopolitics Energy Transition; Geopolitics Renewables; Geopolitics solar energy / technology / power; Economics Competition; Economics Regulation; EU / China competition law; EU / China trade regulation; Political Economy; International Trade; Political Economy International Trade". Through the literature review, I collected articles, papers, reports, books, websites, data-sets and statistics. All the documents were found by Google Scholar, ScienceDirect, Scopus, and by cross-referencing in the documents themselves. The documents' selection is based on a scan of abstract, conclusion and key concepts.

The first topic reviewed is the **Geopolitics of the Energy Transition**, that establishes the broader context where the research will take place. When speaking about global markets, en fact, geopolitical forces among states are a crucial aspect in determining their equilibrium and dynamics [29]. Overall, authors agree that theorisation of this field is lacking, and that the majority of papers do not distinguish between different types of renewable energy technologies: the effects of solar power per se on interstate energy relations is not analysed [30], [31], [32], [78], [79]. Main expectations with regards to future implications of the development of renewable energy technologies worldwide are the switch from oligopolistic to competitive markets, the decentralization of energy production, the increase in competition for rare earth materials, the electrification of energy systems, and the increase in industrial competition over market shares in clean energy technologies [32], [79], [15], [31]. While these observations do not focus on the specific solar technology, still they cover the area of RES technologies. In particular, the decentralization of the energy production implies that new actors will enter the green energy market, followed by the development of new business models [15]. There is the concrete possibility, therefore, for new market entries also in the solar global industry [31]. This option is included in the Market Dominance Assessment, and further evaluated in the **Potential Market Entries** section, as a comparison between the Chinese and European realities. In addition, the growing interest of nations towards the introduction of RES in their energy mix, highlights the increasing importance of access to patents (that allow market parties to exclusively commercialize their inventions) and clean-tech know how. **Patents** data are included in the Market Dominance Assessment as a static variable, and contribute in assessing where the c-Si commercial rights are distributed.

Secondly, principles of **Economics** where researched, in particular **Competition** and **Regulation**. Competition emerges when different economic actors compete in the same market to sell or buy the same or similar products [22]. Usually, as authors agree, from competition for selling what emerges are lower prices, since consumers can choose between a variety of suppliers, and will likely opt for cheaper solutions; competition for buying, instead, causes prices to raise, since consumers' willingness to pay for a certain product will increase [23]. While extremely high levels of competition could unleash barriers for new market parties to enter into a specific industrial area, creating a saturation of the market, low rates of competition can cause a stagnation in technological development [23]. A fair level of competition, is therefore a critical sign of a functioning market [23]. On the other hand, regulation is imposed by governments / supranational authorities to modify economic behaviours in order to deliver safe, appropriate, and just services [24]. The EU has strict rules protecting free competition, under which certain practices are prohibited, such as price fixing, agreement on customer allocation or on production limitation, market sharing [27]. European competition law is mainly represented in the *Articles 101* and *102* of the *Treaty on the Functioning of the European Union* [28]. In China, the major legal statute on the subject of competition law is represented by the *Anti Monopoly Law of China*; the statute has four cornerstone, namely the *Monopoly Agreement*, the *Abuse of Dominant Market Position*, the *Concentration of Undertaking* and the *Abuse of Administration Power* [25]. Antitrust laws, however, have a different weight in the two realities: while the European Union has a series of directives protecting antitrust and promoting a level playing field for companies competing in the same market (such as public and private auctions), the presence of the Chinese government in influencing the national market dynamics above the regulation is undeniable. A clear example are the huge public incentives that the same solar industry received after 2010 [25]. Many case-studies have been analysed, in literature, to evaluate whether and how it can be stated that a company, a country, or an organization has the monopoly over the commercialization of a certain product [21]. In the solar industry context, there are no specific studies; however, these examples remark that, when analysing the dynamics of competition of a market, it is important to identify, if any, the monopolies that have developed in a specific phase of the supply chain of the technology of interest [21]. These bottlenecks, indeed, shape the design of a market; whether monopolies (or quasi-monopolies) have developed along the solar supply chain, that are not of Chinese companies, is evaluated in the **Counter Monopolies** section. This is done to assess whether other countries (or union of countries), rather than China, influence a segment of the global solar industry enough to counteract its invasive presence. In literature, as well, there are numerous frameworks, whose aim is to measure the "monopolistic degree" of a specific firm over others [21]. These frameworks are useful as a starting point for further discussion. For the purpose of this research, **Competition** as well is included in the Market Dominance Assessment as a dynamic variable on its own, and the discussion will start from the application of the Herfindahl-Hirschman Index (HHI) [26]. The index is the result of the sum of the square of the market share of each firm competing in a market. The closer a market is to a monopoly, the higher the HHI, and the lower its competition [26]. While not representative of the market dynamics, the index is able, through a simple calculation, to identify the general shape of market (highly competitive or near to a oligopoly or directly to a monopoly).

In the third place, the topic of *Political Economy of International Trade* has been included in the literature review. Trade policy refers to the regulations and agreements that control imports and exports to foreign countries [33]. Rodrik, a prominent voice in this field, develops a political-economy model of trade policy, used by the majority of authors for further developments and reasoning, composed by four elements: his model notices how trade policies emerge in an Institutional Setting, where Policymaker Preferences are shaped by Individual Preferences of economic actors and Interest Groups [34], such as lobbies. For what regards international trade policy, authors generally state that, since 1980, we can see a "rush to free trade" from countries all over the world [34], [35], [36], [37]. This is due to three main factors, namely: domestic actors that ask for more trade liberalization, a process of democratization in political institutions, and changes in the international political systems [35]. Global trade is ruled for 98% by the World Trade Organization [38]. China joined the WTO on 2001, while the EU is a member since WTO foundation in 1995 [38]. The EU as a strongly open trade regime, to enhance investments: more than 70% of imports enter the EU at zero or reduced tariffs [39]. In addition, the EU is China's biggest trading partner. In 2013 the EU and China launched negotiations for an Investment Agreement, to provide investors on both sides with predictable, long-term access to the EU and Chinese markets [40]. The third topic is helpful in getting insights about the functioning of trade flows and industrial policy practices, therefore in developing the overview of solar-PVs supply chain and EU and China future policies with respect to solar power of Chapter 3. **Trade policy**, also, is included in the Market Dominance Assessment, since trade regulations between two commercial parties are significant in influencing their import and export rates.

There are many knowledge gaps that emerge from the literature review. First of all, there is no clear analysis of the effects of solar power on interstate relations. While the geopolitical impact of the deployment of renewable energy sources is not a novel topic, and, during recent years, is gaining more and more attention, there are no available papers that focus on the specific solar energy technology alone. Given the drastic differences among individual RES, in terms of technical traits and in terms of the dynamics of the related markets, it is indeed important to evaluate the potential impacts on interstate relations of these technologies individually. This research addresses this first knowledge gap, since its main focus is on solar power - specifically on c-Si solar energy - and it assesses its potential to impact the geopolitical relations among two specific realities, namely China and the European Union. Next, frameworks designed to measure the concentration of competition between firms, fail to take into account the actual complexities of markets, reducing - like the HHI - the calculation to the relevancy of market shares of individual firms. Markets are complex, dynamics, and influenced by both external (institutions, laws, social trends) and internal (the composition of a firm, its core business, its strategy) factors [21]. Currently, there are no schemes that are able to reduce these dynamics to a mathematical formula. This research, as well, recognizes the difficulties that emerge when assessing one country's dominance over another in a specific industrial sector, especially when the assessment is based on data-sets that are expressed with different unit of measures or collected through different methodologies; at the same time, it broadens the application of the HHI index, and it uses it as a starting point for a wider comparison among China and the European Union that also includes the broader socio-institutional-technical context where the two realities compete. Thirdly, literature about International Trade Policy lacks applications to concrete and current case-studies; mainly, case-studies found in literature are focused on single episodes, happened in the past, that led to damages in the trade regimes among two or more countries. They thus tend to frame these accidents to a limited period of time and to detach them from other external factors that instead could have a stake in shaping their dynamics. This research, indeed, aims at filling this gap by discussing the existing trade policies among the EU and China not as "photography" of the current trade regime, but as a process that developed during years, changed drastically from unregulated, to unfavourable for goods exchange, until today's standard import-export tariffs. Clearly, this changes were caused by other characteristics of interstate relations within the two market parties, characteristics that evolved during time.

The identification of the knowledge gaps is important for the outlining of the Analytical Framework (section 2.3), since they remark where the existing literature fails in the assessment of the market dominance of a country over another, specifically when applied to the solar industry. There knowledge gaps, as above anticipated, will be addressed in the discussion of Chapter 4 and, while the research is not complete in their analysis, they still find a voice in the Market Dominance Assessment.

2.3 Analytical Framework

This Chapter sees the construction of the Analytical Framework introduced in the outline of the Research Design. Here, the structure of the Analytical Framework is discussed and explained, showing its strengths and weaknesses. The application of the Analytical Framework to the Chinese and European realities will be done later in Chapter 4, after the overview of the global solar supply chain and main energy and industrial policies done in Chapter 2 and 3. Noticeable, the Analytical Framework can be adapted to the Market Dominance Assessment of other case-studies (meaning, other countries), that analyse the supply chain of a different technology, such as nuclear energy.

The variables have been selected from both findings of the literature review and research about methods of Market Dominance Assessment. From a first selection, variables have been then narrowed down to the solar PV industry, in order to choose only the variables that are significant for this industry. Following, some variables have been left out of scope, such as data about energy storage components, in line with the area of interest of this Thesis (see section "Scoping"). Next, variables have been divided into **static** and **dynamic**, as explained below. None of the variable is sufficient, per se, to state whether China has a market dominance over Member States, or the contrary. Each variable concur in determining the final outcome of the Market Dominance Assessment, but it has no significant value when de-contextualized from the area of interest of the research.

Below is the outline of the Analytical Framework.

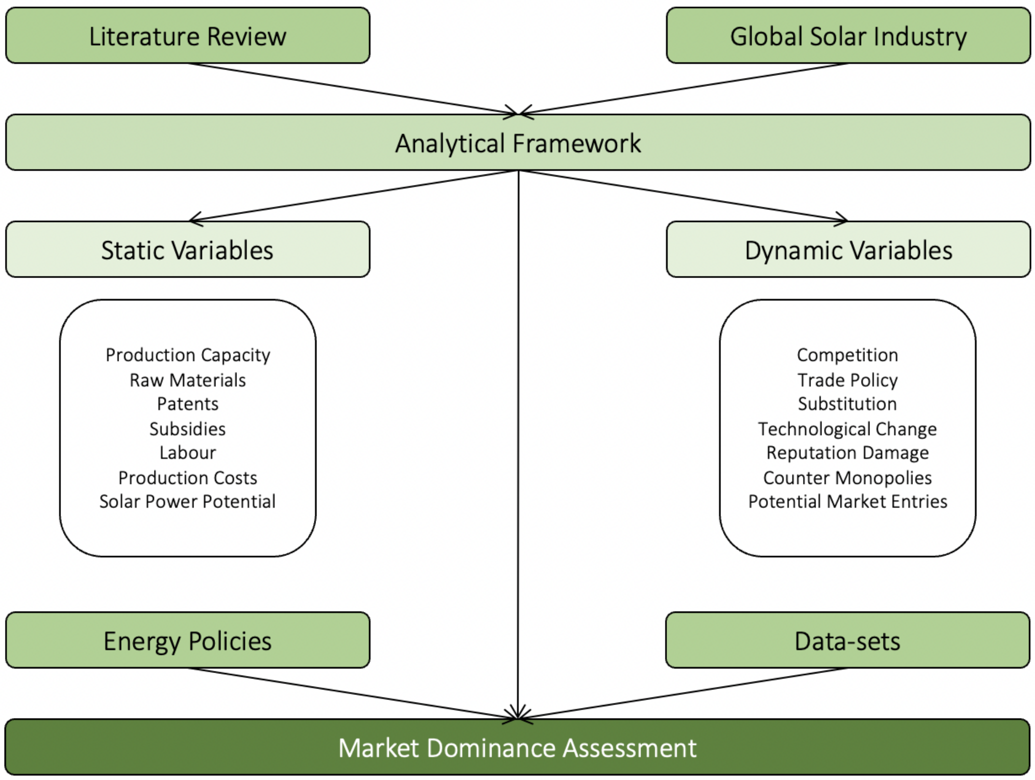


Figure 4: *Analytical Framework*

As shown in the Analytical Framework, the Market Dominance Assessment is done on two levels. **Static** variables comprehend factors that have a quantitative value. The cumulative production capacity of European countries, in terms of c-Si PV panels, for example, can be easily quantified [80]. This type of data give useful insight about Chinese and European current resources to compete in the global solar market. However, the databases collected often refer to different years, or they can be incomplete. In addition, there is a great unbalance, in terms of availability of data, within Member States of the European Union. Updated market statistics are not always available; countries, as well, collect data by using different methods, causing absolute values to be difficult to compare. Data collected on a European basis, therefore, often represent weighted averages of single-nation-based data, that in turn are usually averaged on an individual country basis. To sum-up, data are a precious and significant starting point for further discussion, enriched by a broader contextualization of the data, and a comparison between the European and

Chinese realities. Nevertheless, it is due to remark their limitations [81]. The two realities, en fact, belong to a broader socio-institutional-economic context, where other factors as well influence their inter-dependencies, and the market dynamics that evolve between them [80]. These factors also must be included in the Market Dominance Assessment. That is why the second level of the analysis is defined as **dynamic**: here, variables have a qualitative nature, and they are not discussed individually, but as a comparison between the EU's and China's status. The outcome of the Market Dominance Assessment will be an overall discussion that comprehends each variable of the Analytical Framework, highlighting the interconnections between the different aspects of the industry, and the complex nature of international markets.

Each variable is then break-down and further detailed, outlining both its major contribution to the Market Dominance Assessment and its limitations.

2.3.1 Static Variables

Production Capacity

Data about production capacity recap the ability, for both China and the EU, to manufacture c-Si cells and panels domestically.

Production capacity data are useful in giving insight about the potential of a country (or a union of countries) in satisfying the global and local demand for c-Si solar panels, the ability to compete in the solar manufacturing industry, and the future and past strategies of nations towards the deployment of solar power [80]. High investments in solar manufacturing capacity, indeed, identify a strong interest for a state to increase their domestic production, and therefore to broader the contribution of solar power in their energy mix, or to foster foreign exports; on the other side, countries could opt for an imports-based strategy, causing low to no investments in solar manufacturing facilities [81]. Production capacity data, however, have limitations in identifying whether a country has a market dominance over another: companies with smaller capacities could have a different market strategy, or be the main market players in another phase of the supply chain [82]. Many companies, en fact, prefer to get their profits acting as intermediaries or by offering post-installation services, since they lack the technical know-how required for solar cell production, for example, or simply because they see better profit opportunities in other steps of the value chain [83]. In the available databases, there is no clear distinction between silicon wafers, c-Si cells, and c-Si modules production rates; rather, they tend to encompass all the three phases, and to normalize these values as output rates. Following the availability of data, production capacities will be collected as **output rates**, expressed in **GWp** [84].

Raw Materials

Raw Materials are crucial for the production of c-Si panels [41]. The European Union has outlined a list of raw materials classified as *critical*. The list is subject to change and updated each year; the classification, in fact, is influenced by many factors, like the export dependence, the number of suppliers, or the finale use [41]. Overall, critical materials represent materials that are not replaceable and whose constant supply is critical for the business continuity of a segment of the industry [41]. Many of the ores, minerals, and metals required for the manufacturing of a c-Si panel can be traced within this list (see also Section 2.1.3). Demand for these materials is increasing worldwide, due to national green policies and the growing market share of electric vehicles, batteries, and other renewable energy technologies, that also are associated with the usage of raw materials [85].

Raw materials have a proper own global supply chain [86]. En fact, often, the extraction site, the purification site, and the usage site, do not coincide [86]. From that emerges the need for a global distribution network, and therefore the presence of multiple actors in the raw materials worldwide market [87]. This means that, while control over one of the three value chain phases does not determine alone the dominance of a player over another, nevertheless these data are useful to evaluate which countries are leaders in the management of these fundamental elements, minerals, and ores [87].

For the purpose of this research, raw materials data will be collected only for **silicon metal**, due to its major concentration in the specific c-Si solar cell. Available databases do not make a distinction between different phases of the solar supply chain (extraction data, c-Si cells usage, c-Si panels usage); rather they report production, consumption, and sourcing amounts. Following this line of reasoning, both for the Member States and China, data refer to the **production**, **sourcing**, and **consumption rates**.

Patents

Patents are intellectual property rights that legitimate owners to make, use, or sell an invention, for a pre-established period of time, in exchange for publishing a description of the invention that allows for its industrial reproduction [88]. So patent owners can commercially and exclusively exploit their invention, while enabling research to proceed [89]. While patents reflect the degree of technological innovation accumulated by a firm, a country or a research institute, patent data as a sole measure of market dominance encounter some limitations [14]. Firstly, intellectual property laws, en fact, vary across countries, and are subject to continuous adjustment [90]. In this regard, the leading organization for the management of international intellectual property services, is the World Intellectual Property Organization (WIPO), that accounts for 193 member states worldwide [91]. Main goals of the WIPO are to solve disputes in international patents issues and to maintain a global database of existing patents [91]. Secondly, patents content can range from small incremental improvements, to radical innovation, and generally they aim at resolving technical issues or discovering new materials [14].

For what regards the technological content of patents, the most common clustering system is considered to be the International Patent Classification (IPC), that groups patents depending on the type of technology they outline [14].

Patents analysis can be done from different perspectives: by the trends in patents deposition of the c-Si solar technology, to evaluate the interest of different research parties in the development of the technology; by the depositors, to identify companies and/or institutions that are expected to be leaders in the deployment of the technology; by depository country, to illustrate which countries are active in the R&D of c-Si solar cells; or by patent content, to evaluate what aspects of the solar technology is under active development [81].

Access to patents documents occurs through private or public databases; main databases, worldwide, are the National Institute of Industrial Property (INPI), the European Patent Office (EPO), the United States Patents and Trademark Office (USPTO), the WIPO, the Japan Patent Office (JPO), and Google Patents [90]. Below are the IPC codes of c-Si cells. Chapter 4 will outline data collection and discussion for these **IPC coded patents**, with regards to China and the EU, taking into account the different perspectives of observations above identified.

SECTION	H	ELECTRICITY: Generation of electricity, which covers the generation, conversion, and distribution of electricity	
CLASS	H01	BASIC ELECTRICAL ELEMENTS	
SUBCLASS	H01L	SEMICONDUCTOR DEVICES; ELECTRIC SOLID STATE DEVICES	
MAIN GROUP		H01L 31/00	Semiconductor devices sensitive to infrared radiation, light, electromagnetic radiation of shorter wavelength
SUBGROUPS		H01L31/18	Cooling of PV cells
		H01L31/042	Photovoltaic modules or matrices of individual PV cells
		H01L31/0224	Electrodes
		H01L31/04	Adapted photovoltaic conversion devices
		H01L31/048	Encapsulation of modules
		H01L31/05	Electrical interconnection between the photovoltaic cells inside the PV module, for example, serial connection of photovoltaic cells

Table 3: *IPC Patents Classification for c-Si technology*

source: IPC

Subsidies

Over the last ten years, the solar PV market has grown rapidly due in part to national incentive programs [92]. Subsidies have the potential to foster the expansion of an industrial sector by financially supporting projects, and by enabling producers to access tax reliefs for a period of time, or to obtain higher revenues than the current market price [93]. Subsidies, therefore, are a powerful tool in driving investments [92].

The number one subsidy scheme relatable to solar power is the Feed in Tariff, introduce by Germany [52]. It allowed small-producers and small-consumers to enter the solar PV market [52]. It is important to remark that FiTs reduce over time, and adjust with the decrease of production costs reached through economies of scale and the deployment of the technology; FiTs, therefore, while of critical importance at the initial phase for the creation of a novel solar market, are now reducing their attractiveness, since the financial support they provide has lowered, and will likely stop for solar projects initiated after 2025 [94]. There are other financial instruments as well that have been, or that are currently used, to support solar power deployment, such as financing [92].

Nevertheless, subsidies, as pure method to compare the economic advantage of solar deployment of a country over another, are not sufficient [95]. Subsidy policies, en fact, take place in the broader socio-technical context where a nation is located, and are influenced by inter-state relations [52]. A significant example are the subsidies put in place in China during the years 2011-2012, as a response to the EU's anti-dumping tariffs (see also Chapter 3) [96].

For the purpose of this Thesis, subsidies are classified depending on their **type** (tax relief, FiT, financing), on their **duration**, and on their **final recipients** (companies, private users, public administration).

Labour

High volumes of industrial production, besides adequate infrastructures and facilities, require an appropriate availability of labour [97]. The same reasoning applies for the production of solar PV panels, especially on a global scale [98]. The solar PV industry, worldwide, accounts for 33% of the total renewable energy workforce, that is 3.8 millions of jobs; in 2019, 87% of global PV employment was concentrated in the hands of 10 countries [94].

Depending on the phase of the supply chain, or on the level of competence required to perform a certain task, the need for more or less skilled labour changes [99]. Also, some parts of the supply chain are quite automated, and they relate to a relatively low number of human workers [63]. High level of automation, for example, can be found in the module assembling phase, while technological innovation requires instead high human contribution [63]. Therefore, while being necessary for the business continuity of industrial productions, availability of labour, as absolute value, does not guarantee higher possibilities to dominate in the market [98]. It depends on which skills are needed in the industry. In addition, labour has to comply with domestic and international legislation [100]. Also, labour has different costs in different nations [97].

The International Renewable Energy Agency (IRENA) provides an operational definition of two main different variations, when evaluating jobs in the solar industry [94]. These are:

- Direct jobs: jobs related to core activities, such as manufacturing/fabrication/construction, site development, installation, and operation and maintenance (O&M);
- Indirect jobs: jobs related to the supply of the solar industry at a secondary level, that is jobs close to activities such as the extraction and processing of raw materials, marketing and selling, administration at ministries, or the work performed by regulatory bodies, consultancy firms and research organisations.

Direct jobs are easier to quantify, since they are strictly related to the crucial fabrication and mise-en-place of the PV system. Indirect jobs, instead, are more difficult to identify, since, usually, employees in these segments are not focused on solar energy, but their tasks span to other areas of interest [94].

For the purpose of this Thesis, and based on the available databases design, labour data will be collected as **current rates of employment in the solar industry**, summing direct and indirect jobs, without further distinction, for both China and the EU.

Production Costs

Costs are a core driver in the deployment of a technology [101]. High initial investments can be a barrier when approaching a specific market. A reduction in production costs, instead, can enhance investments, produce economies of scale and, over time, stimulate technological innovation [101]. In the history of solar PVs, China was able to enter the market especially due to its ability to cut down production costs by two thirds when compared to European competitors, and to offer relatively cheap products while maintaining satisfying quality standards [98]. Given the worldwide connections that established, during years, in the global chain of solar technology [102], it comes naturally that some of the manufacturing phases are outsourced where labour and production costs are lower, especially those phases that are characterized by a high degree of automation [15]. Companies running their businesses in countries where these costs are lower, therefore, will have an economic advantage [98]; savings can be re-invested to broaden the company's degree of vertical integration across the value chain, or in the R&D area, to foster technological research [72]. This allows companies to access new markets, and, if successful, to increase their market share at the expenses of their competitors [72].

Production costs, as absolute values, encounter some limitations when defining China's market dominance over Member States [98]. Other policy tools, en fact, could counteract the advantage of having access to lower production costs, such as ad-hoc subsidies or trade rates [101]; anti-dumping tariffs, in particular, could be able to nullify this advantage [101].

For the purpose of this Thesis, production costs data will be collected, for the European Union, as the average costs among Germany, Italy, France and Spain. Productions costs are then normalised as **€/kWh**.

Solar Power Potential

Solar power potential differs between different geographical regions [103]. There are many geographical factors than concur in determining the potential of this technology in an area, such as solar radiation, slope, land use, urban extent, population distribution, and proximity to the power grid [104]. In addition to these technical constraints, there exist legislative limitations to the deployment of solar power [103]. There are, indeed, protected natural areas, water bodies, and forests, where PV power plants cannot be constructed [104].

The solar power potential data collection, for both China and the European Union, is derived from the study conducted from the World Bank Group in 2021 [105]. Data about PV installed capacity for each country has been updated to the 2020 values reported in the IRENA's Renewable Capacity Statistics 2021 [106]. The World Bank Group's study divides PV potential into theoretical, that is the global horizontal irradiation (GHI, measured in [kWh/m2/day]); and practical, that is the actual photovoltaic power output of a PV system. The output is measured as the **specific yield** of the c-Si PV systems, and expressed as **[kWh/kWp/day]** [105].

While solar potential data are not per se sufficient to compare the solar power market dominance [82], they add valuable insights to companies' degree of freedom for the deployment of solar power, given the existing constraints [103].

2.3.2 Dynamic Variables

Competition

Competition subsists when two or more parties trade in the same market, selling their products or delivering their services to the same category of consumers [22]. Competition is a significant variable in assessing one country's market dominance [23]. There exists numerous models, in literature, that aim at describing the dynamics of competition between firms in the market [107]. Competition is vital for the industry [22]; without competition, technological innovation slows down [82], economies of scale (and therefore, lower marginal costs) are harder to reach [92], and monopolies, or oligopolies, can easily develop, creating a situation where few companies are able to influence the market price and to use their market dominance without any significant restrictions [93]. On the other side, competition can result in the saturation of the market [23], or in the development of barriers to entry to new market parties [107]. Analysing the dynamics of competition of an industry, therefore, helps in understanding the broader conditions where countries trade [22].

A widely used measure of industry concentration is the **Herfindahl–Hirschman index** (HHI) [26], introduced in the Literature Review. The primary advantage of the HHI is the simplicity of the calculation [108], when the market shares of the companies are given:

$$HHI = x^2 + y^2 + ... + n^2$$

where *x, y, ..., n* are the market shares of the firms, expressed as whole numbers. Generally, a market is considered to be competitive when the HHI has a value of 2.500 or higher [108]. When the HHI reaches a value near to 10.000, it means that there is a presence of a firm that has a quasi-monopoly in it [26].

In turn, the calculation of the HHI, due to its simplicity, fails to consider the complexities of markets [109]. It does not allow for an accurate assessment of the dynamics of competition in those markets [109]. For the purpose of this Thesis, the HHI will be used as a starting point of further discussion about the market concentration of the solar PV industry. Generally, regulators calculate the HHI considering the 50 largest companies in a particular industry to determine if that industry is competitive or close to being a monopoly [110]. The same line of reasoning will be applied to this research, based on the Bloomberg classification [9]; only the first 25 companies are included in the Market Dominance Assessment.

Trade Policy

Trade policies define the rules, for a country or a region, about international trade [33]. Trade policies can range from free trade, where there are no restrictions on trade, to protectionism, where the priority is on protecting local producers [34].

Trade policy are mainly expressed through tariffs and import quotas [111]. Tariffs are taxes imposed on goods that are imported from foreign countries [112], while import quotas are limitations on the amount of goods that can be imported from foreign businesses [112]. Tariffs and import quotas should be adequate to the local industry, in order to protect the domestic market, enhance a fair level of competition, and allow business continuity [112]. However, trade policies can also be used as a means of exerting geopolitical power [34]. For the purpose of this thesis, data will cover **EU-China trade policies** for what regard the solar PV industry; the collection of databases will be the starting point for further discussion.

Substitution

Substitution evaluates the possibilities that a party has when choosing the supplier of a specific product or service [113], thus expresses the degree of availability, in a market, of different offers of a specific technology [114]. When the substitution degree in a market is high, en fact, the buyer can decide between a wide range of offers, depending on its priorities towards this product [113]. The party could opt for the cheapest option, or for the one with the highest efficiency, or again for the product that is produced in the nearest geographical location, for logistic reasons [115]. When the substitution degree is low, instead, the buyer has fewer possibilities of choice [114], and on the other side the seller can easily influence the market [113].

The variable recaps the **alternatives** (that is, the c-Si PV panels) **available in the market** for the buyer (for the purpose of this research, European Countries) rather the products offered by a single seller (for the purpose of this research, China), that are able to maintain the same quality standards, in terms of costs and efficiencies.

Technological Change

C-Si solar panels are subject to technological change [116], considered to be as the main source of economic growth [117]. Tech-change expresses the variations of a specific product due to technological innovation in efficiency, materials used, number of components, size, flexibility, modularization, and others technological characteristics of a specific product, over time [116] [117] [118] [119]. Tech-change can regard the product per se or the production processes [118]; improvements in the methods and means used to manufacture the product, indeed, can lead to technological innovation, costs reduction, or energy savings [120].

The variable aims at summarizing what are the **main trends in technological change** with respect to c-Si PV panels, and where the potential for EU improvements lays.

Reputation Damage

Reputation Damage results from a mismatch between the services that a firm, an organisation, or a country is expected to deliver, and the actions that are actually taken [121]. Depending on the impact of this mismatch on the stakeholders, Reputation Damage can affect individuals as well as an industry as a whole [122]. A clear example of the latter case is the Fukushima disaster of 2011 [123], when not only the Japanese government had a major drawbacks, but also the all industry of nuclear power lost its worldwide support, while many countries decided to phase it out as energy source [124]. Reputation Damage could also result from what it is considered to be a misbehaviour of a country towards its competitors [121], such as the exploitation of one party's market dominance in an industrial sector to enhance profits exponentially, causing economic damages to other parties [125]. Reputation Damages can cause long-lasting damage to a firm, government, or individual economic welfare, requiring many years, if possible, to rectify [121].

Reputation Damage is a dynamic variable since geopolitical equilibrium between countries are complex in nature [126]; states, en fact, are interconnected with different socio-economic, legislative, and political bounds, that, in turn, are themselves cross-linked [126]. For the purpose of this Thesis, the variable evaluates what are the **main drawbacks that China's solar panels industry** could suffer from, should the country decide to exert its geopolitical power over EU Member States. Examples from the past, as well, are collected and discussed.

Counter Monopolies

A monopoly happens when a person, corporation, or state has the exclusive right to sell a particular product, or is the only supplier of a commodity [127]. Monopolies can be legislative [128], such as the sell of tobacco in several countries, that lays in the hands of the government [129] [130] [131], or they can be natural, meaning that they developed for certain geographical or economic reasons during the years [132].

In the c-Si supply chain, there are no perfect monopolies [133]; nevertheless, when one country controls over 80% of the production, distribution, or installation of a commodity, material, or product [12], it has a clear advantage over other parties [127]. Controlling a phase of the solar supply chain, in turn, is not a sufficient condition to state that one country has a significant market dominance over another in the commercialization of the technology [128]; there could exist counter monopolies in the solar value chain [133]. This variable tends to analyse in which phase of the value chain **other partie**s, with respect to China's presence, **have a major control of the industry**, if any.

Potential Market Entries

Free markets are, by nature, dynamics. There is, therefore, the constant possibility for new parties to access them [134], and increase the degree of competition between the firms that are already commercializing similar products or services [22]. The party that intends to access the market, however, needs to be prepared to face potential barrier entries, such as high initial investment costs, current legislation, the consolidated reputation of existing brands, or long-term partnerships between organisations [135]. Given the significant presence of China in the global PV solar industry, parties accessing the market must therefore be endowed with the necessary supporting infrastructures [6]. This variable evaluates if there are **other countries** that, while entering the solar PV industry, **could be able to counteract China's market dominance**, consequently allowing European Countries to have more options in choosing their commercial partners for the deployment of solar power.

3 Chapter 3: European and Chinese Energy Policies: an Overview

The leading deal on a worldwide scale, in terms of future Energy Policies, is the Paris Agreement [136], adopted by 196 Parties at COP 21 in Paris [137]. The Paris Agreement is a legally binding international treaty on climate change [138]. Main goal of the Paris Agreement is to limit global warming to well below 2°C compared to pre-industrial levels [136].

Each Party that signed the Agreement has set different goals in terms of GHG emissions reduction, that are the nationally determined contributions (NDCs) [139]. NDCs are long-term plans, divided into milestones, and they cover different areas: social, industrial, political [136].

National Energy policies are shaped by different institutional and economic factors. International Trade Agreements are one of these [140], since they can facilitate or block access to specific energy sources and energy technologies [34]. For what regards existing and future Trade Policies [140], the World Trade Organization (WTO) is the leading intergovernmental organization that regulates and facilitates international trade between nations [38]. The WTO is the world's largest international economic organization [141], with 164 member states representing over 96% of global trade and global GDP [38]. Joining the WTO was crucial for China in its entry into the solar panels market [38].

Joining the WTO means that countries have to comply with a series of regulations whose aim is to define fair levels of international competition, that sometimes may lack [38]. In 2013, to counteract China's expansion in the solar PV market, the EU imposed provisional anti-dumping tariffs on Chinese solar panels [142]. Anti-dumping duties are a protectionist tariff [143]; Chinese solar panels had significantly lower costs, when compared to panels produced in European countries [144]. The tariffs, therefore, were imposed to re-establish fair market conditions [142], and to allow European companies to be competitive in the market. However, anti-dumping duties came only after China had already entered the market [142] [144]. In 2018, Chinese anti-dumping policy was removed [142], and Germany cut the FiT scheme [52], causing the European solar industry to have an enormous drawback [144]. China's solar deployment, from those years, grew constantly, reaching today's market dominance [145].

3.1 European Union

In the European Union, energy-industrial policies are set on two different levels [2]: one coming from the decisions of the European Parliament and Commission [146], that sets higher standards for all Member States; one on a national level, set by governments themselves [139].

At the European level, the European Green Deal represents EU's biggest action to reach climate neutrality [2]. The Deal outlines an Action Plan that involves all sectors of the EU economy, towards a "just and inclusive transition" [2]. In 2020, the European Commission proposed to set the reduction of GHG emissions to 55%, compared to 1990 [147]. The Communication prioritizes the creation of an international level playing field for all renewable energy sources (RES) –including PV– and the relevant raw materials [147].

It is under discussion if the EU Green Deal will be reinforced with a European Climate Law [148]. This means that the European Commission could give Member States recommendations in respecting their GHG emissions reduction targets [148]. Through the Climate Law, the EU Commission aims at translating the EU Green Deal into concrete national actions that are legally binding [149].

One of the pillars of the EU Green Deal is to decarbonise the energy sector [2]. The 2020 EU proposal comprehends also the *Impact Assessment* [150]. The document provides future projections for the European energy system (including solar deployment) via an energy model simulation [150]. Here, solar energy is expected to be one of the main contributors to the Green Transition [150]: the results of the simulation show that reaching a 55% reduction of GHG emission means that solar energy should produce 14% of electricity consumed in European Countries, generating 300 TWh of energy [150]. Solar energy, also, has one of the lowest electricity generation costs [151], and the potential to create a significant number of new jobs in the energy sector [150].

At a national level, the European c-Si market had its real start in 1991, with the introduction of the Feed in Tariff scheme in Germany [52]. This policy tool has been adopted, in the following years, from countries worldwide [52]. In the EU, in particular, the FiT scheme was of extreme importance [55], since it gave companies the first real concrete governmental action towards the deployment of renewable energy sources [52]. Before that, initial costs related to solar power installations were extremely high, compared to investment returns, causing low investment and innovation rate [49].

One of the main Industrial-Energy policy in the EU is the German *Energiewende* [152]. Within the initiative, Germany aims at phasing out nuclear power plants before 2022 [153], at increasing the share of electricity generated from renewable energy sources to 80% [154], and at reducing GHG emissions by 95% by the year 2050 [152]. In 2016, Germany accounted for 397 new PV installations, supported by a national funding of 63.99 million euros [84]. Italy aims, by 2030, to reach 30% of total energy consumption and 55% of electricity generation from renewable energy sources [155].

France has numerous nuclear plants in the country, therefore a low carbon electricity mix [156]. Also, the country, in 2019, set the Energy and Climate Act, aiming ad a net zero emissions target by 2050 [156]. Dutch energy policy (the 2019 Climate Act), aims at generating 100% of electricity from RES only by 2050 [157]. Spain, by 2050, aims at a 100% renewable electricity mix [158]. As such, it is centred on the massive development of solar and wind energy [158]. Portugal's National Energy and Climate Plan aim to put the country a path to achieving cost effective carbon neutrality by 2050 [159]. Greece has set targets to reduce greenhouse gas emissions by more than 56% by 2030 compared to 2005 and to have a climate neutral economy by 2050 [160]. Sweden has targets to have a net-zero carbon economy by 2045 [156]. Sweden was the first country to introduce carbon pricing and has the highest carbon price in the world, which has proven effective at driving decarbonisation [156]. Denmark's aims to cut GHG emissions by 70% from 1990 levels by 2030 and for renewables to cover at least half of the country's total energy consumption by 2030 [156].

Table 4 recaps the main European national energy policies, and the solar PV target, up to 2030.

MS	Energy Policy	Main Targets	Solar Power Subsidy
Austria	NECP	GHG emissions: -36% by 2030 compared to 2005	Tax Exemption
Belgium	NECP	GHG emissions: -35% by 2030 compared to 2005 RES: 17% of gross final energy consumption by 2030	Rebates
Denmark	NECP	GHG emissions: -70% by 2030 compared to 1990 RES: 50% of gross final energy consumption Coal: phase out by 2030	/
Finland	Climate Change Act	GHG emissions: net zero target by 2035	Tax Exemption
France	Energy and Climate Act	GHG emissions: net zero target by 2050	FiTs
Germany	Energiewende	GHG emissions: -55% compared to 1990 Coal: phase out by 2038 RES: 50% of gross final electricity consumption	FiTs
Greece	NECP	GHG emissions: -56% by 2030 compared to 2005	Auctions
Hungary	National Energy Strategy	GHG emissions: net zero target by 2050	Auctions, FiTs
Italy	NECP	RES: 55% of electricity generation by 2030	Tax Exemption
Luxembourg	NECP	GHG emissions: -50% by 2030 compared to 2005	Co-investments (20% of actual costs)
Netherlands	Climate Act	GHG emissions: -49% by 2030 compared to 1990 RES: 100% of gross final electricity consumption by 2050	SDE++
Portugal	NECP	GHG emissions: -17% by 2030 compared to 2005	Auctions
Spain	NECP	GHG emissions: net zero target by 2050 RES: 100% of gross final electricity consumption by 2050	/
Sweden	NREAP	GHG emissions: -59% by 2030 compared to 2005	Tax Exemption

Table 4: *Main National Subsidies for solar power in the European Union*
source: IEA https://www.iea.org/countries

During recent years, European energy policies had to face an unexpected event, that was COVID-19. COVID-19 slowed the steep growth curve of solar power that evolved during the last years, but at the same time, it created great opportunities for new rounds of investments, mainly due to the implementation of the European Union's Recovery Plan [161]. The plan represents an unprecedented and ambitious investment plan that aims at accelerating the Green Transition throughout Member States, developing new opportunities for jobs creation and industrial growth [161].

The Recovery and Resilience Facility (RRF) will allocate €672.5 billion to Member States for projects that align with the European Green Deal objectives, under the form of grants, loans, or state guarantees [150].

Within the Recovery Plan, 4 main flagship initiatives are directly relevant for the solar industry [150]:

- Renovate: doubling the renovation rate by 2025;
- Recharge: deploy at least 1 million EV charging points by 2025;
- Power up: integrate 250 GWp of RES by 2030;
- Reskill: foster high-skilled workforce by 2025.

The Recovery Plan, combined with the goals set in the European Green Deal and the objectives of individual National Energy and Climate Plans, represent a unique opportunity for Member States to boost the domestic solar industry and create green employment [161]. Now that both strong subsidies and clear climate targets are set, and considering that, within RES, solar has reached the lowest production costs and the highest possibilities for scalability, all the prerequisites are there to forecast that, in the coming years, new solar installations throughout European countries will peak [161].

3.2 China

In China, the leading Industrial and Energy Policy is the Five-Year Plan (FYP) [18]; the FYP is the main policy tool that China uses to drive economic and social development on a five-years basis [162].

China showed a concrete interest towards environmental issues for the first time in 1998, when it signed the Kyoto protocol [163]. One year later, solar power was first included in Chinese energy policies as key for a successful energy transition [145]. China started a process of rural electrification, supported by a series of tax policies [145].

China's solar deployment started around 2007, with demonstration projects [164]. When the global financial crisis occurred, the Chinese industry suffered drawbacks [164]; nevertheless, China introduced a series of PV-favourable policies, that promoted a new round of investments [164]. Until 2012, China's industry was concentrated in foreign markets [145]; to counteract EU and US anti-dumping tariffs [142], Chinese companies received added subsidies from the national government, causing the domestic market to grow rapidly [145]. In the following years, China strengthened its PV solar subsidy policy (*PV Forerunner, price leverages, FiTs*), causing a rapid technological development and costs to be reduced by two thirds [164] [145]. China is now aiming at reaching PV grid parity [165].

The 14th FYP, for the first time, the Plan outlines long-term China's climate goals, and refers to a potential CO2 emission cap [162]. Also, it aims at a reduction of carbon intensity (-18%) and energy intensity (-15.5%) during the years 2021-2025, to reach carbon-neutrality by 2050 [162]. To achieve this, the country aims for at least 1.200 GWp of combined solar and wind power generation capacity – solar taking the greater share of the two [161].

The FYP welcomed a series of proposals to reduce the nation's emissions coming from important industry actors, such as energy companies, technology firms, and heavy-industry manufacturers [166]. Timeline, road map, and the KPIs at the local and sectoral level, will be clarified in the 14th FYP's forthcoming sector-specific and regional plans (late 2021, beginning of 2022) [162].

Since costs in the Chinese solar PV industry have drop, the government is reducing subsidies and FiTs [165]; subsidies for new solar projects will stop from August 2021 [167].

4 Market Dominance Assessment

This chapter outlines the actual application of the Analytical Framework to the European and Chinese case-study.

The development of the Market Dominance Assessment follows sequential steps. First, each of the static variables is valorised through the collection of quantitative data. The type of data needed for the research differ for each variable, as well as its unit of measure. Also, China and the European Union have diverse data collection methods for statistic purposes. Within the European Union, countries are more or less interested in collecting certain typologies of data, depending on their industrial and energy policies. Normalizing the data, therefore, was not a simple process. Limitations in access to databases and the lack of up-to-date statistics are detailed in the following sections, for each variable. Data are not collected as absolute values, but always associated with a detailed description, explanation, and interpretation. Data, as well, have been often narrowed down to the specific purpose of this research, and many assumptions have been drawn to simplify the process of collection. The comparison between the quantitative data collected, from variable to variable and from China to the EU, is outlined in Chapter 5.

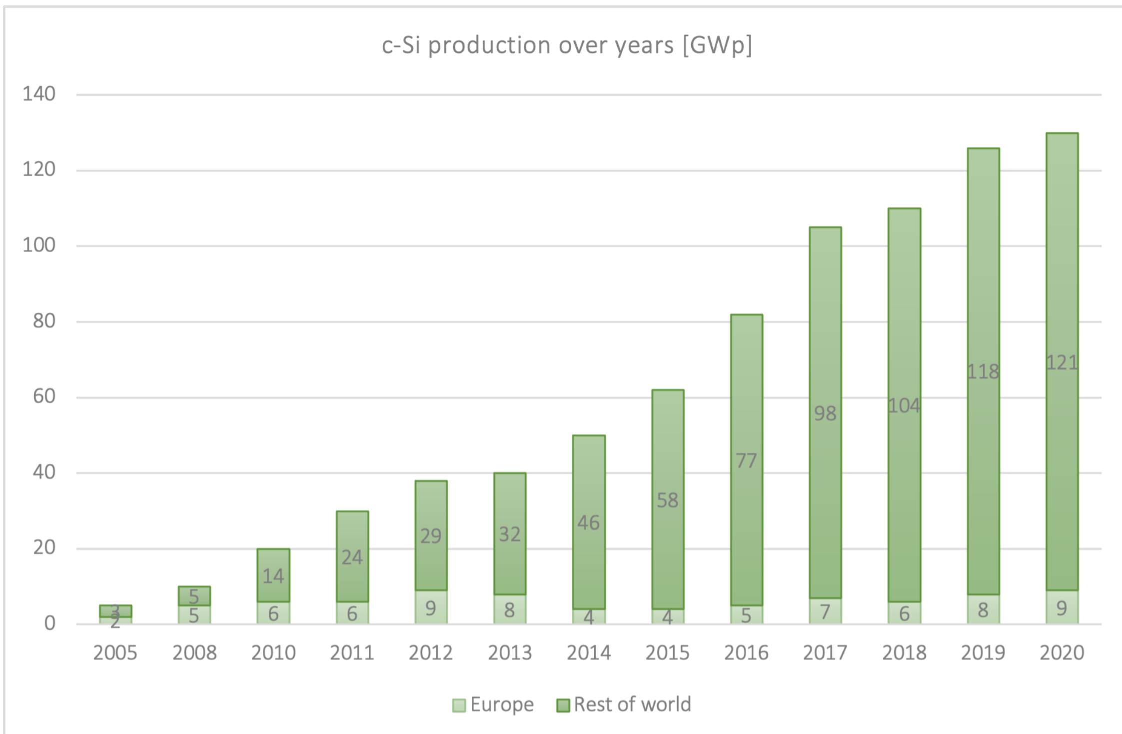
Next, literature, reports, and journal articles are the basis for the collection of qualitative data. Dynamic variables are valorised as a comparison between China and the EU, since they only add valuable insight in the discussion when both the two parties are involved in the analysis. Here, the interconnection and the mutual influence of one variable over another (whether static or dynamic) are easier to notice.

The final outcome of the Market Dominance Assessment consists in an overall discussion that takes into account all the previously identified significant characteristics of the c-Si solar industry, and structures them into an Analytical Framework that analyses how and to what degree China is dominant in the global c-Si supply chain.

4.1 European Union

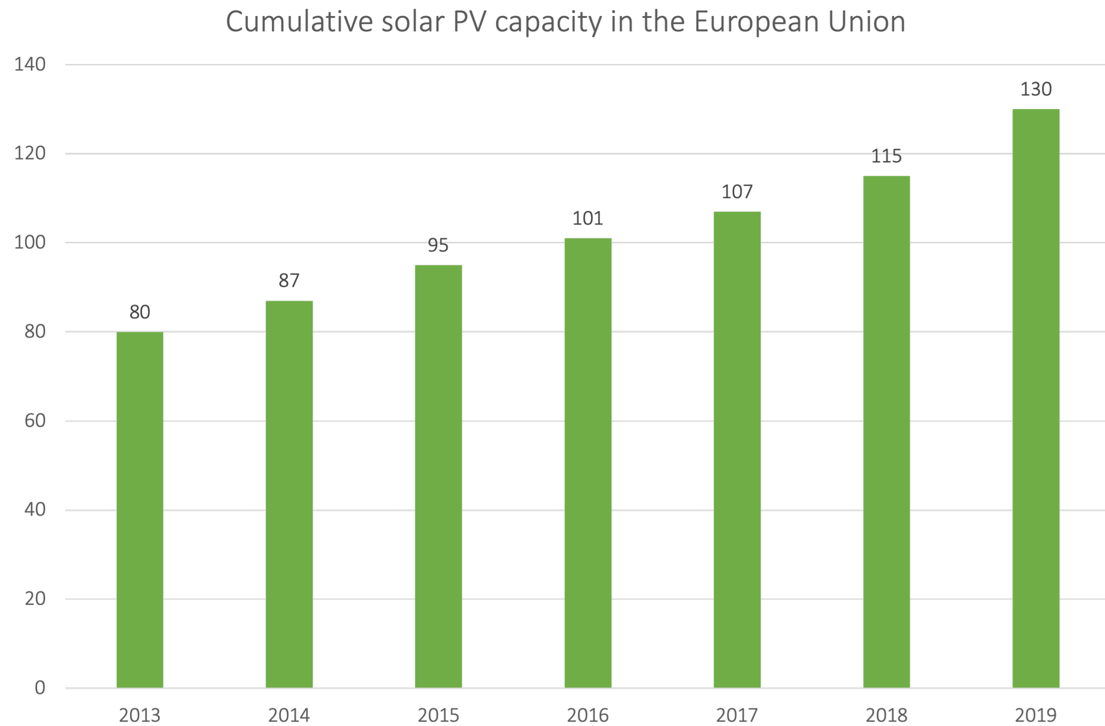
4.1.1 Production Capacity

The PV Status Report 2019, composed by the JRC Science for Policy Report under the European Commission, states that, up to 2020, the cumulative c-Si solar PV cell, wafer and module production output in the European Union amounted to 9 GWp [168]. Compared to the worldwide PV panels manufacturing, the European production capacity is equal to the 6% of the global c-Si solar wafers, cells, and modules production, that accounted, in 2020, for approximately 130 GWp [168].



Graph 1; Source: IRENA

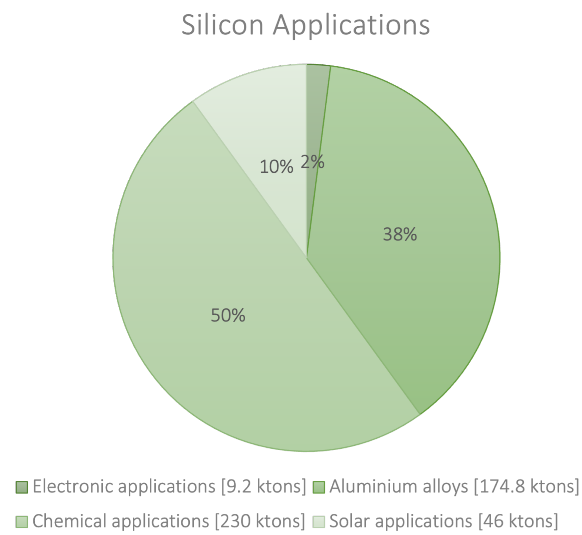
In terms of solar power capacity, during 2020, EU members states together installed 20 GWp [169]. Up to 2024, SolarPower Europe sees annual demand crossing the 35 GWp level; increments are expected to bring the total installed solar PV capacity to 253 GWp [161]. These expectations are mainly drawn from the National Climate Plans of individual states, that, with different percentages, aim at increasing the share of solar power in their energy mix in the coming years [161].



Graph 2; Source: IRENA

4.1.2 Silicon Metal

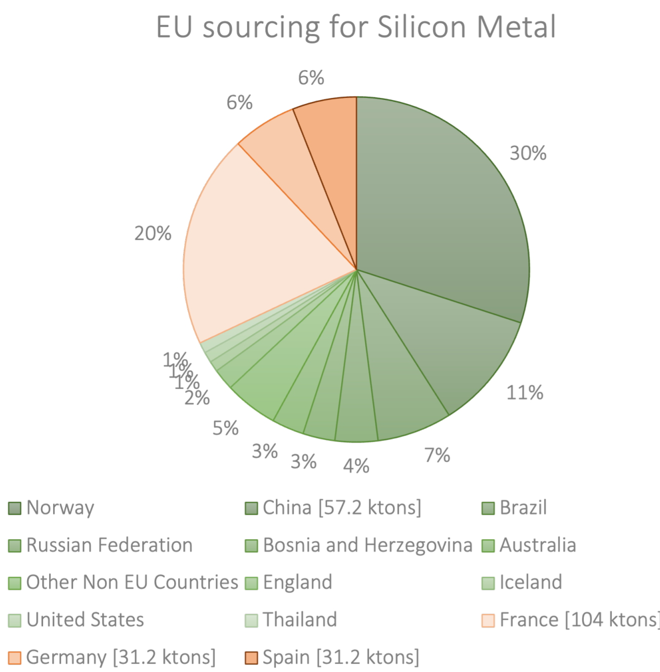
Silicon metal is on the EU's list of CRMs, and its production falls under the Directive on the Emissions Trading Scheme, meaning that there are limits on its refinery [170]. Three EU Member States extract and process high purity quartz into silicon metal, namely Spain, Germany, and France. While extraction data are not precise, since the refinery process happens mainly onsite, the total consumption of silicon in the EU, both for metallurgical and photovoltaics applications, up to 2020, corresponded to 460 metric tons per year [170]. Silicon, in Europe, is purchased for different end-uses; within these, main applications in Member States are electronic (2%), aluminium alloys (38%), chemical (50%), and solar (10%) [170], as illustrated in Graph 3.



Graph 3: *Main Silicon Metal applications in the EU (2016-2020)*
Source: EUROSTAT

While there are three Member States that contribute to the production of this material, the EU remains a net importer of silicon metal, with an average import of 350 metric tons per year [170]. Foreign supplies for the European Union mainly come from Norway (30%, that is 105 metric tons), with China and Brazil, respectively, second (11%, that is 38 metric tons) and third (7%, that is 25 metric tons) [170].

Overall, the European sourcing for silicon Metal reached an average of 520 metric tons per year, surpassing the total averaged annual consumption of this material [170]. Main domestic sourcing of silicon metal comes from France (20%, that is 104 metric tons), Germany (6%, that is 31 metric tons), and Spain (6%, that is 31 metric tons), that together produced an average of approximately 170 metric tons in one year [170]. Graph 4 recaps the EU's sourcing of silicon metal in 2020.



Graph 4; Source: EUROSTAT

The total consumption of silicon in European Countries for solar applications corresponded between 2016 and 2020 to approximately 46 metric tons per year [170]. Being the usage of silicon metal for solar applications equal to the 10% of the total European consumption, and, within these applications, 95% dedicated to c-Si wafer-based solar panels, the annual needs of the EU for silicon metal amounts to 37 metric tons per year [170]. C-Si solar panels are becoming crucial in the energy transition towards more sustainable methods of energy production, and the needs for silicon metal applied to c-Si solar panels are consequently forecast to grow rapidly in the coming years. More specifically, the compound average growth rate will be of 10% up to 2025 [170].

In c-Si technologies, the usage of silicon metal corresponds to 3g/Wp [171]. This means that, to reach a generation capacity in the order of 230 GWp, in line with the European Green Deal goals, the European demand for silicon metal, used in c-Si solar applications only, will increase of approximately 8 metric tons [171]. Table 5 recaps the data collection about silicon; it shows the import, export, consumption, and production trends in the EU.

EU sourcing [520 metric tons/y]		
Norway	30%	
China	**11%**	56 kt/y
Brazil	7%	
Russia	4%	
Bosnia	3%	
Australia	3%	
Non-EU	5%	
England	2%	
Iceland	1%	
US	1%	
Thailand	1%	
France	**20%**	108 kt/y
Germany	**6%**	33 kt/y
Spain	**6%**	29 kt/y

EU production [170 metric tons/y]		
France	**63%**	108 kt/y
Germany	**19%**	33 kt/y
Spain	**18%**	29 kt/y

EU consumption [460 metric tons/y]		
Electronic	2%	
Aluminium alloys	38%	
Chemical	50%	
Solar	**10%**	46 kt/y
Solar C-si		**37 kt/y**

Global production [2700 metric tons/y]		
China	**66%**	1782 kt/y
US	8%	
Brazil	7%	
Norway	6%	
France	**4%**	108 kt/y
South Africa	2%	
Australia	2%	
Russia	2%	
Germany	**1%**	33 kt/y
Spain	**1%**	29 kt/y
Canada	1%	

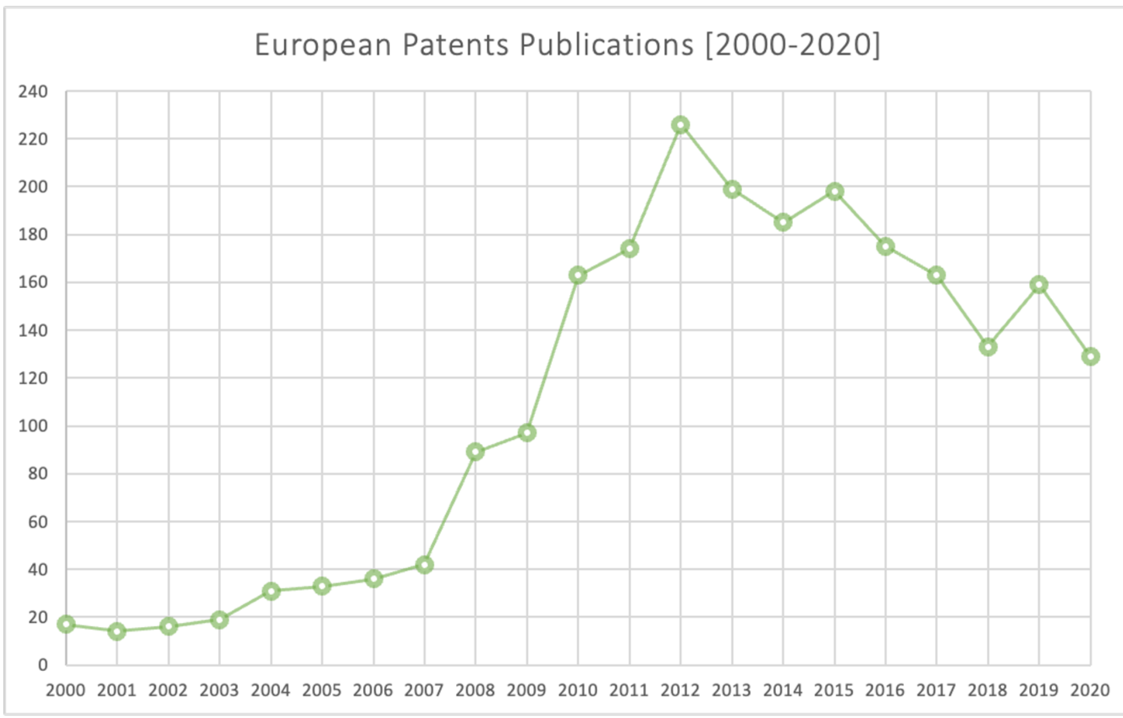
EU imports [350 metric tons/y]		
Norway	44%	
China	**16%**	56 kt/y
Brazil	10%	
Russia	6%	
Bosnia	5%	
Australia	5%	
Non-EU	7%	
England	2%	
Iceland	2%	
US	2%	
Thailand	1%	

Table 5: *EU Silicon metals sourcing, consumption, production rates*

Source: EUROSTAT

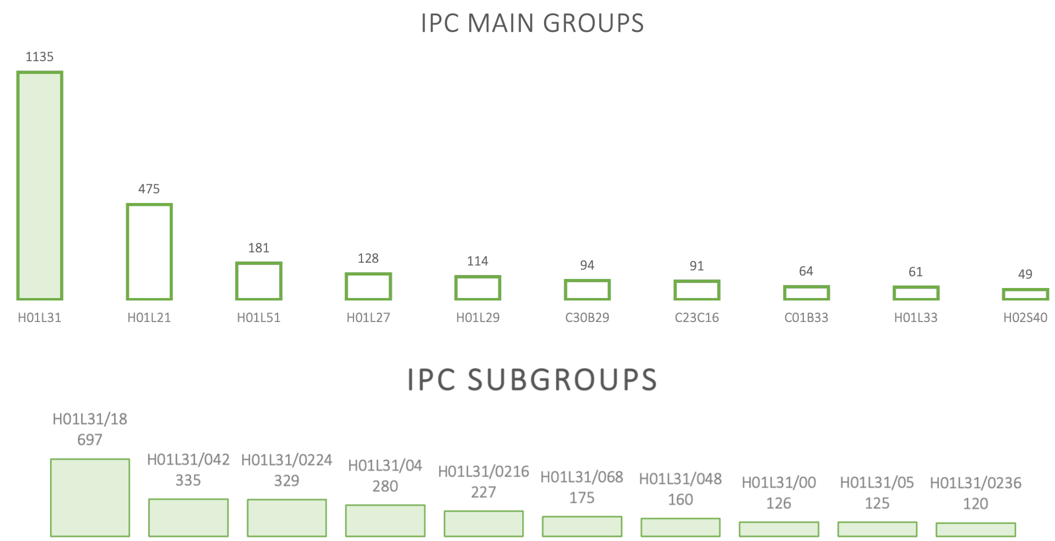
4.1.3 Patents

For the purpose of this Thesis, the database used was the EPO, since it represents one of the most complete data-set, and it collects patents for countries worldwide. The search query was <"crystalline" AND "silicon" AND "solar" AND "cell">, in order to include in the research only patents strictly related to the c-Si-based technology. More filters have been then applied to limit the publication date from 01-01-2000 to 31-12-2020; the exclusion of the year 2021 was done on purpose, since the database could be incomplete of the patents that are now awaiting for approval [90]. Next, the applicants of the patents have been filtered only to European companies or research bodies. Lastly, the selection has been narrowed down to include only the IPC groups and subgroups related to c-Si solar cells, excluding other PV-systems components such as storage applications.



Graph 5; Source: EPO

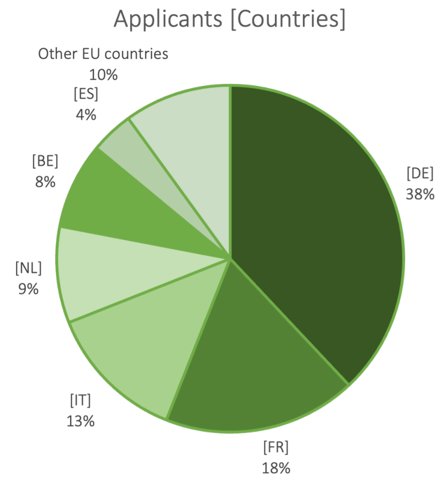
From the search query, 1655 patents were selected. As for the International Patent Classification (IPC), the highest concentration of the patents retrieved is in the class H01L031 (45%), that comprehends *semiconductor devices sensitive to light or infrared radiation*. Significant is also the contribution of class H01L21 (20%), that defines *processes or apparatus adapted for the manufacture or treatment of semiconductor*. Within the main class, there are 5 primary subgroups, that are: H01L31/18 (27%), H01L31/042 (13%), H01L31/0224 (13%), H01L31/04 (11%), and H01L31/216 (9%) (see Table 3 for detailed definitions).

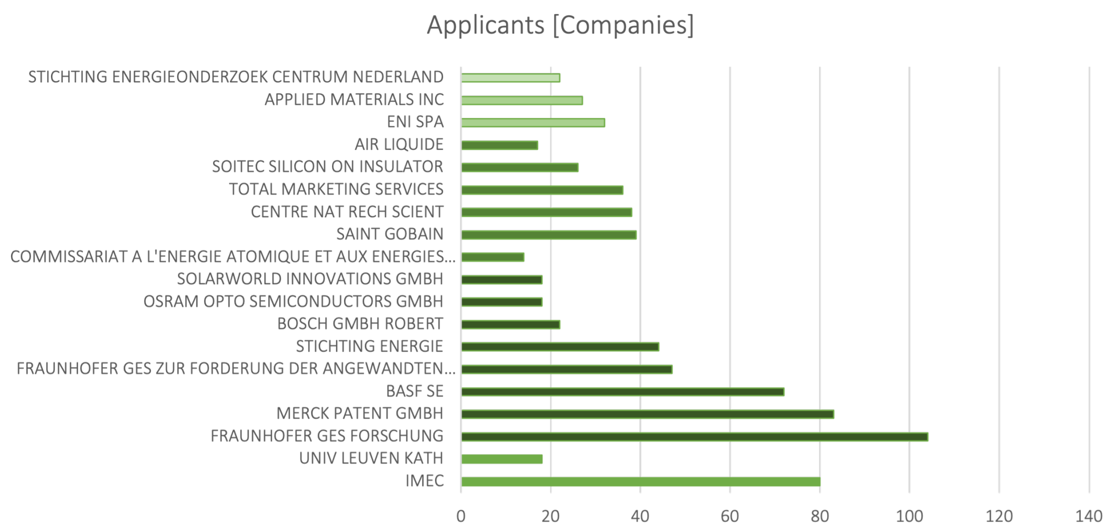


Graph 6: *EU's patents main IPC groups and subgroups*

Source: EPO

For what regards the applicants, the number one country is Germany, with a share of 38% out of the total patents retrieved, followed by France (18%), the Netherlands (13%), Italy (9%), Belgium (8%), and Spain (4%). As already stated, Germany started the market for PV solar applications with the introduction of the FiT scheme, reason why its industry developed to the point that it accounts for the almost the same number of patents deposited by France, the Netherlands, and Italy together [96]. The percentages are also relatable to the favourable energy policies and subsidy schemes put into place in the Member States listed above, that favored the deployment of the c-Si technology.





Graph 7: *EU's main patents applicants*

Source: EPO

4.1.4 Subsidies

Seven are the different main types of subsidies that, throughout European countries, support the deployment of solar power applications [172]. Namely, these are: subsidies, loans, FiTs, premium tariffs, quota systems, net-metering, and tax regulation schemes [172]. Each European country has a proper subsidy-mix for solar energy, adapted to the domestic institutional and economical setting [2] [152] [153] [154] [155] [156] [157] [158] [173] [160]. Some countries have opted for subsidy policies on a national basis, while others have different schemes for each region [172]. Belgium, for example, has three individual solar policies, one for Brussels, one for Wallonia, and one for the Flanders, in addition to the national quota system [172]. The detailed description of subsidy schemes, on both nationwide and type levels, are outlined in Annex B.

The most common type of subsidy is the FiT, with 10 countries active on it, followed by the net-metering system (9 countries) [172]. Next are tax regulation, premium tariffs, and subsidies, all of which implemented in 8 member states [172]. Each EU country has at least one support scheme that is currently active; while these schemes are directed to different solar industry segments and more or less vast audiences, with different budgets, it is important that a financial support is available and accessible for some categories of users, since economical aid is a powerful tool in driving investment, research, and deployment of a technology [58].

Country	FiTs	Subsidies	Quotas	Net-Metering	Tax regulation	Loans	Premium Tariffs
AT	X	X					
BE		X	X	X			
BG							
CY		X		X			
CZ	X	X					X
DE	X					X	X
DK				X		X	X
EE							X
ES							
FI		X					
FR	X				X		
GR	X	X		X	X		X
HR						X	
HU	X			X			X
IE		X					
IT		X		X	X		
LT				X	X	X	X
LU	X						
LV				X			
MT	X						
NL				X	X	X	X
PL			X		X	X	
PT	X						
RO			X				
SE			X		X		
SI						X	
SK	X				X		

Table 6: *EU solar subsidies*

Source: RES LEGAL EUROPE

FiTs

FiTs are allocated, in European countries, depending on a series of factors. FiTs, first of all, differ depending on the year in which the PV system has been installed, and reduce over the years, in order to adapt to the reduction in costs for PV systems operators [58]. Austria, for example, assigned

FiTs for €ct 7.91/kWh in 2018, reduced to €ct 7.67/kWh in 2019. Also, the amount of tariff assigned varies for every solar technology, being higher for those technologies that have higher costs, such as thin-film panels [172]. In Portugal, concentrated photovoltaic (CPV) receives €380/MWh, while concentrated solar power (CSP) gets €270/MWh [173]. In addition, FiTs change depending on the capacity of the solar PV system [173]. Malta, in 2019, assigned €0.155/kWh for solar systems with a capacity between 1-40 kWp and €0.1405/kWh for capacities in the range 40 kWp - 1 MWp [172]. Lastly, some EU countries adopted different tariff rates depending on the time of the day, like Hungary, that structured different tariffs for peak, valley, and deep-valley period [58].

Premium Tariffs

Premium tariffs, implemented in 8 European countries, have a similar structure when compared to FiTs: their amount varies depending on the same characteristics of FiTs, that are the year of installation of the PV system, the type of solar panels, to reflect the costs of different technologies, the capacity of the PV system, and the time of the day. In addition, premium tariffs reduce over the years, adapting to the dynamics of the solar market [174]. FiTs and premium-price policies are different since the latter offers a premium above the average spot electricity market price [174].

Subsidies

Unlike FiTs, subsidy schemes across the EU cannot be related to a standard structure, adapted to the national institutions. Instead, each country that provides financing for the implementation of solar systems proposes a different method for the allocation of the financial resources; methodologies differ both inter-nations, and within the country themselves [175]. Subsidies can differ by amount, aim of the project, technical requirements, methods of calculation, ecological requirements, minimum initial investment, type of investors, or solar technology, between others [174]. Austria, for example, proposes five different types of subsidies for solar installations [172]. Subsidy III, in particular, is dedicated to off-grid installations: with a minimum investment of €10.000 and a cap of €1.500.000, the investor receives 30% of the cost of the installation. The investor can request an additional 5% for installations in ecologically sensitive areas, EMAS, or EU co-funded projects [172].

Brussels, instead, focuses on enterprises, and allocates subsidies depending on the size of the company. Finland finances up to 30% of the initial investment in solar PV facilities, depending on the aim of the project; funding can easily reach 40% in case of the use of a new technology [172].

Quotas

Throughout the EU, RES quotas are allocated to certified installations producing electricity through renewable energy sources [175]. The number of quotas, or green certificates, depends on the amount of electricity generated in proportion with the CO2 saved: one certificate is issued for every unit of CO2 saved, with units being defined on a national level [175]. Certificates can then be traded by means of a dedicated market for renewable energy certificates [175].

Quotas are expressed as percentages of the total electricity consumption and calculated through formulas set by law; each member state has its own calculation method [175]. Each year, the amount of quotas tends to increase. Quotas are a useful tool in the deployment of renewable energy technologies; in some countries, quotas are divided between different types of RES [172]. In the EU, six regions are actively using green certificates [172].

Net-Metering

Net-metering consists in a reduction of the electricity bill, equal to the electricity fed back into the grid from the producer [176]. If the put back into the grid exceeds the amount of electricity taken from the grid, the difference between the two values is not refundable [176]. In the EU, net-metering is usually applicable for households, public administration buildings, and commercial industrial units, without significant differences between the final consumers in the net-metering structure. Nine member states have active net-metering systems [172].

Tax Regulation

Tax regulation mechanisms consist in a reduction of a particular taxation for the installation of renewable energy technologies as electricity sources [172]. In the EU, each country applies the tax reduction depending on specific local criteria [172]. France has two types of tax regulation, one is a tax credit, that implies a discount on physical individuals, therefore on the single-person; the second method applies on the value-added tax, therefore on goods (10% on the solar PV system components). Greece, instead, focuses on protecting enterprises, with diverse tax discount depending on the size of the company [172]. Italy implemented, in addition to a value-added tax relief, a reduction in real estate tax to 0,4%, when solar technology is installed [172]. In the Netherlands, one tax regulation mechanism allows for a reduction of the environmental protection tax, where consumers are exempted from the taxation if they produce electricity for self-consumption through solar power, and get a reduction when they buy it from renewable sources [172].

Loans

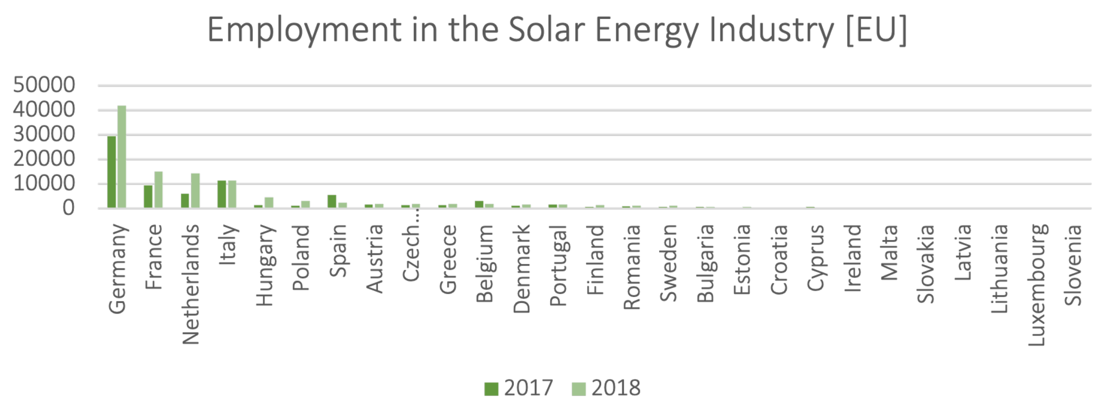
In the EU, seven member states have implemented national loan systems [172]. Loans are usually allocated as percentages of the total investment required to install a solar facility, that vary depending on the year in which the investment is done, to reflect the variations in costs of the solar technology [172]. Loans, within the EU, differ due to the pay-back year of the loan (usually ranging between 5 to 30 years), the interest rate, that is turn varies depending on the type of investor, the type of investment (such as investments in generation capacity or storage components), or the evaluation of environmental criteria [172]. In addition, there are usually requirements on the minimum investment, and a cap is fixed for maximum amounts allowed [172]. Also, loans for investments in solar technologies fall under a national or regional budget; if the investments exceed the total budget, investors can incur in a reallocation of resources, and will receive lower financing [172].

In Denmark, loans for solar PV systems are allocated from the Ministry of Energy, that must work within a budget of 10 million DKK; Slovenia proposes different interest rates for residents and corporations, and local communities [172].

4.1.5 Labour

The European Union is home of the 4.4% of the global solar PV industry employment, with Germany being the top leading country [161]. In 2018, Germany accounted for more than 40.000 jobs in its domestic solar market alone [161]. Spain, thanks to the law enforcement in the context of the European Renewable Energy Directive, saw a growth of around 1.000 jobs in 2018 [161]. During the same year, in France, solar PV employed around 15.000 people [161].

In terms of job creation, in the European Union, it is estimated that each MW of a solar PV system that uses c-Si technology, requires a labor equal to 43 people [171]; in particular, 10 workers are needed for the manufacturing process of the solar modules, while 33 for the actual installation of the PVs [171]. In a study by the European Photovoltaic Industry Association, jobs for these two phases of the solar supply chain are calculated as [person-year/MW]; this means that, for each MWp of a PV installation, 43 jobs, of the duration of 1 year, are activated [171]. Once the PV system is manufactured and installed, en fact, if the demand for new PV installations ceases, consequently the employment rate will drop down [171]. The O&M phases, instead, require, on average, 0,5 jobs for each MW of a PV system [171]. The units here are expressed as jobs because, usually, being the medium life-span of a c-Si PV system near to 20-25 years, the duration of these jobs is equated to the longevity of the PV installation [171].



Graph 8; Source: IRENA

4.1.6 Production Costs

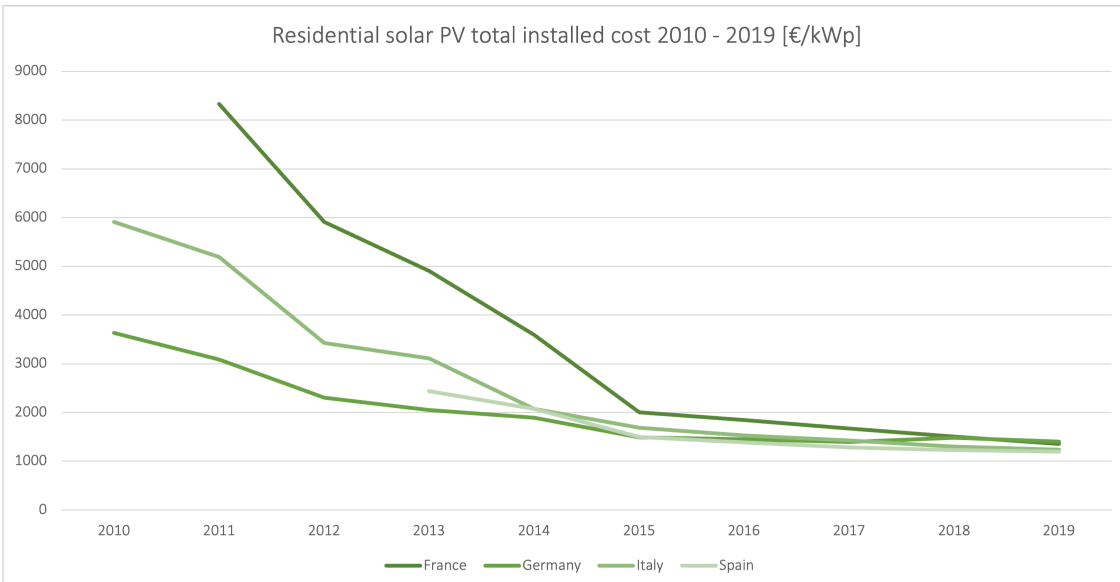
Between December 2009 and December 2019, c-Si module prices declined between 87% and 92% for modules sold in Europe, depending on the type [177]. While the weighted average cost reduction would be in the order of 80% during that period, a wide range of costs exists, depending on the type of module considered, with costs for December 2019 varying from as low as €0.18/Wp for the lower cost modules to as high as €0.32/Wp for all black modules [177]. Reductions in production costs have mainly been related to the optimisation of the manufacturing process, and to a process of vertical integration of the different phases of the manufacturing chain, that led to economies of scale [84]. Up to 2021, in the European Union, the average spot market price for c-Si modules is €0.25/Wp [178].

Three main types of solar applications are significantly present in European countries, namely residential solar PV installations (mainly, rooftop installations), utility-scale PV systems, and commercial PV systems [177]. For each scale, production costs differ; each scale, en fact, requires specific PV components [177]. Up to 2019, in France, for example, the average production cost for a residential c-Si PV system was in the order of €1360 for each kWp; a commercial c-Si PV system would cost approximately €1426,3 per kWp; 1 kWp of a utility-scale PV system of the same technology, instead, would require an investment of €979, an amount that is significantly lower [177].

Germany saw a reduction in utility-scale PV total installed costs of 76%, Italy and Spain in the order of 84%, France reduced costs by 82% [177].

Residential PV systems

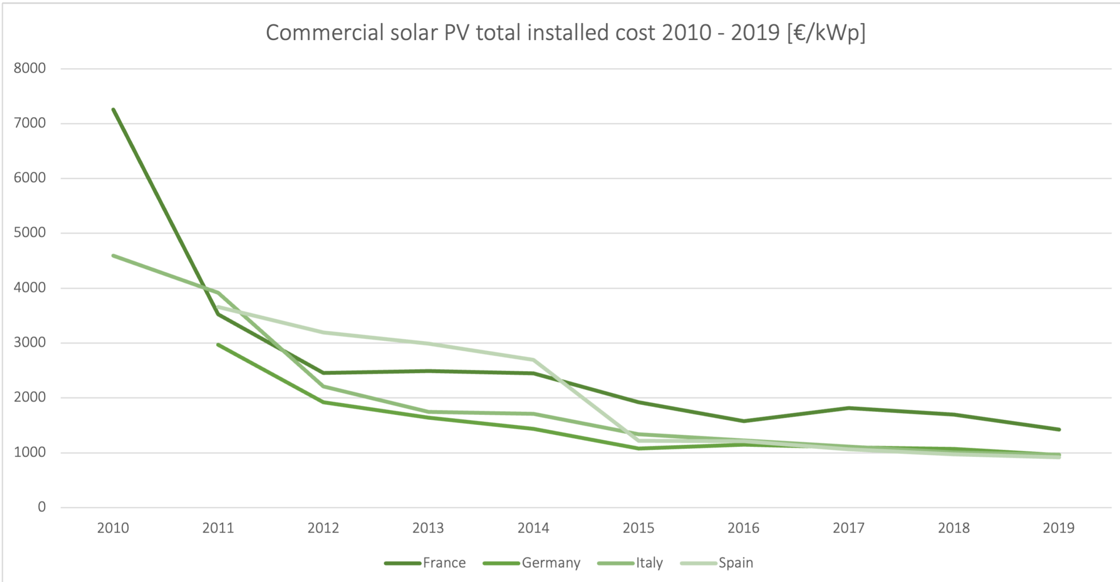
Up to 2019, the average total installed cost for residential c-Si solar PV systems, in the EU, was in the order of €1300 for each new installed kWp [177]. Where historical data are available, costs are averaged taking as benchmark Italy, Germany, Spain, and France, considered to be representative of the European solar market [177].



Graph 9; Source: IRENA

Commercial PV systems

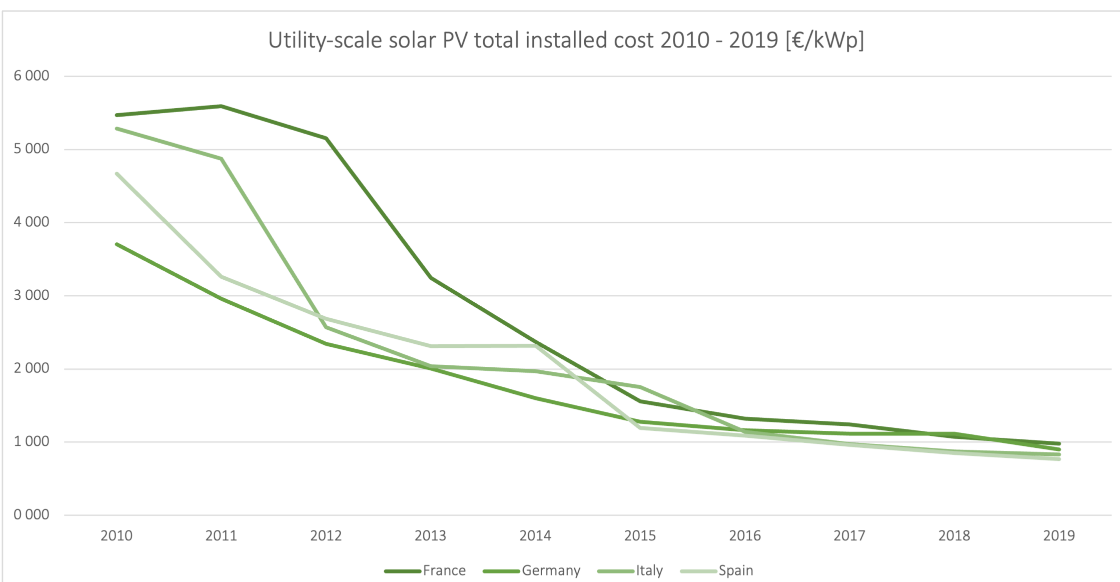
On average, up to 2019, commercial c-Si solar PV systems accounted for a total installed cost of €1000 per kWp [177]. Where historical data are available, costs are averaged taking as benchmark Italy, Germany, Spain, and France, considered to be representative of the European solar market [177].



Graph 10; Source: IRENA

Utility-scale PV systems

At the end of 2019, utility-scale c-Si PV systems in the European Union had an average total installed cost of €850 per kWp. Where historical data are available, costs are averaged taking as benchmark Italy, Germany, Spain, and France, considered to be representative of the European solar market [177].



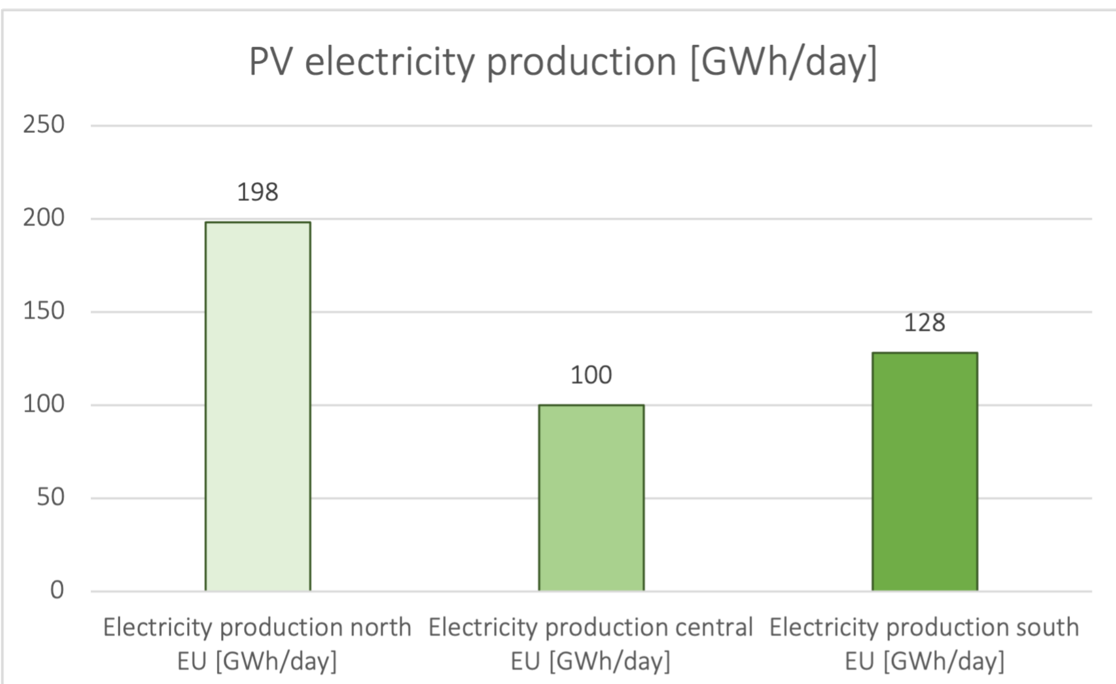
Graph 11; Source: IRENA

Understanding differences in the individual cost components of PV systems in the individual markets, consequently, remains key to understanding how to unlock further cost reduction potential [84].

4.1.7 Solar Power Potential

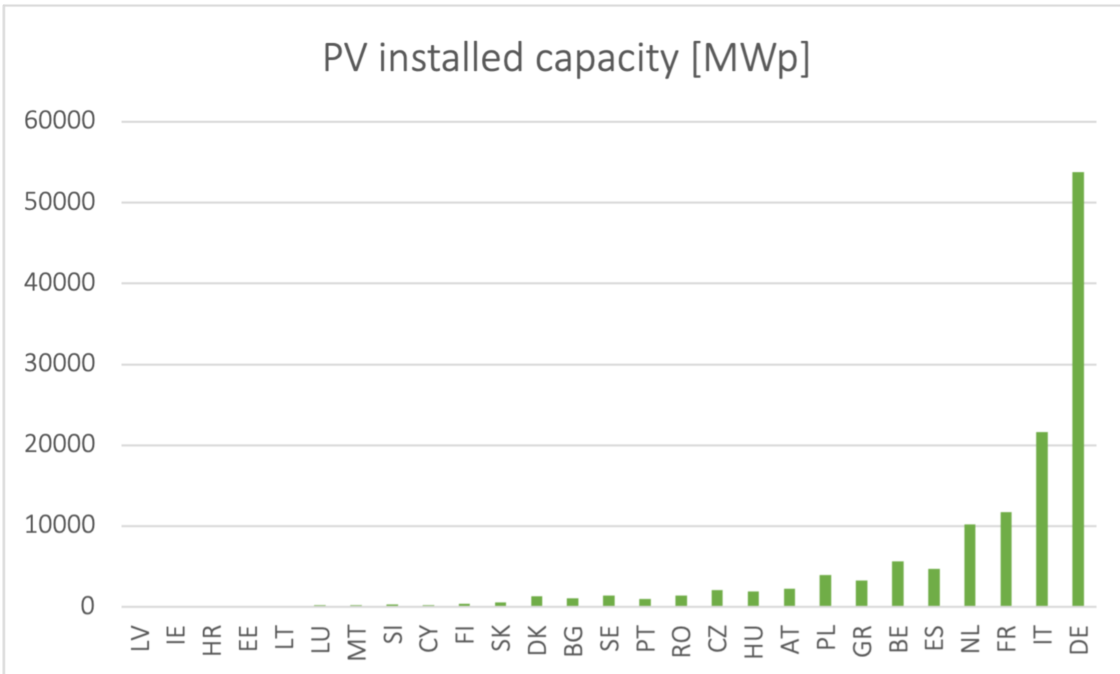
Annex C reports the complete data collection, while below are the main results from the data analysis.

Countries with the highest average practical potential are those countries located in the southern part of Europe, namely Cyprus, Malta, Spain, Portugal, Greece, Croatia, Italy, and Slovenia [105]. Here, the potential ranges from 4000 to 4700 kWh/kWp. Together, these countries produce, on a daily basis, 128 GWh of electricity [105]. Next are Italy, Bulgaria, Croatia, Romania, Hungary, Slovenia, France, Slovakia, Austria, and Czech Republic. Their average practical potential can vary from 3000 to 4000 kWh/kWp. The medium zone produces 100 GWh per day of electricity through solar power [105]. Last, but not least, northern European countries have an average practical potential between 2500 and 3000 kWh/kWp. Northern Europe produces on average 198 GWh/day [105].



Graph 12; Source: World Bank Group

In terms of installed capacity, Germany leads the way with almost 54 GWp of existing solar generation capacity [105]. Germany, alone, produces almost the same amount of electricity from solar PV facilities produced by other European Countries together, with the exception of Italy [105]. Other major contributors in the generation of electricity from solar PV installations are France (39 MWh/day), the Netherlands (29 MWh/day), and Spain (21 MWh/day) [105].



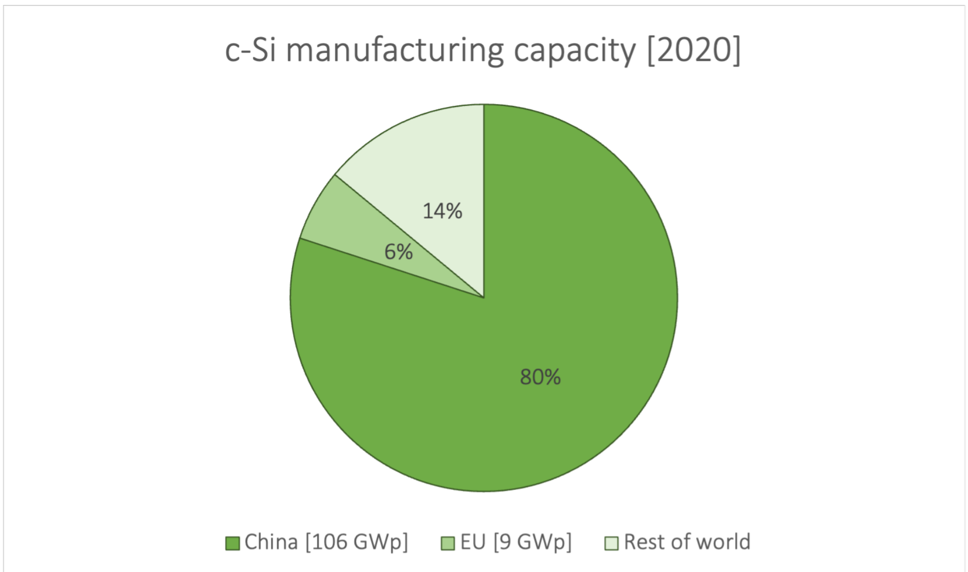
Graph 13; Source: IRENA

On average, a single citizen, in the European Union, consumes approximately 6038 kWh/year [105]. From this value, multiplied for the total European population (449 millions), emerges a total consumption of electricity equal to 2.711 TWh/year [105]. The cumulative PV installed capacity in different member states corresponds to 130 GWp, with an average energy production of 426 GWh/day [105]. Annually, the PV plants in the European Union are altogether able to produce 155 TWh of electricity [105]. This means that, up to 2020, in the EU 6% of electricity is generated through solar power; the vast majority of electricity (94%) is, therefore, produced by using other types of energy sources, both renewable and fossil-fuels based.

4.2 China

4.2.1 Production Capacity

On a global scale, approximately 80% of the c-Si production is located in China alone, with a manufacturing capacity of 106 GWp up to 2020 [161]. According to the latest roadmap of the China PV Industry Association, at the end of 2021, wafer production is believed to reach 181 GWp; silicon cell production will increase to 152 GWp, and module output is forecasted to expand to 145 GWp [161].

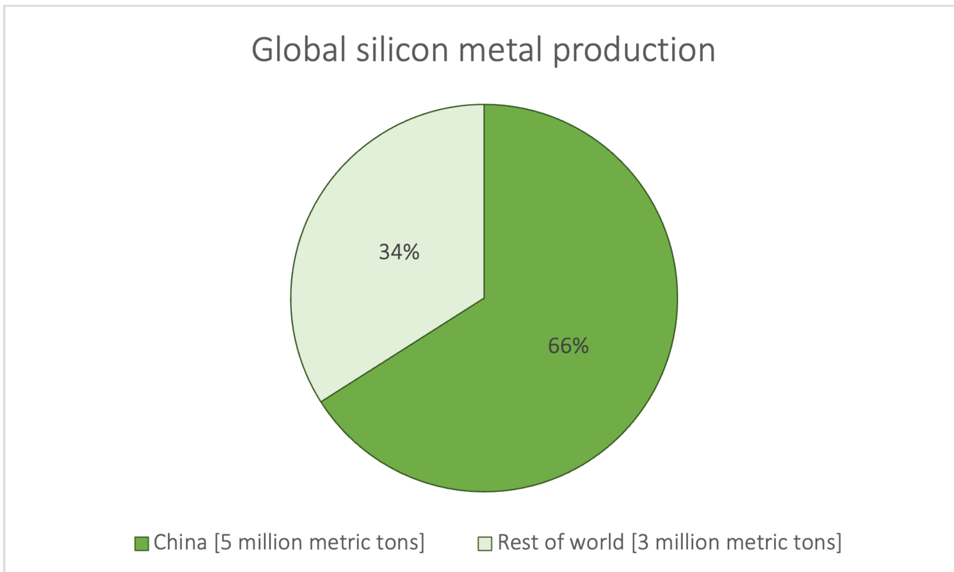


Graph 14; Source: IRENA

The rapid expansion in c-Si manufacturing capacity is due to multiple factors. Firstly, the implementation of favourable national policies for the development of solar technologies, that in turn stimulated significant rounds of investments in solar technologies [179]. Next, an increase in vertical integration of the different phases of the solar supply chain, that led to dramatic cost reduction, and consequently investments in additional manufacturing capacity [179]. Lastly, the development of the domestic solar market increased local demand for c-Si technologies [179]. After 2015, these series of investments caused the global solar industry to suffer from oversupplies; as a consequence, solar wafer, cell, and module prices drop worldwide [179].

4.2.2 Silicon Metal

China is the world's largest producer of silicon metal [170]. Around 5 million metric tons of silicon were produced in 2020 in China, that is more than two thirds (66%) of the global production, equal to 8 million metric tons [180]. Other countries whose production of silicon metal is significant are the United States (8%), Brazil (7%), and Norway (6%) [180]. During the same year, China consumed 61% of worldwide production [170]. Strong efforts undertaken by the Chinese government to accelerate the growth of the solar industry are also expected to bolster the demand for silicon metal over the coming years [180].



Graph 15: Source: STATISTA

Silicon metal has three main industrial applications in the Chinese market, that are: aluminum, silicones, and solar applications [181].

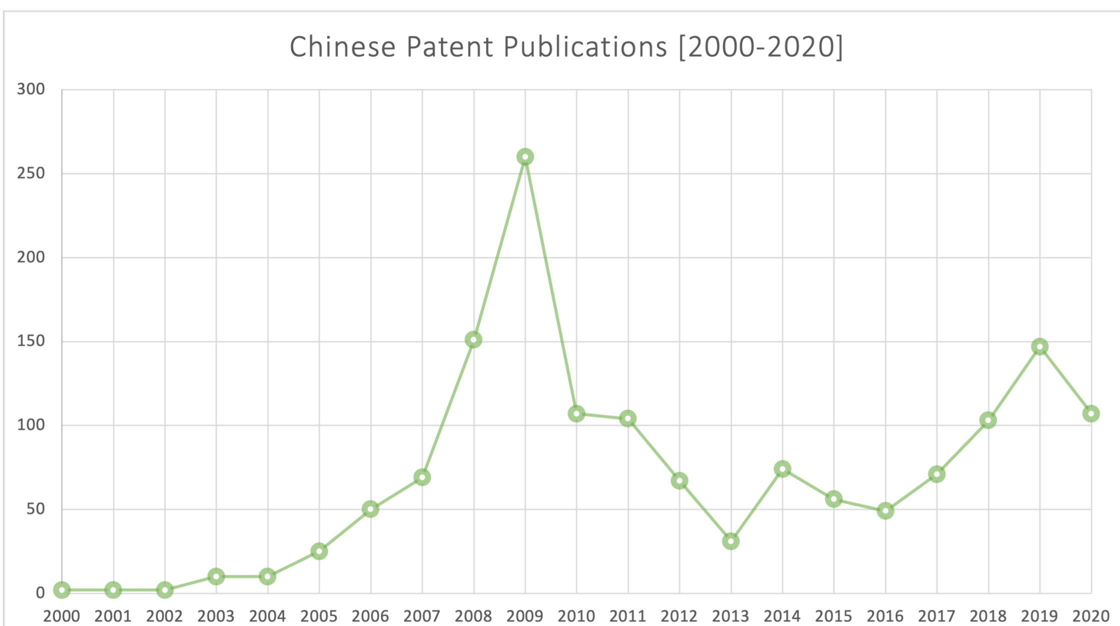
Aluminum, in 2020, dominated the market with a share of more than 50%. Silicon metal is used as a strengthener and an alloying agent in the production of aluminum [181]. The stringent pollution standards set for automakers across the world are likely to push the demand for automotive aluminum owing to its lightweight properties and ability to reduce pollution. This pressure on automakers is likely to drive the segment over the coming years [181].

Apart from the production of aluminum alloys, a significant share of the total silicon metal output goes for the production of silicones [181]. Silicones are man-made polymers used in varied end-use industries, such as building and construction, automotive and transportation, and healthcare. The increasing demand for silicones, especially in developing economies, is expected to benefit the segment growth [181].

Silicon metal is the solar industry is mainly dedicated to the production of c-Si technologies (95%) [182]. Solar power is key in the 14-th Five Year Plan for the transition to a green economy; this means that, in the coming years, silicon metal consumption allocated to solar applications, in China, is expected to increase rapidly [18].

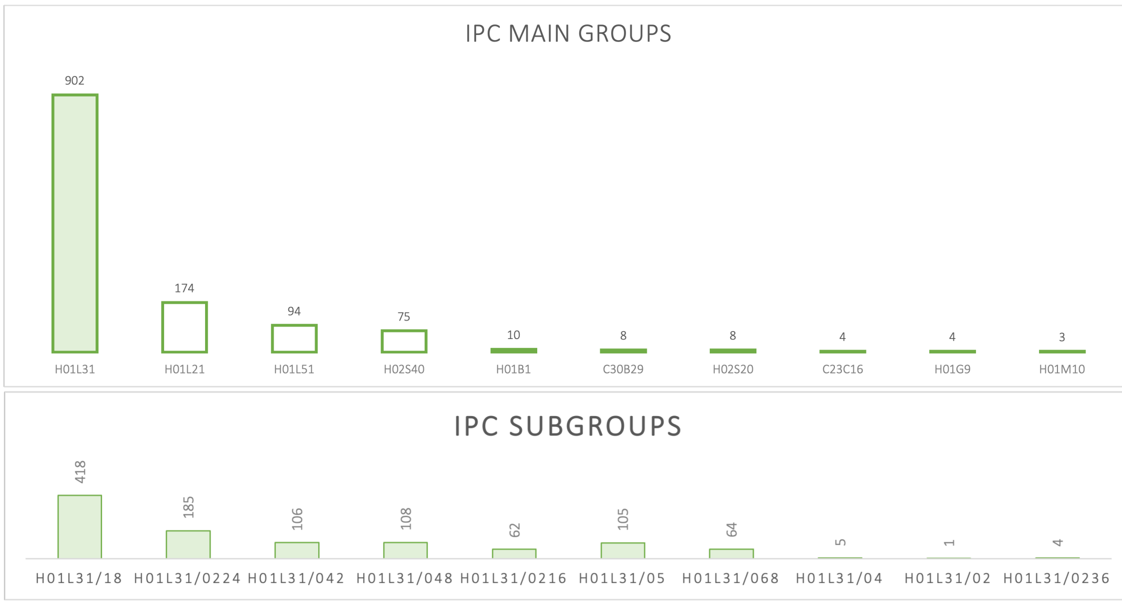
4.2.3 Patents

For the purpose of this Thesis, the database used was the EPO, since it represents one of the most complete data-set, and it collects patents for countries worldwide. The search query was <"crystalline" AND "silicon" AND "solar" AND "cell">, in order to include in the research only patents strictly related to the c-Si-based technology. More filters have been then applied to limit the publication date from 01-01-2000 to 31-12-2020; the exclusion of the year 2021 was done on purpose, since the database could be incomplete of the patents that are now awaiting for approval [90]. Next, the applicants of the patents have been filtered only to Chinese companies or research bodies. Lastly, the selection has been narrowed down to include only the IPC groups and subgroups related to c-Si solar cells, excluding other PV-systems components such as storage applications.



Graph 16; Source: EPO

From the search query, 1282 patents were selected over the specific time span. As for the International Patent Classification (IPC), the highest concentration of the patents retrieved is in the class H01L031 (70%), that comprehends *semiconductor devices sensitive to light or infrared radiation*. Within the main class, there are 5 primary subgroups, that are: H01L31/18 (40%), H01L31/0224 (17%), H01L31/042 (10%), H01L31/048 (10%), and H01L31/05 (10%).



Graph 17: *China's patents main IPC groups and subgroups*

Source: EPO

4.2.4 Subsidies

As already noticed, the central and local Chinese governments deeply influence the deployment of solar power throughout the country [183]. As for European countries, the most common subsidy scheme in China has been the feed-in tariff, allowing solar projects to lock-in an above market electricity price for 20 years [183]. FiTs peaked, in 2010, 80 cents / kWh; in the following years, FiTs started phasing-out [183]. As to April 2020, the National Development and Reform Commission further reduced the subsidy to about 5 cents / kWh [183].

The general structure of the subsidy regime, in China, is quite complicated [184]. In 2020, the total subsidy for PV amounted to about €200 millions, almost halved when compared to 2019 [184].

Starting in August 2021, China will enter a subsidy-free era, meaning that the government will no longer grant subsidies to large-scale solar parks and large rooftop systems. As the coming end of subsidies was known by industrial players in advance, this may also explain the high growth observed in 2020; the industry concluded many projects in 2020 in order to benefit from the final subsidy offers [161].

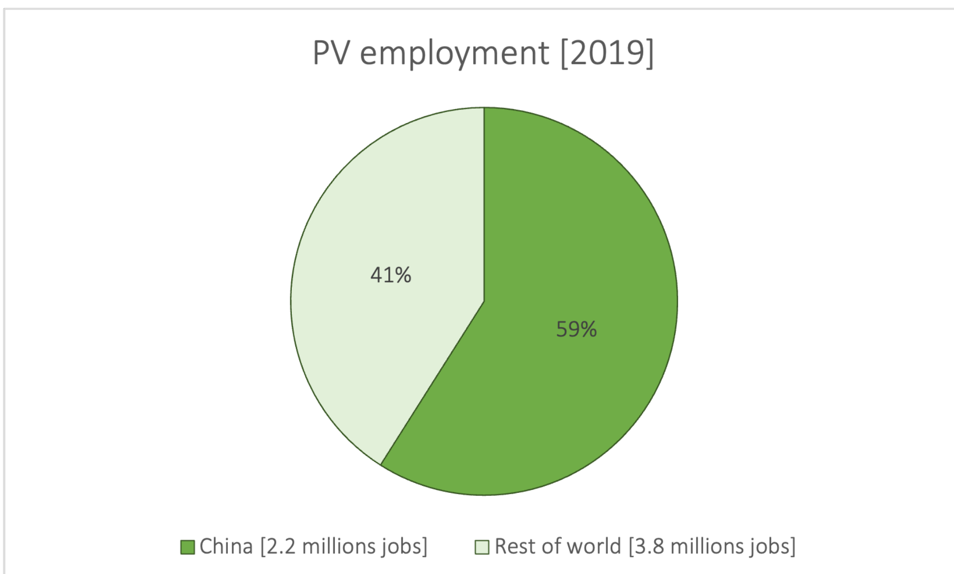
Project category	Subsidy
Residential PV Projects	2021: 0.03 yuan/kWh 2022: no subsidy allocated
PV Thermal Demonstration Projects	2021: 1.05 yuan/kWh 2022: no subsidy allocated
Centralized/Decentralized C&I Projects	No subsidy allocated for new projects

Table 7: *China solar subsidies*

source: NREL

4.2.5 Labour

IRENA estimates that, in 2019, 59% of PV employment was located in China [94]. This means that, out of the 3.8 million jobs of the solar PV industry in 2019, 2.2 millions were of Chinese competence.



Graph 18; Source: IRENA

China has a solar employment factor of 497 jobs of the duration of one year for each GWp of new capacity installed [185]. Chinese jobs in the manufacturing and installation phases peaked during the European anti-dumping tariffs period, when the Chinese local solar installations increased rapidly, due to the development of the domestic market [185]. Since 2015, instead, given the slowdown of the Chinese new solar installations, jobs in these segments reduced; in the following years, until now, they have been replaced and overcame by those jobs in the O&M and manufacturing areas [185].

When comparing different renewable energy sources, solar, in China, is the source with the highest potential to replace existing jobs in the coal industry [185]. In particular, 29% of coal mining areas are defined as suitable for solar power installations, with the potential to create 1.5 additional millions of jobs in the Chinese solar industry [185].

4.2.6 Production Costs

The total installed cost reductions that developed in China from 2009 to 2019 are related to various factors [177]. Key drivers of lower c-Si module costs are reduced labour costs, enhanced module efficiency, and the improvement of manufacturing processes [177].

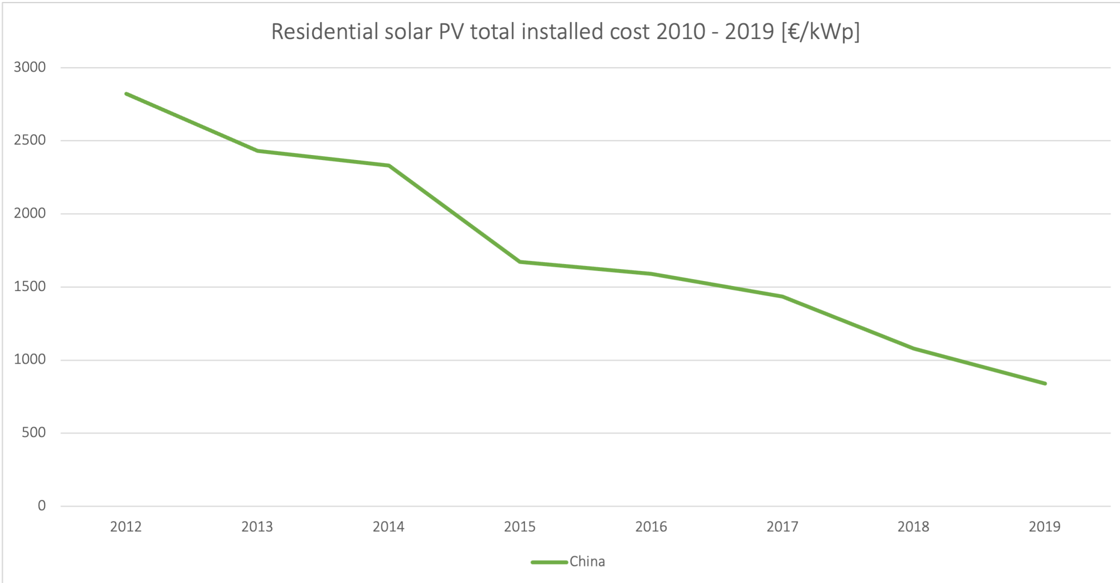
In particular, 2019 was the year that saw a significant reduction in total installed costs across all the major solar markets, such as China, India, Japan, the US, and Korea [84].

In the residential sector, China and India lead the way in terms of lowest total installed costs [177]. Worldwide, costs since 2013 have been between two and three times than those of India and China [177].

Three main types of solar applications are significantly present in European countries, namely residential solar PV installations (mainly, rooftop installations), utility-scale PV systems, and commercial PV systems [177]. For each scale, production costs differ; each scale, en fact, requires specific PV components [177].

Residential PV systems

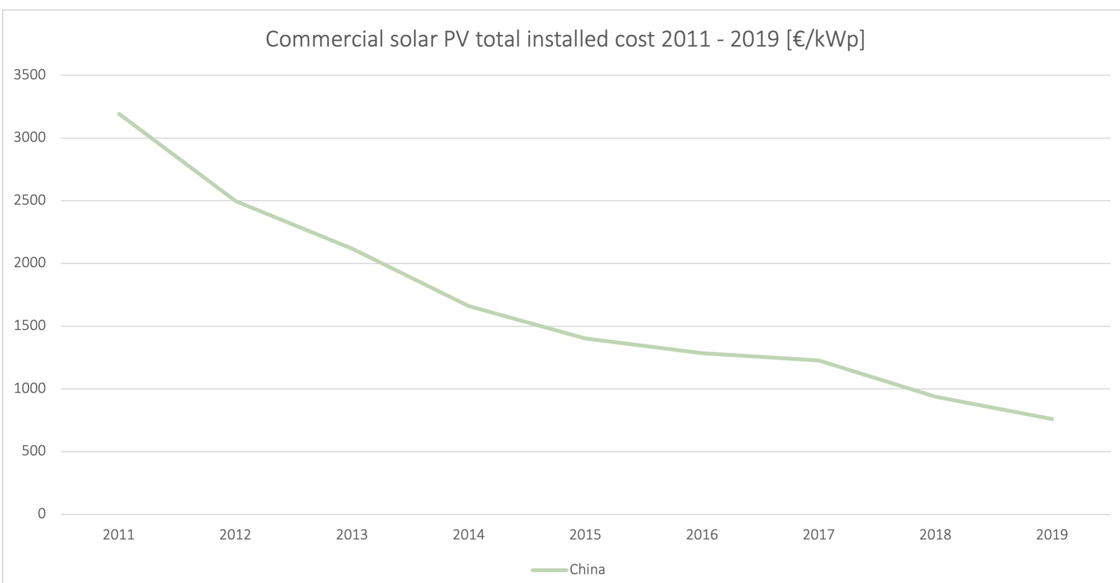
Up to 2019, the average total installed cost for residential c-Si solar PV systems in China amounted to €840 per kWp [177]. Worldwide, China and India have the lowest total installation costs for residential c-Si PV systems [177].



Graph 20; Source: IRENA

Commercial PV systems

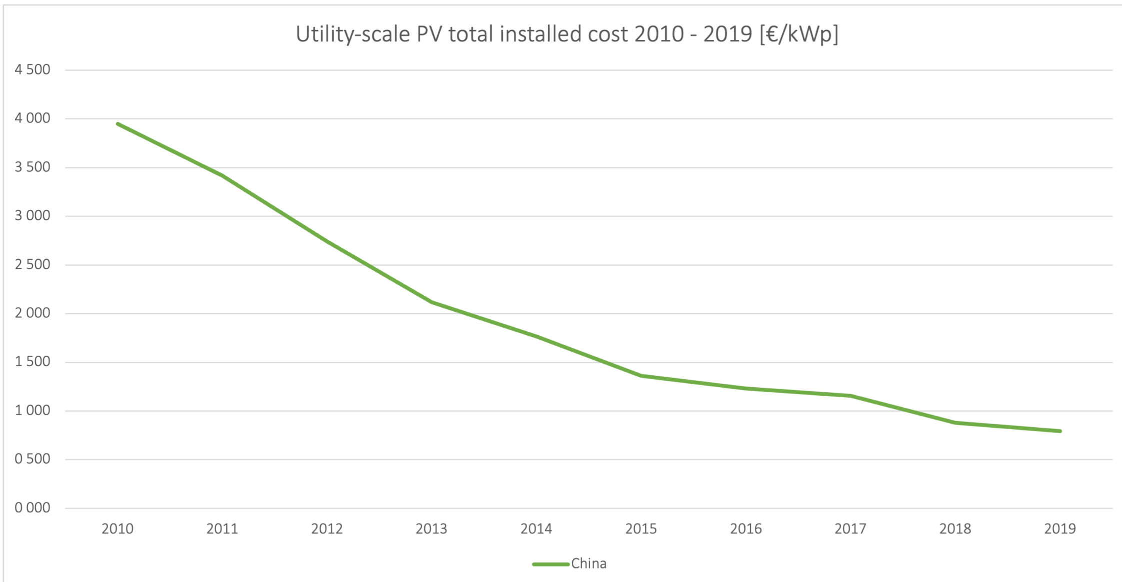
On average, up to 2019, commercial c-Si solar PV systems accounted for a total installed cost of €760 per kWp [177]. Chinese total installed costs for commercial PV systems, worldwide, represent the benchmark as the lowest [177].



Graph 21; Source: IRENA

Utility-scale PV systems

At the end of 2019, utility-scale c-Si PV systems in China had an average total installed cost of €794 per kWp [177]. For the case of utility-scale PV systems, China was second only to India (€618 per kWp) in terms of lowest total costs [177].



Graph 22; Source: IRENA

Further discussion about these data-sets will be outlined in Chapter 5, including the comparison with the European values.

4.2.7 Solar Power Potential

Annex C reports a more detailed data-set about China's solar power potential, while below are the main results from the data analysis.

China has an average practical potential of 3.883 kWh/kWp/day, against an average theoretical potential of 4.127 kWh/mq/day [105]. China is a vast country (in the range of 10 million square kilometers), where solar irradiance varies among different regions; the study divides the country into two main macro-regions: 50% of the evaluated area has a practical potential in the range of 4.0 to 4.8 kWh/kWp, while, in the rest of the country, the practical potential ranges between 3.2 and 3.8 kWh/kWp [105].

China has an electricity consumption rate, per capita, equal to 3.927 kWh/year, well below the

European average (6.038 kWh/year) [105]. With a population, in 2018, of almost 1.4 billion of people, the total electricity consumption, in that year, was equal to approximately 5.500 TWh/year [105]. The cumulative PV installed capacity in China, up to 2020, corresponded to 250 GWp, with an average energy production of 970 GWh/day [106]. Annually, the Chinese PV plants are altogether able to produce 355 TWh of electricity [106]. This means that, up to 2020, in China 7% of electricity is generated through solar power; the vast majority of electricity (93%) is, therefore, produced by using other types of energy sources, both renewable and fossil-fuel based [106].

4.3 Competition

As explained in the outline of the Analytical Framework, the index used in this research as a starting point to evaluate the degree of competition in the global solar market, with a focus on the European and Chinese realities.

Bloomberg New Energy Finance collects detailed statistics, within other fields, about solar power companies [9]. For the purpose of this thesis, the first 25 companies manufacturing c-Si wafers, modules, and cells have been considered in the calculation, as reported in the Bloomberg statistics [9]. Bloomberg clusters companies into three main tiers, that are Tier 1, 2, and 3 [9]:

- Tier 1 is represented by those companies that are highly automated, that are in the market since at least five years, that present vertical integration at all phases of the supply chain, and that invest in R%D;
- Tier 2 comprehends smaller and newer companies with some industry reputation, with some projects that have bank financing, and little investment in research and development;
- Tier 3 are companies that assemble using other manufacturers' solar cells, that use human manual labor rather than automation, and that are new, typically 1 to 2 years in business.

The classification considered in this thesis mainly comprehends companies belonging to Tier 1, with little room for companies belonging to Tier 2; none of the companies selected is related to Tier 3.

Below is the classification of the companies. The column on the right reports the average annual output, expressed in MWp.

Market shares are calculated considering an annual global production of 130 GWp of c-Si solar modules [168]. As a result, individual market shares range between 1% and 3%. Summing up the market shares of single companies, the ranking would be:

1. China, with a market share of 51.18%;
2. the US, with a market share of 15.89%;
3. South Korea, with a market share of 13.71%;
4. Germany, with a market share of 2.5%;
5. Canada, with a market share of 2.32%;
6. India, with a market share of 2.25%;
7. Taiwan, with a market share of 2.14%;
8. Japan, with a market share of 1.21%.

It is due to remark that these market shares are only abstractions of the actual state of the solar market dynamics. As stated above, many assumption have been made in the data-sets collection. In addition, the list only comprehends the "first" 25 companies of the solar market, and rankings are assigned depending on Bloomberg's standards [9].

When applying the HHI formula, its final value amounts to 3.082. Therefore, despise China having a supposed market share of more than 50%, what results from the calculation is that the market is competitive [26]. Remembering that the HHI is a simplification of the actual market dynamics, the result is useful to evaluate that there are no single companies that control the worldwide PV panels production. Still, the major presence of China in the global solar market is undeniable, especially when compared to the European reality.

4.4 Trade Policy

China and the European Union are two of the biggest worldwide traders [186]. Today, China is the EU's second biggest trading partner, behind the United States; in turn, the EU represents China's biggest trading partner [186]. China and Europe trade on average over €1 billion per day [186]. In 2020, the EU imported goods and service from China for a total amount of €400.000 millions; in turn, China imported from the EU €200.000 millions, with an unbalance equal to €200.000 millions [186].

In 2013, the EU and China launched negotiations for a Comprehensive Investment Agreement, that concluded in December 2020, with the development of the EU-China 2020 Strategic Agenda for Cooperation [186]. The main aim of the Strategic Agenda is to strengthen the EU's long-term bilateral relations with China, and to enhance a level playing field and fair competition across all areas of cooperation [186]. Also, the Agenda wants to increase transparency of China's trading system; China, en fact, joined the WTO in 2001, agreeing to reform and liberalise important parts of its economy [38]. Many companies, however, remained in the position of state-owned firms, and the government intervention in the economy is still nowadays quite significant, creating unbalances in international open trade [38].

In the context of solar power, the Chinese government interventions emerged clearly in 2013, when the EU imposed anti-dumping duties (in the range of 11.5% to 64.9% for non-cooperating companies) on imports of Chinese solar panels [187]. The anti-dumping tariffs were imposed following an investigation of the EU commission over non transparent subsidy allocation for the deployment of solar power to Chinese companies [187]. In 2018, the anti-dumping duties were removed, since the Commission stated that there were no more market conditions that justified the extension of the duties [187]. In addition, the EU gave priority to the deployment of solar energy in member states, that could be significantly speeded up thanks to foreign imports of c-Si solar panels [187].

In the EU, no customs duties are paid on goods moving between EU Member States; EU Member States apply a common customs tariff for goods imported from outside the EU; goods that have been legally imported can circulate throughout the EU with no further customs checks. Today, imports of solar c-Si panels from China are subject to regular import tariffs, with no additional duties [188].

4.5 Substitution

There are mainly three different alternative solar technologies that have a future market potential, rather than c-Si Chinese technologies [189]. These alternatives, however, have an overall reduced performance [70].

The most prominent alternatives available in the market are represented by thin-film solar panels and perovskite cells [70]. Thin-film panels can be composed of a variety of materials, namely Cadmium telluride (CdTe), Amorphous silicon (a-Si), and Copper indium gallium selenide (CIGS) [70]. Within these, CdTe and CIGS are the options with the highest commercial potential [70].

- CdTe constituted 51% of total thin-film production and 2.3% of the global PV panel production in 2017; its main disadvantage is the toxicity of cadmium, and therefore its environmental impact, that caused a reduction of the global production, since 2009, of 13%; cadmium is specifically listed in the European Restriction of Hazardous Substances. The scarcity of the other main ingredient in CdTe, tellurium, is a further drawback. CdTe is very limited in its cross-industry applicability, which further limits its disruptive potential [70];

- CIGS is the most promising thin film technology; it has high potential for efficiency increases and cost reduction. CIGS constituted 42% of total thin-film production and 1.2% of total global PV production in 2017. CIGS, however, do not offer advantage in utility-scale PV plant applications in which features such as flexibility are all but irrelevant.A further shortcoming, much like CdTe, is that CIGS has no compelling cross-industry applicability outside of solar energy [70].

- Perovskite cells are primarily lead-halide based technologies. Latest lab performances report an efficiency of approximately 20%, the fastest rate-of-efficiency increase for all PV technologies. The main disadvantage of perovskite cells consists in their instability, since they degrade quickly: perovskite cells can generate stable power for more than 2.000 hours under full sunlight. However, the industry standard 25 year lifespan of c-Si technologies equals 54.000 hours under full sunlight. Further, the cross-industry synergies of perovskite, if any exist, have yet to emerge [70].

Compared to c-Si, CIGS has a slightly lower cell (23.4% versus 25%) and panel efficiency (19.2% versus 23%) [70]. In terms of costs, thin-film technologies are still higher, when calculated as €/ kWh [70]. In addition, thin-film technologies are not ideal for residential installations; comparatively, they will be cheaper, but occupy more space and produce less electricity, due to lower efficiencies [70]. But the main bottleneck in the deployment of CIGS technologies is the lack of production capacity: globally, 130 GWp are dedicated to the manufacturing of solar PV applications [168]. Out of these, only 5% is suitable for thin-film production [168]. CIGS, as c-Si, requires adequate production infrastructures for the processing of copper, indium, gallium, and selenide and the creation of CIGS panels [70]. CIGS technology, while being an interesting alternative to c-Si solar applications, is not ready to compete with the Chinese c-Si solar technology in the global solar industry [70].

4.6 Technological Change

C-Si solar technologies have been subject to rapid technological advancement, during time, while being deployed in worldwide countries [46].

In particular, the technological advance can be noticed from the increase of cell efficiencies and from the modules price drop after 2009, due to improvements in the manufacturing methods [46].

Most of the technological advance potential, therefore, resides in the production of solar wafers, solar cells, and solar modules, both for materials used and manufacturing processes [46].

However, since its commercialization, research in further technological developments of c-Si technologies has significantly lowered; up to now, c-Si is considered to be a in a state of mature technological advance, with little space for further innovation [70]. In most recent years, the only traits of innovation can be found in the usage of silicon metal, reduced to 3g/Wp from the initial stages of 12Wp [70]. Also, c-Si is a consolidated technology, with solid supporting production infrastructures that are highly expensive and well structured: modifying the manufacturing processes, therefore, would imply major investments to adapt existing production facilities to new technological developments [46]. Instead, the current focus of research is on the development of other solar PV technologies, as outlined in the previous section, in the analysis of potential alternatives to c-Si technology [70].

4.7 Reputation Damage

A crash in the reputation image of a country can impact its interstate relations the overall interrelations between the two states, by many perspectives (political, economic, institutional, logistic) [187].

One major case-study is represented by the solar dispute happened between India and the US in 2018 (identified in the WTO as Dispute Settlement DS456) [190]. India accused the US with a dispute settlement pronouncing that subsidies and mandatory local content requirements instituted by eight American states breached global trade rules while damaging India's domestic renewable energy industry [190]. The accusation came after the US, in 2014, in turn accused India's Jawaharlal Nehru Solar Energy Mission, on the grounds that it included incentives for domestically produced solar cells and modules [190]. The dispute reached other industrial segments (such as alcohol trades), and had repercussion on the political and economic relations between the two states; the dispute peaked in 2019, when the United States terminated India's participation in the generalized system of preferences program [190].

From this example, it is easy to notice the complexities of interstate relations, especially in today's international market, where globalization has reached almost every segment of worldwide industry dynamics [191]. In this regard, China is a particular reality, since, while its trade policies are increasingly open to foreign countries and more transparent, the structure of the government remains strongly centralized, with a high number of state-owned or state-controlled firms [191]. In an institutional context similar to the Chinese, therefore, reputation damages caused by governmental decisions can have major drawbacks for the all industrial sectors as well [191].

As already outlined, in 2013, the European Commission, after an investigation on the Chinese subsidy program allocated to solar companies, decided to impose anti-dumping duties on Chinese imports of PV panels [192]. Therefore, decisions coming from the central government, had repercussion on the national solar industry, causing damages both for solar companies, that suffered from over-capacities, and to the image of the country itself [192]. The European Commission decided that companies contributing to the investigation would seen a duty rate of on average 47.7%, that is the duty rate applicable to the majority of exporters under normal trade conditions, while a duty of 64.9% would be applied to those exporters who did not cooperate [192]. As a result, the Chinese solar industry had to slowdown its exports to the European Union; the Chinese government had to institute national subsidies to foster domestic solar installations, in order to restore its solar market share and avoid companies to bankrupt [192].

In addition, China, since 2001, is a member of the WTO [38]. The membership require that countries comply with international trade agreements in a transparent way [38]. The WTO is a global organisation, where trade disputes are solved publicly; nations misbehaviour could potentially mine their global interstate relations [38]. China and the European Union, also, signed the Strategic Agenda for Cooperation, in order to increase China's transparency in long-term bilateral relations; with the Agenda, the EU aims at enhance its trade with the Chinese government, while creating a level playing field for companies of both commercial partners [193].

4.8 Counter Monopolies

As previously outlined, the c-Si PV global supply chain is divided in different phases.

First, the production of c-Si panels requires the extraction and refinery of silicon metal with a degree of purity equal to 99.99999% [63]. In this regard, China controls 80% of the global production of silicon metal, with an average production of 4.5 million metric tons of silicon metal per year [168]. In terms of sourcing, Norway leads the way with a share of 30% of European annual supplies, compared to China that accounts for a share of 11% [170]. Silicon metal, however, is used in other segments of the European industry, with c-Si solar applications accounting for less than 2% of the total consumption [170]. It is difficult to imagine that silicon produced in member states will change its current usage, and in turn be applied to solar applications: Member States do not currently have enough production capacity to manufacture enough silicon wafers to satisfy local demand [170].

Section 4.5 reports data on the European Union c-Si solar installations: up to 2021, approximately 90% of the installed solar c-Si cells and modules throughout member states are imported from China or other Asian countries [189]. Also, if the EU wants to reach the goals of the European Green Deal, and increase its PV capacity up to 230 GWp, Chinese imports are expected to keep rising in the coming years [2]. There are no significant available options, worldwide, for the EU in terms of c-Si cells and modules supplies, rather than China.

The absence of counter monopolies along the global c-Si supply chain is also explicable with the high degree of vertical integration of Chinese solar companies [84]. The process of vertical integration developed mainly due to the control over silicon metal production (that, in the past years, also reached over-supply), and the favourable subsidy scheme, that allowed Chinese companies to expand along the solar value chain [179]. European companies, in turn, mainly focuses on single-phases of the supply chain [84].

The only phases of the c-Si supply chain where the presence of China is not significant, are the installation and the O&M stages [84]. These operations, en fact, take place locally, where domestic companies control the market [84]. In these phases, however, there are a multiplicity of companies competing [84].

4.9 Potential Market Entries

In the 2021 Snapshot of Global PV Markets [169], the IEA Photovoltaic Power Systems Programme recaps the main trends of 2020 in the global solar market; it evaluates who are the main market parties, what are the current policies, and where solar power places in the broader energy transition [169].

Outside of China, the global PV market grew from approximately 80 GWp of 2019, to at least 90 GWp in 2020, with an increase of 14% year on year [169]. The EU installed 20 GWp of new generation capacity, with Germany being the largest European market (5 GWp), followed by the Netherlands, Poland and Spain (3 GWp), Belgium and France (1 GWp) [169]. Other key markets were India (5 GWp), Australia and South Korea (4 GWp), and Brazil (3 GWp) [169]. Among the top 10 countries, six are Asia-Pacific countries (China, Japan, South Korea, Vietnam, and India), two countries in the Americas (Brazil, the US), and two European countries (Germany, the Netherlands) [169]. These countries alone represent around 80% of the global annual PV market [169].

China, therefore, represents the number one leading country in terms of both installed solar generation capacity, and annual growth. Ranking number two is the European Union [169]. The level to enter the top 10 global markets in 2020 was around 3 GWp: this means that few countries, worldwide, have the potential to significantly approach the market and gain a concrete market share, when compared to the current solar leaders [177].

While countries worldwide are pushing for the deployment of solar as energy source, to reach their national climate goals and keep up with the Paris Agreement targets, currently there are no market parties that, by entering in the global solar supply chain, could impede or counteract the current rate of the Chinese expansion in this industry [177].

4.10 Discussion

This section sees an overall discussion of the data-sets and the documentary analysis just drawn, to structure the Market Dominance Assessment and outline the main results.

1. Why is the EU a net importer of c-Si panels?

The Market Dominance Assessment shows how, during 2020, European countries were able to manufacture less than one third of the c-Si panels required for new installations. While European manufacturing capacity was not able to satisfy domestic demand [161], on the other side, China, in 2020, produced 120 GWp of c-Si solar panels: the production of c-Si panels in China during recent years grew so much that the industry suffered from overcapacity. This wide unbalance that evolved during the last decade was amplified by the disincentive, for European solar companies, to expand their manufacturing capacity: firstly, c-Si manufacturing facilities require extremely high initial investments, creating barriers for companies that do not possess adequate financial assets [135]; secondly, given the need for highly sophisticated infrastructures for the refinery of silicon metal and the manufacturing of solar cells and modules, many companies, in the European Union, have no interest in integrating the manufacturing phases in their core business. Rather they prefer to import these products from foreign markets, assembly the final product locally, and selling it to retailers, installation companies, or directly to final consumers, being these alternatives more cost-effective [84].

The ability to produce solar panels grew, in China, in parallel to the silicon wafers manufacturing facilities. USGS estimates that the silicon metal production coming from China, the US, Brazil, and Norway, is sufficient to supply the global demand for many decades [170]. The market in China, indeed, is oversupplied; as a result, China exports a considerable proportion of its output [182]. One of the main worldwide recipients of the Chinese silicon metal production is actually the European Union, that, in turn, is a net importer of this material. Taking the absolute values of production and consumption as benchmarks, up to 2021, the European domestic production of silicon metal would be sufficient to satisfy the needs of the c-Si solar panels European industry [171]. However, given the vast use of silicon metal in other industrial applications (mainly, metallurgical), the European dependency on non-European countries will either remain steady, or rise [171]. By now, the import reliance for silicon metal in the EU is estimated at 63% [170].

Despite the over-capacities, China is planning to increase its manufacturing facilities; the country, indeed, wants to place solar power as one of the top energy sources in the national energy mix

[161]. While the Chinese domestic solar market has increased during recent years, consequently causing local demand for c-Si panels and silicon metal to rise, the country is still able to export a vast amount of solar panels, being European countries the worldwide number one importers: up to 2021, approximately 90% of the solar c-Si cells and modules installed in the European Union are imported from China and other Far East countries, like Mongolia [189]. The absence of a clear regulation on international trade of solar modules, during the years when the import rates started increasing dramatically, has enhanced the dependency of the EU on foreign cheaper options [189].

Given the vastness that solar PV manufacturing facilities, as well as the existing PV systems, have reached, they are considered to be expensive stranded assets, which can hardly be adapted to the production process or installation of other solar technologies. Each solar technology, in fact, has different requirements in terms of materials, production steps, and support infrastructures. The disposal of existing c-Si PV systems to be replaced with newer solar technologies would be too expensive for individual countries. In addition to that, the c-Si technology is a mature technology, with little space for further innovation, and investments in research for technological advance of c-Si technologies are today considered as not convenient [46]. European Countries, and other nations as well, therefore, have little space of action in this regard: as outlined in the Market Dominance Assessment, the potential for technological change of c-Si panels is too low to offer possibilities in significant increase of current efficiencies [46]. Two promising alternatives to c-Si panels imported from China, described in the Market Dominance Assessment, are already in the market or under development, that are perovskite and thin-film technologies. However, these options are not ready to counteract the preponderant presence of c-Si panels in the market, and cannot compete with the efficiencies, costs, and production pace offered by the Chinese competitors. Also, for what regards CdTe and CIGS panels (that is, thin-film technologies), China is already investing in these products: standing to the ENF Solar rankings, 16 out of the 25 top companies manufacturing thin-film panels are Chinese, followed by the United States [194]. Perovskite cells, instead, are the main focus in the US; these cells are currently under development, but they could break in the global solar market, should this technology be able to reach the same performances (in terms of costs and efficiencies) when compared to c-Si panels [70]. This, added to the bottlenecks presented by the design of the existing manufacturing and generation facilities, increases the dependency of European countries towards their c-Si top supplier.

In the past, the European Commission tried to stop the aggressive expansion of Chinese solar panels in its domestic market. To protect local companies, the Commission imposed anti-dumping tariffs on solar panels imported from the Asian country. Nowadays, there are no additional duties on solar panels imported from China, a part from standard import-export tariffs, and no specific protection measures for the domestic European solar market against China's dominance market share. The European institutional environment on international trade, therefore, promotes goods exchange with foreign markets, and especially with China, through the Strategic Agenda for Cooperation. Consequently, European parties can accede to solar panels at a price near to their production costs.

Considering the expectations of growth in solar power capacity, and the high costs related to the implementation of solar panels manufacturing facilities, it can be inferred that European countries are and will remain net-importers of c-Si solar wafers, cells, and modules and that, at the moment, there are no alternatives to Chinese imports [161].

2. Why does China have the lowest c-Si panels production costs worldwide?

In terms of production costs, the Member States have to face costs that are, on average, at least one third higher with respect to their Asian competitor. From Graphs 9, 10, 11 it can be noticed that, while countries in the European Union started, in 2010, with different total residential, commercial, and utility-scale installed costs, being France the country with the highest costs, up to 2019 the amounts tend to converge to the same value [177]. National subsidy schemes and European goals, in terms of solar deployment, indeed, developed synergies between countries, allowing for the creation of a European solar PVs market [195]. Companies, therefore, started to align their costs to the European standards, to remain competitive in the solar market [177].

On the other side, China has the lowest total installed costs for residential and commercial PV systems, being second only to India for utility-scale PV systems. Considering the just outlined favourable trade regime for exchange of goods between China and the European Union, it comes natural that Chinese companies have an economic advantage over European competitors. This economic advantage is enhanced by the reduced labour costs, that, together with the immense availability of workforce, are one of the key factors that allowed Chinese companies to cut down production costs so drastically [185].

The Market Dominance Assessment shows that a great contribution in the reduction of production costs that evolved during the last decade was also given by national incentives. The critical subsidy scheme used by both China and the EU are FiTs. Chinese and European companies, however, saw a different allocation of subsidies over time, especially in terms of amounts. In response to the anti-dumping tariffs imposed by the European Commission, the Chinese central government allocated billions of RMB for the development of solar projects (specifically for manufacturing facilities), in order to allow the domestic market to escalate and avoid local companies to bankrupt. These huge rounds of national incentives have created the right conditions, for the Chinese LCOE of electricity produced by solar, to almost reach grid-parity at the end of 2020. China, in 2021, has just entered a free-subsidy era.

Massive subsidies, associated with low labour costs, and availability of local reserves of silicon metal, allowed Chinese companies, since China's break-in in the global solar market, to initiate a process of vertical integration that included all manufacturing phases, from the silicon metal extraction until the fabrication of c-Si solar panels. This, in turn, led to economies of scale. While subsidies continued, and production costs kept on reducing, the degree of automation of intermediaries production steps, such as silicon wafers, cells, and modules assembling, started to gradually increasing. On the other side, European companies are now focused in the installation of PV panels imported from foreign markets and in the O&M phases of existing PV systems.

These dynamics are reflected in the calculation of the HHI, outlined in section 4.3 Competition. Remarkably, the index does not take into account data about the production of silicon metal, the production capacities of individual countries, their solar potential, the advancement in the c-Si technology, the production costs, the subsidies put in place, the availability of labour, neither the trade policies of the countries analysed.

What is more interesting and valuable, instead, are the data collected along the calculation process: with the assumptions being made, 12 of the 25 companies selected are Chinese [9]. In addition to that, these 12 companies alone make up for more than 50% of the global production of c-Si panels [9]. For what regards the EU, instead, only Germany reports a significant market share (2.5%), relatable to the company Solar World. No other European firms are included in the calculation of the Index.

These observations, drawn from the data-sets and papers collected with the Market Dominance Assessment, show how the European Union cannot compete with the production costs - and consequently with the prices - offered by their counter market party. Member States, indeed, lack the broader institutional context that led China to reach its current position. European companies did receive subsidies, but in strictly lower amounts than their Asian competitors: national incentives, in the EU, mainly created the market for solar power and, over time, kept reducing to adapt to the changing conditions of the market and to allow a level playing field between competitors of this industry. Chinese subsidies, instead, disrupted in the market to the point that the European

Commission had to impose anti-dumping tariffs, considering the allocation of national incentives against the rules of fair international trading. Labour costs, as well, are, in average, higher in the European Union. Also, European solar companies did not reach the degree of vertical integration that Chinese competitors, instead, accomplished, facilitated by the direct access to local reserves of silicon metal. European solar companies, therefore, are not, up to know, in the position to compete with the production costs reached by China.

3. Why European energy policies do not optimise solar power potential?

The Market Dominance Assessment shows, also, how national solar policies - and the subsidies that came with them - influenced the patents application rate both for China and the European Union. For what regards Member States, as shown in Graph 5, the number of patents deposited per year grows exponentially until 2012, the peak-year, then it slightly but constantly reduces until 2020. Patents applications, following the national solar policies, significantly increases from 2007, year in which the FiT scheme became properly effective in many European countries [2] [152] [153] [154] [155] [156] [157] [158] [173] [160]. Lower production costs and economies of scale promoted research in the development of the c-Si solar technology, and consequently an increase in the number of patents deposited [90]. The peak years of patents applications (2011-2013) correspond to the years in which the EU and the United States imposed anti-dumping tariffs on solar panels that had Chinese origins, to counteract their aggressive entrance in the European market and protect domestic companies [96]. The tariffs allowed, for a short period of time, European patents deposits to increase [96]. However, forecasts expect patent trends in the c-Si solar technology to keep reducing in the coming years, since FiT subsidies and financial benefit coming from the installation of new PV projects are ceasing in most EU member states [90]. On the other side, as shown in Graph 16, the number of patents deposited per year in China exponentially grows until 2009, the peak-year, then it reduces in the period 2010-2013. Next it rises again until 2019, and falls down in 2020. The growth of patents deposited until 2009 can be linked to the FiT scheme and the Township Electrification Program, which goal is to bring electricity to rural areas through solar PV systems [183]. On contrast, the drawback on patent applications of the following years reflect the European and American anti-dumping tariffs on Chinese solar panels imports of those years [183]. To counteract these effects, China in 2011 started the National Patent Development Strategy, until 2020, that guarantees financial benefits for patent-producing companies [183]. European countries, altogether, as absolute values, exceed their Asian competitors; however, from a technological content perspective, China accounts for the majority of "critical" c-Si patents. Intellectual property rights in the hand of Chinese companies allow them to protect their domestic production, and give them the exclusive commercial rights to produce the specific c-Si panels that are nowadays more common in the market.

While trends in patents applications and allocation of national subsidies are easily relatable, what also emerges from the Market Dominance Assessment is that the quick response of China to international trade accidents and the consequent implementation of ad-hoc solar policies that safeguarded its domestic solar industry was facilitated by the high centralization of the government. This institutional setting, combined with the vast availability of land, empowers China with better possibilities to design large-scale solar projects, and to adapt geographical characteristics with solar incentives that reflect the potential of solar power in different territorial bands. China, currently is only using 0,46% of its territory for the production of solar energy [105]. The country, therefore, has great potential to increase the share of solar power in its energy mix. Specifically, China aims at reaching a solar share of 11% before the end of 2021 [106]. Incentives in the European Union, instead, even if they partially succeeded in optimising the solar potential of individual countries and in fostering the deployment of c-Si technologies, led to a situation where northern countries (with the lowest solar potential, in the range of 2500 to 3000 kWh/kWp), on a daily-basis, produce way more electricity trough solar power (namely, 198 GWh/day) than southern European countries altogether (128 GWh/day), despite the definitely higher solar power potential of the latter area (4000 to 47000 kWh/kWp). Member States do have the potential to reach the goals, in terms of solar deployment, set in the European Green Deal; however, the data-sets collected show that, up to know, solar projects, on different scales, mainly followed a national-based logic, instead of including the geo-technical characteristics of the European territory. These, indeed, could allow for the design of interstate solar projects that aim at optimising both costs and possibilities offered by the solar power potential of different regions.

What is the actual market dominance of China, in the c-Si solar industry, when compared to the European Union?

Considering the current status of the global solar supply chain, and the market parties that have a stake in it, it can be stated that China has a clear market dominance above its European competitors. The EU's dependency on Chinese c-Si panels is undeniable. In terms of manufacturing capacity, China remains leader, with an output of c-Si solar panels 15 times higher than the European production rates, and the control over two thirds of the global production of silicon metal, facilitated by the direct access to domestic reserves; as for patents, China was able to protect those "critical" commercial inventions that actually disrupted in the market; Chinese production costs standards were only reached, worldwide, by India; labour availability, both low and high skilled, is massive, and accessible through reduced prices; the solar power potential of the region is optimised due to the highly centralized institutions, that in turn allow for the allocation of optimal subsidies; exports of c-Si panels to Member States is enhanced by an open trade regime, that fosters goods exchange; the stranded assets along the c-Si value chain create bottlenecks for European companies to shift their businesses towards alternative solar technologies, that, anyhow, are not commercially ready to replace the existing c-Si PV systems; there are no counter monopolies in the c-Si global value chain, nor new market parties entering the global solar market, that could replace China's dominant position with regard to silicon wafers, solar cells, and solar modules production, able to supply the EU's PVs demand; last, but not least, the learning curve of the c-Si technology has reached a state of maturity such as to make any technological advance insignificant with respect to the R&D costs associated with it.

Nevertheless, the current Chinese market dominance does not preclude the European Union to remain competitive in the solar energy industry. There exists options, for Member States, to circumvent China's absolute predominance in the commercialization of the c-Si technology. On the other hand, while the domestic solar industry, in China, exponentially increased during the last decade, the European Union remains China's number one c-Si panels importer. This means that the two markets evolved in parallel, creating, within net unbalances in terms of import-export rates, a situation of mutual dependency among the two competitors: Members States are dependent on imports from China whose solar industry, in turn, is dependent on exports to the EU for its business continuity, risking a massive over-supply should the rate of exports slow-down. In addition, the Market Dominance Assessment highlights a number of measures that the European Union could adopt, internally, to strengthen its international position in the global solar industry and reach the objectives of the European Green Deal, without necessarily increasing the local production of c-Si panels, but instead by adopting a market strategy that accepts strengths and weaknesses of China, that reflects the actual potential of European Countries in the deployment of solar power, and that focuses on an European vision. These policy options, drawn from the Market Dominance Assessment, together with the risks that emerge from the Chinese market dominance at the expenses of their European competitors, are outlined more in detail in the following chapter.

5 Chapter 5: Risks and Policy Options for the EU in the deployment of solar energy

5.1 Risks

The increase in share of solar power in the European energy mix does not come without risks for Member States [196]. The Market Dominance Assessment is a useful tool to evaluate where these risks reside, in the different phases of the solar supply chain, and to address the weaknesses of the European solar industry, with policies designed on purpose to counteract these risks and to avoid to incur in drawbacks for European companies.

First of all, the Market Dominance Assessment shows how the European Union is a net importer of silicon metal; more than 70% of the silicon metal used in the European Union is sourced from Norway, France, Germany, Spain, and China. Forecasts state that worldwide facilities, as already reported, are currently able to satisfy the global demand for silicon metals for almost a decade, with no additional extraction sites to be opened. The industry, therefore, is in a condition of oversupply. However, global crisis such as the economic crash caused by COVID-19 during these recent years, can cause the prices of materials like silicon metal to spike, due to the surcharges that parties in the distribution network would call for. The same reasoning remains valid for the import rates of c-Si panels, that, without policy measures that aim at reducing the impact of price spikes caused by international financial crisis, could become inaccessible for European companies, especially for those of smaller sizes.

Global crisis are not the only source of risks for supply interruptions from China to the EU [196]. The potential resides also in drawbacks of the Chinese solar industry, whose roots have other nature rather than a global pandemic, such as divestments or disruptions of the distribution network, that would cause damages in the worldwide solar sector [196].

Also, governments and companies are not the only stakeholders for the business continuity of the solar industry. As outlined in the Market Dominance Assessment, PV systems can be installed on three main scales, that are residential, commercial, and utility-scale. Final consumers, therefore, have a stake as well in their deployment and are somehow involved in their installation, in the case of residential systems especially. There is the potential, therefore, to encounter the resistance from local communities for the development of solar projects near to inhabited areas, or actions from activism groups that oppose to solar facilities impacting the surrounding environment [196]. The potential for such opposition must be taken into account and mitigated throughout the project implementation [196].

In addition to that, solar power is a renewable energy source, and it is, by nature, intermittent, since its power output depends on weather conditions. Electricity, instead, is needed at each time of the day, especially for those activities that are critical in a society, such as hospitals. Solar, in line with the European Green Deal goals, is becoming a large part of these critical infrastructures [196]. To ensure constant energy supply, solar energy needs to be supported by adequate storage systems, that, up to now, are still lacking, mainly due to their high prices [196]. If the European Union wants to phase-out energy generated from fossil-fuels, and switch towards sustainable and renewable modes of energy production, energy infrastructures need to be updated to the requirements imposed by intermittent energy sources, such as solar and wind.

In addition to that, as outlined in the Literature Review, one main expectation, with the deployment of RES, is electrification, in the broader sense of the term. This means that utilities that are now powered through fossil-fuels, in the near future, will be replaced or upgraded to electric-based technologies. Therefore, the European Union has to be able to reinforce its electricity grids, where needed. Considering that the global energy infrastructure is one of the most expensive worldwide infrastructure, Member States need to include, in their Energy Transition budgets, these aspects, strictly linked with the deployment of renewable energy sources.

While these considerations, drawn from the analysis set in the Market Dominance Assessment, now represent risks for the European solar industry, when accompanied by favourable policies, and addressed in advance, they can transform in opportunities for jobs creation, new business models, and the deployment of alternative solar energy technologies, with respect to Chinese c-Si panels. The next chapter outlines how the Risk Analysis just developed from the Market Dominance Assessment, in turn, developed through the application of the Analytical Framework structured in the previous chapters, represents an useful tool to derive concrete policy options that, while circumventing the current market dominance of China, can foster the deployment of solar energy throughout Member States.

5.2 Policy Options

The European Union has high potential to expand its solar industry and foster green jobs creation [161]. A favourable institutional setting, through the Recovery Plan, has been established, and it only needs European solar companies to invest in the right directions [161]. From the outputs collected with the development of the Market Dominance Assessment, the opportunities offered by European future solar policies, and the Risks Analysis drawn in the previous chapter, I derived a series of policy options that can encourage the deployment of solar power facilities in the coming years, while tackling the weaknesses of the current design of the European solar supply chain.

1. Enhance European solar projects

As outlined in the Market Dominance Assessment, the solar power potential of the European territory is not currently exploited at its best. Past and current European solar subsidy-schemes, indeed, are designed to optimise the deployment of solar energy through what policy makers have decreed to be the most cost-efficient methodology on a national basis. Member States lack the installation of solar projects that go beyond national borders, and whose design reflects the geo-technical characteristics of the territory with an international vision. RES, instead, are, by nature, strictly dependent on weather conditions, and are able to deliver their optimal output only with specific geographical conditions; solar power makes no exception. Including the overall European territory in the design of international solar projects can also offer possibilities to cut down the total investments required for their installation, and to split costs among those Member States that are involved in the project implementation.

These international projects could also be able to include in the deployment of solar power those countries that are behind in reaching their future RES goals, because they lack the financial availability to foster renewable energy sources, or because they find it more convenient to remain fossil-fuels sourced. While splitting the costs of these projects among Member States would be a complex process that sees a multiplicity of stakeholders - as learned from the endless negotiations, still on course, regarding the North Sea Wind Power Hub project -, the benefits, in terms of financial savings and optimisation of power outputs, surpass the complications that can derive from international cooperation among countries.

Also, international solar projects have the potential to create new green energy jobs. As outlined in the presentation of the variables that compose the Analytical Framework, the IRENA makes a clear distinction between direct and indirect jobs. Direct jobs created through the implementation of European solar projects would be of three main types: jobs related to the installation of the PV system, jobs linked with its O&M, and high-skilled employment, needed for the technical design of the solar powered system. Indirect jobs would be connected with all of the personnel needed to define the institutional and economic setting where the project would take place. Solar, on the other side, as outlined in the Market Dominance Assessment, is, among all types of renewable energy sources, the most jobs-creating technology. The creation of new jobs, also, must come with the European Energy Transition: considering that the European Union aims at becoming the first climate-neutral continent before 2050, people nowadays employed in the oil and fossil fuel industry need to be relocated towards other renewable industrial sectors. International solar projects have the potential to concur in filling this gap.

2. Foster the development of high-skilled workforce

The design of international solar energy projects, as above outlined, requires the contribution, especially during the engineering phases of the projects, of highly skilled workforce. The latter, however, as reported in the Market Dominance Assessment, is currently not sufficiently available in the European Union. The European Union, therefore, should work on filling this gap, with specific programs that aim at developing the knowledge required to accomplish these tasks.

Also, as stated in the Risk Analysis, the increasing electrification of the energy systems will have to be supported with adequate storage systems. This opens the opportunity, for the European Union, to become leader in the R&D and in the commercialization of these technologies. As for PV systems, the design, implementation, and O&M of these storage systems are able to create new green employment and call for specialized employees able to manage the correct functioning of the utilities.

Highly-skilled workforce cannot only contribute to the implementation of solar Energy projects, but also on the technological advance of other types of solar technologies, that better adapt to the local geo-technical characteristics of European countries, or that as well use other types of raw materials and / or manufacturing processes, therefore reducing the dependency of the European Union towards Chinese c-Si panels imports.

3. Create a European electricity market

The Market Dominance Assessment shows that there is an unbalance of electricity generated through solar power within different European regions. Northern countries, indeed, while having a lower practical solar power potential, produce, on a daily basis, 80 GWh more than the southern region.

A European electricity market could lower the unbalances within European countries. As explained in Policy Option 1, the design of international RES projects allows for both the optimisation of costs and the maximisation of output power. In addition to that, the implementation of an European electricity market has the potential to redistribute the electricity generated through renewable energy sources, at different times of the day, in the areas where it is more needed. Solar power and wind power are seen as the top renewable energy sources that will allow the European Union to reach its climate goals. Implementing international wind projects in northern parts of the EU, and international solar projects in the south, where the potential of the respective technologies is higher, means that, on an European scale, the electricity produced through these technologies would be optimised from both an economic and a technical perspective. The European electricity market would not only enhance the optimal use of the existing electrical grid, but also call for new market parties to access it and for new business models to emerge. A major electrification, as above outlined, requires the reinforcement of the grid, and higher maintenance of the power utilities, that, in turn, creates the opportunities for employment in the PV industry.

As remarked in the Market Dominance Assessment, lessons from China show that highly centralized governments can, within certain terms, better manage some parts of the industry. While this type of institutional setting cannot fit with the European Union, still the creation of an electricity market directly regulated from European institutions can facilitate the implementation of ad-hoc subsidies that foster the deployment of solar energy on a European level.

4. Facilitate bottom-up initiatives

From the Risk Analysis, it emerges how final consumers have a stake in determining the rate of deployment of solar energy technologies. The European Union, to counteract the risk of incurring into social resistance for the implementation of solar PV systems, should allow the same electricity final consumers to get access in the decision-making process that leads to the development of solar energy policies.

Including these market parties in the discussion facilitates the creation of policies that better reflect the needs and expectations of European citizens towards solar energy. At the same time, it allows for concrete bottom-up initiatives to emerge, such as solar energy communities, and to spread throughout Member States. As outlined in the European Green Deal, indeed, the Energy Transition that the EU wants to accomplish should be a *just* transition, that includes the population as well. On the other side, European citizens are the ones that will benefit from the implementation of the steps declined in the European Green Deal, when applied to their fullest potential.

From an economic and technical perspective, also, these initiatives have the potential to unleash the true opportunities offered by solar power, since they are able to highlight specific local applications of this technology that national policies usually do not cover. Depending on factors such as solar radiation, slope, land use, urban extent, population distribution, and proximity to the power grid, these initiatives can call for the implementation of alternative solar technologies with respect to Chinese c-Si panels. Therefore, they can ask for new business models that reflect the characteristics of these alternatives, and create the opportunity for new green employment.

6 Conclusion

This research has analysed, through the application of a novel Analytical Framework, the actual market dominance of China, with respect to the European Union, in the c-Si solar panels industry.

The research starts with Documentary Analysis, and it sets an overview of the evolution of the global solar industry over the last decade, until its current design. This section gives insights on the global solar supply chain structure, on the production process of a c-Si cell, and on the influence of national subsidies in the deployment of solar energy over time. Main takeaways are that the solar energy market was initiated by the implementation of Feed in Tariffs; that the solar supply chain can be seen as a pyramid, where a handful of companies control the production of silicon wafers, solar cells, and solar panels, while they peak in number in the O&M and installation phases; and that Chinese solar companies, opposed to the European competitors, were able to vertically integrate all the different phases of the solar value chain, with the exception of the installation and O&M phases, that happen locally. Next, is the literature review. Following, with the knowledge collected from the two first steps, the novel Analytical Framework is drawn. The Analytical Framework is a powerful tool that supports the Market Dominance Assessment of China above the European Union in the c-Si solar industry. The Analytical Framework consists of a set of variables, divided into static and dynamic, that represent all the significant factors that influence the dynamics of the c-Si solar market.

Namely, static variables are: production capacity, access to silicon metal reserves, patents application, labour costs and availability, national subsidies, production costs, and solar power potential. Instead, dynamic variables are: the degree of competition in the solar panels industry, the availability of alternative solar technologies - with respect to Chinese c-Si panels - available in the market, the c-Si rate of technological change, the trade regimes among the two market parties, the potential for reputation damage, should China exert its dominance through unfair market strategies, and the potential for new market parties to enter the solar PV market, causing the Chinese presence to slow-down.

The literature review allows for the identification of three main knowledge gaps, that were addressed throughout the development of the Thesis. Firstly, the main takeaway from the overview about geopolitics of renewables is represented by the lack of distinction among different renewable energy technologies, when evaluating their impact on interstate relations. This research fills this gap by focusing on the geopolitical implications that could emerge from the deployment of solar power. Specifically, this thesis turns around two market parties, that are the European Union and China. A concrete case-study, therefore, is the center of the research. This concur in addressing the third knowledge gap identified with the literature review, that is the absence of papers that, while analysing the dynamics that led to damages in the trade regimes among two or more countries, leave out of discussion the broader socio-institutional context that led these accidents to happen. This same reasoning applies to framework whose aim is to calculate the concentration of competition in an industrial sector. The research, instead, by including in the Market Dominance Assessment all the significant variables that influence the market dynamics of solar power, oversteps the limits imposed by mathematical formulas applied to a complex context such as international markets.

Next, is the overview of European and Chinese future policies with regard to energy. While the EU has set policies on a double level, that are European and national, China, being an highly centralized government, recaps future directions of the solar PV in its 14th FYP. Both realities, in the near future, aim, with different shares, at reducing their GHG emissions, especially those related to the modes of energy production, by fostering the deployment of solar power. The European Union, in particular, has recently approved the Recovery Plan, an unprecedented investment plan that aims at speed up the achievement of the goals set in the European Green Deal in terms of RES - and solar - generation capacity.

Following, is the Market Dominance Assessment, that applies the Analytical Framework to the EU-China case-study. Three are the main takeaways that can be drawn from the Market Dominance Assessment. First, China, technically, controls over 80% of the worldwide c-Si solar market; each variable of the Analytical Framework confirms the predominance of Chinese companies along the global solar supply chain, creating a situation where European parties cannot have access to those resources that allowed China to reach its current status. Secondly, the European Union is dependent on imports of Chinese c-Si panels, at the point that 90% of the current PV installations in the European territory come from China and few other Asian countries; at the same time, the EU is China's number one trading partner. C-si panels trading, therefore, over years, created a situation of mutual dependency among the two market parties, where the EU is dependent of Chinese export rates, while China, to avoid over-supply, is dependent on European import rates. Thirdly, the best market strategy that Member States can apply is to accept and recognize the market dominance of China, and work to strengthen the domestic solar industry by tackling local weaknesses. As outlined in the policy options, the European Union, on my advice, should work, in the first place, towards the implementation of a European electricity market.

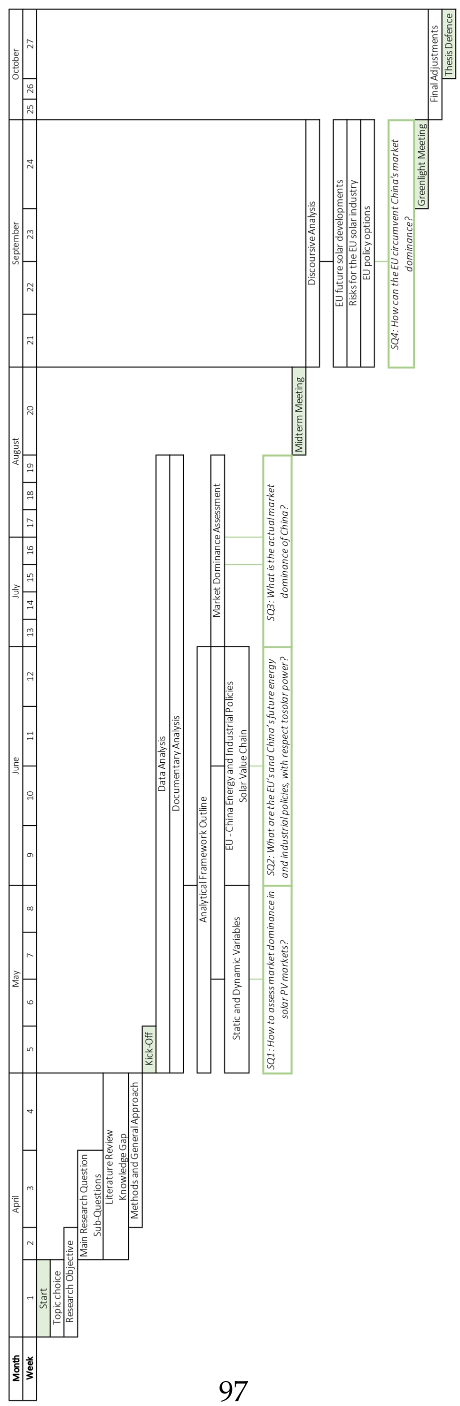
In conclusion, the European Union, therefore, remains highly dependent on Chinese c-Si panels, and this dependency is expected to rise in the coming years, due to future European plans to foster solar energy. Anyhow, with the right policies and an adequate degree of investments in the solar industry, European countries will easily be able to reach the goals set in the European Green Deal.

Possibilities for further research

In terms of possibilities for further research, it would be interesting to apply the Analytical Framework to other case-studies, such as the relations between India and the United States, or to other RES technologies, like wind power. At the same time, the Analytical Framework could be improved, by including in the Market Dominance Assessment other variables not considered for the purpose of this research. Also, to have a more comprehensive overview of a specific RES technology, it would be appropriate to include also complementary components, such as storage and electrical components such as cables and wires.

Annex

Annex A: Planning



Annex B: EU Subsidies for Solar Power

<table>
<tr><th>Country</th><th>Type</th><th>Amount</th><th>Amount for Solar energy</th></tr>
<tr><td>AT</td><td>Feed-in tariff (ÖSG 2012)</td><td></td><td>PV installations on roof-tops and façades with capacities over 5 kWp, up to 200 kWp 2018: €ct 7.91 per kWh 2019: €ct 7.67 per kWh (§ 6 para. 1 ÖSET-VO 2018) In addition to the feed-in tariff, an investment subsidy of 30% of the investment costs up to 250 € per kWp is granted for PV installations on buildings</td></tr>
<tr><td>CZ</td><td>Feed-in tariff (State-purchasing Price)</td><td></td><td>Since 1 January 2014, the feed-in tariff for new PV installations has been abolished. Tariff levels for PV installations put into operation until 31 December 2013 depend on the date of commissioning and are set as follows:
From 1 July – 31 December 2013: CZK 3,367 (€ 129) per MWh for installations with a capacity of up to 5 kW.
From 1 July – 31 December 2013: CZK 2,739 (€ 105) per MWh for installations with a capacity between 5 to 30 kW (No. 1.10. Price Decision of the Energy Regulatory Office No. 3/2018).
The feed-in tariff for PV installations put into operation between 1 January 2010 and 31 December 2010 is subject to a tax of 10% (§ 14 and § 18 Letter a Act No. 165/2012). The exception is represented by installations with a capacity of up to 30 kW (§ 17 Act No. 165/2012). The tax applies to all electricity generated in the respective PV plants from 1 January 2014 (§ 14 Act No. 165/2012).</td></tr>
<tr><td>FR</td><td>Feed-in tariff (Tarif d´achat)</td><td></td><td>The tariff applies to photovoltaic and thermodynamic installations and plants below a maximum power capacity of 100 kW fixed on buildings. The tariffs depend on the type and the total capacity of the installation, without distinction of the use of the building. Every quarter, the degression coefficients Sn and Vn will be adjusted to the number of grid connection requests adopted in the previous quarter (Arrêté du 9 mai 2017 soleil). The French regulatory authority will publish the new coefficients and the resulting changes in tariff levels online approx. 3 weeks after the end of each quarter (art. 14 Arrêté du 9 mai 2017 soleil). The tariffs are published at the following addresses: www.cre.fr/operateurs/producteurs/obligations-d-achat</td></tr>
<tr><td>DE</td><td>Feed-in tariff (EEG feed-in tariff)</td><td></td><td>The amount of tariff depends on the site of production and the installed capacity.
specific building-mounted systems (e.g. roofs, facades, noise barriers, other building) €ct 8.91 – 12.70 per kWh (§ 48 par. 1 and 2 EEG 2017) minus €ct 0.4 per kWh (§ 53 no. 2 EEG 2017);</td></tr>
<tr><td>DE</td><td>Tenant electricity surcharge</td><td>).</td><td>The amount depends on the installed capacity and is EUR ct 8.5 lower than the feed-in tariff (§ 48 par. 2 EEG 2017, § 23b par. 1 EEG 2017), which is classified for installations <10 kW, 10-40 kW and 40 – 100 kW in addition to the deduction of EUR ct 0.4 (§ 53 par. 2 EEG 2017</td></tr>
<tr><td>GR</td><td>Feed-in tariff I</td><td>The feed-in tariffs vary according to the renewable energy source and are set at the levels indicated below (ch. D art. 13 Par. 1 b Law No. 3486/2006).</td><td>Photovoltaic (PV) generation:
<table>
<tr><th>PV</th><th colspan="2">Interconnected system</th><th>Non-interconnected islands</th></tr>
<tr><td>€/MWh</td><td>up to 100 MW</td><td>> 100 MW</td><td></td></tr>
<tr><td>From February 2014</td><td>115</td><td>90</td><td>95</td></tr>
<tr><td>From August 2014</td><td>115</td><td>90</td><td>95</td></tr>
<tr><td>From 2015</td><td>1.2 * MASPv-1</td><td>1.1 * MASPv-1</td><td>1.1 * MASPv-1</td></tr>
</table>
MASPv-1= Marginal Average System Price of the previous year (art. 15 par. 1 Law No. 3468/2006 in conjunction with FEK B´ 97/2012)</td></tr>
<tr><td>GR</td><td>Feed-in tariff II (rooftop PV)</td><td>Since February 2017: € 105 per MWh (art. 3 par. 3 FEK 1079/2009).</td><td></td></tr>
<tr><td>GR</td><td>Feed-in tariff I (Feed-In premium exemptions)</td><td></td><td>CSP: 257-278 €/MWh (art.4 par.1b Law No. 4414/2016)</td></tr>
<tr><td>HU</td><td>Feed-in tariff</td><td></td><td>Plants of up to 0.5 MW or less: HUF 31.77 per kWh (approx. € 0.0989); No difference between peak, valley and deep-valley period.</td></tr>
<tr><td>LU</td><td>Feed-in tariff</td><td>The amount of tariff varies for every technology (Art. 7-13 RGD du 1 août 2014).</td><td>For 2019, the following tariffs apply:
● Electricity from PV installations ≤ 30 kW fed into the grid receive a tariff amounting to €ct 12,1 per kWh (Art. 17 RGD du 1 août 2014)
● Electricity from PV installations between 30 kW and 100 kW fed into the grid receive a tariff amounting to €ct 13,12 per kWh (Art. 17 RGD du 1 août 2014)
Electricity from PV installations between 100 kW and 200 kW fed into the grid receive a tariff amounting to €ct 12,55 per kWh (Art. 17 RGD du 1 août 2014)</td></tr>
<tr><td>MT</td><td>Feed-in tariff</td><td>The feed-in tariff is paid per kWh of electricity generated and exported to the grid by solar PV installations with a capacity up to 1 MWp (2nd Schedule LN 2/2019).</td><td>Between 2 January and 30 December 2019, the following feed-in tariff is applicable:
● € 0.155 per kWh of electricity generated and exported to the grid by a PV installation which did not benefit from any form of grant or subsidy and having an installed capacity of more than 1 kWp but less than 40 kWp (2nd Schedule LN 200/2019).
€ 0.1405 per kWh of electricity generated and exported to the grid by a PV installation which did not benefit from any form of grant or subsidy and having an installed capacity of more than 40 kWp but less than 1 MWp (2nd Schedule LN 200/2019).</td></tr>
<tr><td>PT</td><td>Feed-in tariff (Tarifas feed-in)</td><td></td><td>For existing photovoltaic installations as defined in DL 132-A/2010, the Indicative average rate of the FiT is € 257 per MWh (DL 132-A/2010). For existing concentrated photovoltaics (CPV) with Installations with a capacity ≤ 1 MW up to a limit of 5 MW of installed power on the national level the indicative average rate of the FiT is € 380 per MWh (Ordinance 1057/2010). For existing Concentrated Solar Power (CSP) installations with a capacity ≤ 10 MW the Indicative average rate is € 267-273 per MWh (DL 225/2007). For UPPs, the FiT consists of 100% of the reference tariff (art. 3 of Ordinance 15/2015). The reference tariff in 2018 is € 95/MWh (art. 2 of Ordinance 15/2015 in conjunction with art. 2 of Ordinance 32/2018, which kept the same tariffs from Ordinance 20/2017).</td></tr>
<tr><td>SK</td><td>Feed-in tariff</td><td></td><td>Roof-top or façade-integrated installations of up to 30 kW, from 1 January 2017: € 84.98 per MWh (§ 10 par. 1 Letter b Decree No. 18/2017)</td></tr>
</table>

<table>
<tr><th>Country</th><th>Type</th><th>Amount</th></tr>
<tr><td>AT</td><td>Subsidy II (Investment subsidy for PV on buildings)</td><td>For PV installations on buildings, the investment subsidy amounts to max. 30% of the investment costs but no more than 250 € per kW. The feed-in tariff amounts up to 7.91 €ct/kWh (§ 6 para. 1 ÖSET-VO 2018).</td></tr>
<tr><td>AT</td><td>Subsidy IV (Investment subsidy for small PV)</td><td>For single installations • € 275 per kWp for roof-top or ground-mounted installations for maximally 5 kWp. • € 375 per kWp for building integrated installations for maximally 5 kWp (PV Subsidy Guidelines 2018). For joint PV installations • € 200 per kWp for roof-top or ground-mounted installations for maximally 5 kWp per applicant (but not more than 30 kWp in total) • € 300 per kWp for building integrated installations for maximally 5 kWp per applicant (but not more than 30 kWp in total, PV Subsidy Guidelines 2018) The overall budget amounts up to € 4.5 million for 2018 and was increased by another € 360,000 in June 2018 (PV Subsidy Guidelines 2018).</td></tr>
<tr><td>AT</td><td>Subsidy III (Investment subsidy for offgrid installations)</td><td>Standard subsidy: 30 % of the costs of installation eligible for funding with a cap of € 1,500,000 and a minimum investment sum of € 10,000.
Additional subsidy:
5 % for installations in areas higher than 1200 meters or in ecologically sensitive areas.
5 % in case the project is selected for EU co-funding by the European Regional Development Fund
5 % or a maximum of € 10,000 for EMAS and eco-label (Offgrid subsidy guidelines)</td></tr>
<tr><td>AT</td><td>Subsidy V (Investment subsidy for PV installations in the agricultural and forestry sector)</td><td>€ 275 per kWp for roof-top or ground-mounted installations
€ 375 per kWp for building integrated installations (p. 3 AF Subsidy Guidelines).
The amount granted shall not exceed 40% of the net investment costs (p. 3 AF Subsidy Guidelines)</td></tr>
<tr><td>BE</td><td>Brussels: Subsidy (Aide à l'investissement)</td><td>The amount of the investment assistance depends on the size of the company (Art. 24 Arrêté du 2 avril 2009):
Micro and small enterprises: 40 % of the eligible costs
Medium enterprises: 30 % of the eligible costs
Large enterprises: 20 % of the eligible costs
Moreover, the subsidy can be increased by 5 % if the company is certified Emas, ISO 14.000 or "eco-dynamic enterprise" (Art. 26 Arrêté du 2 avril 2009).
The amount of the investment assistance cannot exceed € 80,000 per company and per calendar year (Art. 22 Arrêté du 2 avril 2009).</td></tr>
<tr><td>BE</td><td>Flanders: Subsidy (Ecologic Premium Plus/Strategic Ecologic Support)</td><td>The amount of subsidy is calculated as the percentage of extra investments needed in order to obtain a certain level of environmental protection (additional cost of investment) laid out in the LTL list (Art. 21 Decree on Ecological Investment in conjunction with Art. 16 Decree on Economic Aid Policy). The amount of premium (holds for both EP-PLUS and EP-STRES) is determined by the ecological performance of the technology (eco number), the eco class and the volume of the investment differentiating between small and medium enterprises (SME) and large enterprises (LE) (Art. 22 §1 Decree on Ecological Investment). The eco class for EP-PLUS is listed already in the LTL. Concerning EP-STRES an evaluation is done by VITO on an ad-hoc basis. The amount of EP-PLUS and EP STRES is the following:
<table>
<tr><th>Eco class</th><th>Eco number</th><th>Premium in % SME</th><th>Premium in % LE</th></tr>
<tr><td>A</td><td>9</td><td>55</td><td>45</td></tr>
<tr><td>B</td><td>6</td><td>30</td><td>15</td></tr>
<tr><td>C</td><td>3-4</td><td>0</td><td>0</td></tr>
<tr><td>D</td><td>1-2</td><td>0</td><td>0</td></tr>
</table>
Maximum premium is € 1 million per company over a period of 3 years (Art. 22 Decree on Ecological Investment). The premium is paid in 3 rates: the first rate amounting to 30 % is paid earliest 30 days after the application was approved, the second rate corresponds to 30 % and is paid after 60 % of the investment has been realised. Finally, the last rate is paid after the investment is completed and monitored (Art. 24 Decree on Ecological Investment).</td></tr>
<tr><td>CY</td><td>Subsidy (PV in households with net-metering - "Support Scheme for PV and Biomass/ Biogas 2017)</td><td>The grant amounts to € 900 per kW (max. € 2,700 per installation). In aggregate 1.2MW of PV installations will be subsidised (ch. 3. par.5 "Support Scheme for PV and Biomass/ Biogas 2017").</td></tr>
<tr><td>CZ</td><td>Subsidy II (Operational Programme Environment 2014-2020 – OP ŽP)</td><td>The Operational Programme Environment grants subsidies up to the total project's eligible expenditures (Annex No. 4 MŽP Directive No. 6/2014). Under the Specific Objective 5.1, only individual projects (except large projects) are eligible for support (2.4.3.2.4 OP ŽP). Further terms and conditions will be set out in each call for applications.</td></tr>
<tr><td>FI</td><td>Subsidy I (Energy Aid)</td><td>The amount of subsidy depends on the aim of the project in question. The support allocated to investments in renewable energy production facilities can make up to 30% of the project's overall cost, but can increase up to 40% in case the project involves the use of new technology. The support allocated to research can make up to 40% of the project's total cost (§7 Decree No. 1063/2012). A company or entity receiving the subsidy has to finance at least 25% of the total project costs from non-state funding (§ 5 Decree No. 1063/2012).</td></tr>
<tr><td>FI</td><td>Subsidy II (Investment Aid for Renewable Energy and New Energy Technologies)</td><td>Under Decree No. 145/2016, the investment aid is granted against a fixed assets investment with eligible costs exceeding € 5,000,000. Investment aid can be up to 40 per cent of the project's costs (§5, §10 Decree No. 145/2016).</td></tr>
<tr><td>GR</td><td>Subsidies I (Development Law)</td><td>To be eligible for support, minimum investment should amount to (art.5 par.3 Law No. 4399/2016):
Large enterprises: € 500,000
Medium enterprises: € 250,000
Small enterprises: € 150,000
Very small enterprises: € 100,000
Social cooperatives/ cooperatives: € 50,000
RES for self-consumption can make up to 15% of eligible regional support. Regional support maximum is stipulated in the Regional Support Map (C (2014) 2642/7.5.2014), which is approved by the European Commission and is available at: http://ec.europa.eu/competition/state_aid/cases/252063/252063_1547272_57_2.pdf As far as a CHP plant is concerned, eligible costs include (1) additional investments in the installation of an equipment that is needed for a CHP plant to function as a high efficient CHP, as compared to a conventional power plant of the same capacity, or (2) additional investment cost for upgrading the performance of the CHP plant (art.7 par. 7 Law No. 4399/2016). Eligible for support are also investment plans for small-scale hydro-power. In addition, support for RES used for self-consumption only is also foreseen (art.7 par.8 Law No.4399/2016). The Development Law alternatively offers the following types of support (art. 10 Law No. 4399/2016): 1. Subsidies 2. Leasing subsidies 3. Subsidies for the creation of new jobs Eligible for leasing subsidies and subsidies for the creation of new jobs are general entrepreneurship and supporting innovation for SMEs (art.38 and art. 48 Law No.4399/2016). New independent SMEs are eligible for all three categories of support: subsidies, leasing subsidies and subsidies for the creation of new jobs (art.43 Law No.4399/2016). RES projects are eligible for support, subject to the following limitations (art. 11 par.3 subpar.2h and 2z Law No. 4399/2016): For CHP (art. 11 par.3 subpar. 2z Law No. 4399/2016):
45% of the eligible expenditure for large enterprises
55% of the eligible expenditure for medium enterprises
65%of the eligible expenditure for small enterprises
For small hydro and hybrid plants (art. 11 par.3 subpar. 2h Law No. 4399/2016) there are two options: Option 1 If extra investment costs necessary to promote the production of energy from renewable sources are eligible costs under art. 41 par. 6 cases a and b of the EU Regulation 651/2014:
45% of the eligible expenditure for large enterprises
55% of the eligible expenditure for medium enterprises
65% of the eligible expenditure for small enterprises.
Option 2 If extra investment costs necessary to promote the production of energy from renewable sources are eligible costs under art. 41 par. 6 case c of the EU Regulation 651/2014:
30% of the eligible expenditure for large enterprises
40% of the eligible expenditure for medium enterprises
50% of the eligible expenditure for small enterprises.
Further support between 5%-15% is foreseen, if the investment takes place in certain regions specified in the Regional Support Map (C (2014) 2642/7.5.2014), which is approved by the European Commission.</td></tr>
</table>

IE	Subsidy ("Solar PV Pilot Scheme")	The amount is set at (ch. 2 "Solar PV Pilot Scheme"): • Solar PV Systems €700/kWp (up to 2kWp) Battery Storage €1,000 (up to 4kWp)
IT	Premium tariff (Ritiro dedicato)	The amount of payment decreases with increasing output and are adjusted for inflation (Art. 7.5, Annex A, AEEG 280/07). The updated formulas for calculating the exact guaranteed minimum price are available in Art. 7. 6, Annex A, AEEG 280/07.
LT	Subsidy (LEIF)	The maximum subsidy is approx. € 200,000 and must not exceed 80% of the total project expenses (Chapter II Item 7 Order No. 437/2003). Applicants shall demonstrate that they are able to provide funding for the rest of the project through their own resources (Chapter II Item 12 Order No. 437/2003). The first part of the awarded subsidy (60%) is paid when the applicant has acquired, installed and started operating facilities as intended in the project plan and the head of LEIF confirmed the report on the project technical implementation. The remaining part of the awarded subsidy (40%) is paid when the applicant has submitted data on the environmental compliance achieved during the first year of the supported project. The remaining part of the subsidy is paid under the condition that during the first project year the environmental indicators set in the grant application are met by at least 95%. If 50% - 95% of environmental indicators are met, the grant shall be reduced accordingly. Finally, if during the first project year less than 50% of environmental indicators are met, environmental compliance is considered as not achieved and the second part of the subsidy will not be paid to the applicant. In this case the applicant shall also pay back the first part of the subsidy (which he has already received) to the LEIF (Chapter II Items 9-11 Order No. 437/2003).
LT	Subsidy (Climate Change Special Programme)	The maximum level of funding for applicants not engaged in economic and commercial activities shall be € 1 450 000 and for applicants engaged in economic and commercial activities € 200 000. However, the amount of a subsidy may not exceed 80% of the eligible project costs (Chapter IV Item 28 Order No. D1-275/2010).
LU	Subsidy I (PRIMe House)	The subsidy for PV installations amounts to 20% of the eligible costs, subject to a maximum of €500 per kWp (Art. 3, RGD du 23 décembre 2016). The following expenses are eligible: PV modules, mounting system, wiring, inverter, electrical protection devices, meter and installation costs (Annex I).
LU	Subsidy II (Régime d'aide à la protection de l'environnement et à l'utilisation rationnelle des ressources naturelles)	Grants may cover up to 45% of the additional costs arising from the use of renewable energy as compared to non-renewable sources. Regarding certain small installations for which it is impossible to imagine a less environmentally friendly investment because of the lack of limited size facilities, grants may cover up to 30% of the total investment costs incurred to reach a higher level of environmental protection. The grant may increase by 20 percentage points for small enterprises and by 10 percentage points for medium-sized enterprises (Art. 9 Loi du 15 décembre 2017).
LU	Subsidy III (Régime d'aide en faveur des classes moyennes)	Grants may cover up to 40% of the eligible investment costs (Art. 4, Loi du 30 juin 2004). The grant may increase by 10 percentage points for small and medium-sized enterprises (Art. 4, Loi du 30 juin 2004). Moreover, the grant may increase by 10 percentage points if the installed renewable energy plant allows the self-sufficient supply to a community of beneficiaries (Art. 4, Loi du 30 juin 2004). According to this law, medium-sized companies shall employ less than 250 persons and have an annual turnover not exceeding €40 million. Small companies shall employ less than 50 persons and have an annual turnover of maximum €7 million (Art. 1, Loi du 30 juin 2004).
LU	Subsidy IV (Fonds pour la protection de l´environnement)	The fund supports up to 50% of the whole investments costs, including equipment and installation costs (Circulaire n°3178).
LU	Premium tariff (Prime de marché)	The amount of market premium (PM) results from the sum of the direct sales premium (PVD) and the difference between a technology-specific reference remuneration (PRR) and the monthly market price (PMM): PM = PRR – PMM + PVD (Art. 27ter. RGD du 23 juillet 2016)
PL	Subsidy (National Fund for Environmental Protection and Water Management - Prosumer)	The budget of the programme for the timeframe 2015-2019 is: • for subsidies: PLN 144.088 million (€ 33.53 m) • for loans: PLN 194.312,2 million (€ 45,21 m) (3 Prosumer) Taken together, the amount of a loan and the subsidy granted may cover up to 100% of the eligible costs and must be more than PLN 200,000 (€ 45,564) for municipalities and between 5,000 and 40,000 PLN (€ 1,164 – 9,312) for individuals and housing cooperatives ((7.2.1 and 7.3.1 Prosumer). The interest rate of the loan is 1%. The maximum duration of loan support is 15 years. The investment must be finalised within 24 months from the first loan payment (NFOŚiGW governed) or 18 months from the date of the loan agreement (bank governed) (7.3.3, 7.3.5, 7.3.6 and 7.3.8 Prosumer). The subsidy shall cover up to 30% of investments costs. However, in the years 2015-2016 up to 40% (7.2.1b Prosumer). Maximum eligible investment costs for residential buildings in case of installations using only one energy source: • PLN 100,000 (€ 23,283) for private persons, except for biogas micro co-generation installations • PLN 300,000 (€ 69,844) for homeowner associations or housing cooperatives • PLN 500,000 (€ 116,417) in case of biogas micro co-generation installations Maximum eligible investment costs for residential buildings in case of installations using at least two energy source: • PLN 150,000 (€ 34,923) for private persons, except for biogas micro co-generation installations • PLN 450,000 (€ 104,775) for homeowner associations or housing cooperatives • PLN 500,000 (€ 116,417) in case of biogas micro co-generation installations (7.2.4 and 7.2.5 Prosumer).
RO	Subsidy (Measure 4 "Investments in physical assets")	Under the current call for proposals, the subsidy programme's total budget is € 150,000,000. The subsidy is to a certain percent (30 to 50%) irredeemable. The percentage depends on the size of the farm or the project. The maximum eligible sum is € 2 million (Call for proposals – Measure 4).
SK	Subsidy (Operational Programme Quality of Environment)	The amount of the subsidy will be determined in the individual call for applications.
SI	Subsidy (Support of the Ministry of Infrastructure)	The subsidies, state aid and "de minimis" aid are intended to cover some of the costs related to the use of renewable energy instead of traditional energy sources. Please note the following important information: • Subsidies are subject to a maximum of 50% of the eligible costs of an investment project, state aid and "de minimis" aid grants are subject to a maximum of 30%. Exceptional projects may be awarded 40/50% of the costs (§10 and 20 of RS 89/2008). • The maximum grant is defined in each specific tender (§ 29 par. 2 RS 89/2008). Certain grants are subject to a maximum (e.g. € 50,000 for state aid and € 200,000 / € 100,000 for "de minimis" aid). In these cases, a report must be submitted to the Ministry of Finance.
SE	Subsidy (Grants for the installation of photovoltaic installations)	Grants amount to 30% of the eligible costs for both companies, private individuals and municipalities (§ 5 par. 1 Regulation No. 2009:689). Eligible costs include labour costs, costs of materials and planning costs (§ 6 Regulation No. 2009:689). Costs of the connection to an external electricity grid are excluded from the eligible costs (§ 6 Regulation No. 2009:689). The maximum grant per installation is SEK 1.2 million (§ 5 par. 2 Regulation No. 2009:689). The total eligible costs must not exceed SEK 37,000 (plus VAT) per kW of installed maximum capacity. The eligible costs for hybrid installations must not exceed SEK 90,000 per kW of installed maximum capacity. (§ 5 par. 3 Regulation No. 2009:689). If the photovoltaic system was funded by insurance payments, aid shall be reduced by an amount corresponding to the remuneration (§ 5 par. 4 Regulation No. 2009:689). The budget for the scheme for 2017 was SEK 440 million (€ 43 million) and for 2018 SEK 1,085 million (€ 106 million) annually.

<table>
<tr><th>Country</th><th>Type</th><th>Amount of Quota and period of application</th></tr>
<tr><td>BE</td><td>National: Quota system (Green Certificates)</td><td>The green certificates allocated to offshore plants and hydropower by the CREG have a validity of five years (Art. 13, §2 Arrêté royal du 16 juillet 2002).</td></tr>
<tr><td>BE</td><td>Brussels: Quota system (Certificats verts)</td><td>The quotas for the following years are published on the website of Brugel and are defined as follows:
<table>
<tr><th>Quota</th><th>%</th></tr>
<tr><td>2013</td><td>3.5</td></tr>
<tr><td>2014</td><td>3.8</td></tr>
<tr><td>2015</td><td>4.5</td></tr>
<tr><td>2016</td><td>8.2</td></tr>
<tr><td>2017</td><td>7.8</td></tr>
<tr><td>2018</td><td>8.5</td></tr>
<tr><td>2019</td><td>9.2</td></tr>
<tr><td>2020</td><td>10.0</td></tr>
<tr><td>2021</td><td>10.8</td></tr>
<tr><td>2022</td><td>11.5</td></tr>
<tr><td>2023</td><td>12.3</td></tr>
<tr><td>2024</td><td>13.1</td></tr>
<tr><td>2025</td><td>14.0</td></tr>
</table>
Green certificates have a validity of 5 years (Art. 24, Arrêté du 17 décembre 2015).
• 3.8 % for 2014;
• 4.5 % for 2015;
• 5.1 % for 2016;
• 5.8 % for 2017;
• 6.5 % for 2018;
• 7.2 % for 2019;
• 8.0 % for 2020;
• 8.8 % for 2021;
• 9.5 % for 2022;
• 10.3 % for 2023;
• 11.1 % for 2024;
• 12.1 % for 2025.
Green certificates have a validity of 5 years (Art. 20, Arrêté du 6 Mai 2004).</td></tr>
<tr><td>BE</td><td>Flanders: Quota system (Groenestroomcertificaten)</td><td>The quota is calculated according to a formula set by law (Article 7.1.10 § 2 Energy Decree) The factor “Gr” is determined by law. It is equal to:
• 0.14 in 2013
• 0.155 in 2014
• 0.168 in 2015
• 0.18 in 2016
• 0.23 in 2017
• 0.205 in 2018
• 0.215 in later years
Since 31 March 2017, the factor Ev is decreased for intensive industries (Art. 7.1.10. §3 Energy Decree):
• By 47% if the total amount of electricity consumed in the year n-1 was between 1,000 MW and 20,000 MW
• By 80% if the total amount of electricity consumed in the year n-1 was between 20,000 MW and 100,000 MW
• By 80% if the total amount of electricity consumed in the year n-1 was between 100,000 MW and 250,000 MW
• By 98% if the total amount of electricity consumed in the year n-1 was above 250,000 MW</td></tr>
<tr><td>BE</td><td>Wallonia: Quota system (Soutien kECO – certificats verts)</td><td>From the 1st of January 2017, the quota increase is as follows (Art. 25, Arrêté du 30 novembre 2006, as modified by the decree of 26 November 2015):
• 34.03 in 2017
• 35.65% in 2018
• 37.28 in 2019
• 37.9 % in 2020
• 34.03% in 2021
• 35.65% in 2022
• 37.28% in 2023
• 37.9% in 2024
The grid operators are obliged to purchase green certificates from the generators of electricity and submit them to CWaPE; otherwise they shall pay a fine of €100 per green certificate missing (Art. 25, Arrêté du 30 novembre 2006).</td></tr>
</table>

<table>
<tr><td>PL</td><td>Quota system (Renewable portfolio standards)</td><td>The quota is a percentage of the total annual amount of electricity sold (§ 1.1 of Order of 5/5/2014). The quota has been fixed until 2021 and amounts to:
<table>
<tr><th>Year</th><th>Quota</th></tr>
<tr><td>2016</td><td>15%</td></tr>
<tr><td>2017</td><td>16%</td></tr>
<tr><td>2018</td><td>17%</td></tr>
<tr><td>2019</td><td>18%</td></tr>
<tr><td>2020</td><td>19%</td></tr>
<tr><td>2021</td><td>20%</td></tr>
</table></td></tr>
<tr><td>RO</td><td>Quota System</td><td>Amount of quota per year: The yearly quota is established by ANRE in December for the following year. The quota is calculated taking into consideration the estimated final energy consumtion for the upcoming year and the medium impact on cosumers that should not exceed 12.5 EUR/MWh in 2019, 13 EUR/MWh in 2020 and 2021 and 14.5 EUR/MWh from year 2022. A new methodology for defining the obligatory annual quota aquisition of Green Certificates was developed by ANRE (following the provision of the art. 4 par. 7 and par. 91 - 94 Law. No. 220/2008) and approved by the Decree No. 157/2018, according to which the methodology entered intor force on 1 August 2018.</td></tr>
<tr><td>SE</td><td>Quota system</td><td>The quota shall be calculated by multiplying the number of megawatt hours of electricity sold or used during the calculation year with the quota obligation for the calculation year. The quotas for the period from 2018 to 2045 have been set as follows (Chapter 4 § 4 Act No. 2011:1200):
<table>
<tr><th>Obligation period</th><th>Quota obligation per MWh of electricity sold or consumed</th></tr>
<tr><td></td><td></td></tr>
<tr><td>2018</td><td>0.299</td></tr>
<tr><td>2019</td><td>0.305</td></tr>
<tr><td>2020</td><td>0.288</td></tr>
<tr><td>2021</td><td>0.263</td></tr>
<tr><td>2022</td><td>0.267</td></tr>
<tr><td>2023</td><td>0.271</td></tr>
<tr><td>2024</td><td>0.270</td></tr>
<tr><td>2025</td><td>0.272</td></tr>
<tr><td>2026</td><td>0.280</td></tr>
<tr><td>2027</td><td>0.293</td></tr>
<tr><td>2028</td><td>0.298</td></tr>
<tr><td>2029</td><td>0.304</td></tr>
<tr><td>2030</td><td>0.299</td></tr>
<tr><td>2031</td><td>0.284</td></tr>
<tr><td>2032</td><td>0.268</td></tr>
<tr><td>2033</td><td>0.245</td></tr>
<tr><td>2034</td><td>0.221</td></tr>
<tr><td>2035</td><td>0.206</td></tr>
<tr><td>2036</td><td>0.187</td></tr>
<tr><td>2037</td><td>0.176</td></tr>
<tr><td>2038</td><td>0.154</td></tr>
<tr><td>2039</td><td>0.132</td></tr>
<tr><td>2040</td><td>0.110</td></tr>
<tr><td>2041</td><td>0.088</td></tr>
<tr><td>2042</td><td>0.066</td></tr>
<tr><td>2043</td><td>0.044</td></tr>
<tr><td>2044</td><td>0.022</td></tr>
<tr><td>2045</td><td>0.011</td></tr>
<tr><td></td><td></td></tr>
</table>
The quota shall be calculated by multiplying the number of megawatt hours of electricity sold or used during the calculation year with the quota obligation for the calculation year (Chapter 4 § 4 Act No. 2011:1200).</td></tr>
</table>

Country	Type	Amount
BE	Brussels: Net-Metering (mécanisme de compensation)	The producer benefits from the compensation mechanism for the period between two meter-readings. The compensation applies for the amount of electricity fed into the distribution grid, provided that the latter does not exceed the amount of electricity taken from the grid (Art.34, Arrêté du 17 décembre 2015).
BE	Flanders: Net-Metering	Net-metering only applies to installations with a capacity ≤ 10 kW. There is no direct financial compensation for the injected electricity, but the financial equivalent of the injected kW is deducted from the overall electricity bill. However, if an installation feeds more electricity into the grid than it has taken from the grid during a billing period, this amount is not financially reimbursed.
BE	Wallonia: Net-Metering (Mécanisme de compensation)	The prosumer benefits from the compensation mechanism for the period between two meter-readings (Art. 153 § 4 Arrêté du 3 Mars 2011). The compensation mechanism remains valid only during the technical life span of the installation (Art 24 bis Arrêté du 30 mars 2006).
CY	Net-Metering I (for households, public administration buildings and commercial industrial units)	The electricity offsetting will be carried out once every two months or each month for each calendar year by EAC or by any other electricity supplier to which the consumer has contracted. Any surplus will be transferred in the next two months or next month while any deficits will be invoiced. The final account (measurement of February- March) of the calendar year will be the final settlement. Electricity surplus cannot be carried over from one calendar year to the next (ch. 3 par. 3 "Support Scheme for PV and Biomass/ Biogas 2017"). In addition, electricity produced by PV and Biomass/ Biogas installations for self-consumption purposes (industrial/ commercial units) shall not be fed into the grid (ch .4. par. 3 "Support Scheme for PV and Biomass/ Biogas 2017").
CY	Net-Metering II (for households, public administration buildings and commercial industrial units)	The electricity offsetting will be carried out once every two months or each month for each calendar year by EAC or by any other electricity supplier to which the consumer has contracted. Any surplus will be transferred in the next two months or next month while any deficits will be invoiced. The final account (measurement of February- March) of the calendar year will be the final settlement. Electricity surplus cannot be carried over from one calendar year to the next (ch.4 par.3 SSRES 2018). With regard to the net-billing scheme for industrial/ commercial units and public administration buildings, a bi-directional meter will be installed by the Cyprus DSO to record the imported electricity and the energy to be supplied to the electrical system. If this is not technically feasible, two meters can be installed to record the above-mentioned data. If the cost of the exported electricity does not exceed the cost of the imported electricity, then the plant operator should pay the difference resulting from offsetting the cost of exported and imported electricity for the relevant billing period. If the cost of the exported electricity exceeds the cost of imported electricity, the surplus amount will be credited for the next billing period. The final account (measurement of November) of the calendar year will be the final settlement. Electricity surplus cannot be carried over from one calendar year to the next (ch.5 par.5 SSRES 2018). In addition, electricity produced by PV and Biomass/ Biogas installations for self-consumption purposes (industrial/ commercial units) shall not be fed into the grid (ch.6 par.1 SSRES 2018").
DK	Net-Metering	Every consumer is obliged to pay a surcharge, the so-called Public Service Obligation (PSO). It depends on each consumer's individual level of consumption. The surcharge for the support of renewable energy is part of the PSO tariff. The surcharges are determined by the Danish Energy Agency four times a year. Which surcharge a plant owner is exempt from depends on the installed capacity of his plant. ● The following plants are exempt from the whole PSO tariff: ○ Solar energy installations up to 50 kW ○ Wind energy plants up to 25 kW ○ Other technologies up to 11 kW (§ 4 par. 2 BEK 999/2016). ● The following plants are exempt from the surcharge for the support of renewable energy: ○ Solar energy installations > 50 kW ○ Wind energy plants > 25 kW ○ Other technologies > 11 kW (§ 3 par. 2 BEK 999/2016).
GR	Net-Metering	Primarily, the electricity produced by an installation or plant is offset with self-consumed energy. Any surplus electricity is fed into the grid without any obligation for remuneration. Apart from that, PV installed on public buildings in the context of the EU funded programmes can receive up to 20% of the value of the total annual electricity production (art.14A par.4 Law No.3468/2006).
HU	Net-Metering	The electricity produced by the household-sized plant is offset with the generator's consumed electricity. Any surplus will be fed into the grid and will be remunerated with the retail electricity price. The payment of fix basic grid distribution charges and dis-tribution capacity charges are due. Three situations can be distinguished: ● The electricity consumption exceeds the electricity generation: the grid user pays for the balance of electricity con-sumption and electricity generation (Chapter IV. No. 1 HMKE Regulations). ● The electricity consumption equals the electricity generation: the grid user does not have to pay for any electricity con-sumed, but the fix basic grid distribution charges and the distribution capacity charges are due (Chapter IV. No. 2 HMKE Regulations). ● The electricity consumption is below the electricity generation: the grid user has to pay the fix basic grid distribution charges and the distribution capacity charges; the electricity trader pays the retail price for the excess electricity fed in-to the grid (Chapter IV. No. 3 HMKE Regulations)
IT	Net-Metering (scambio sul posto)	Plant operators receive as much energy for free as they produce (Art. 6 par. 2 570/2012/R/efr). Furthermore, in case the electricity fed in the grid is more than the one taken from the grid, plant operators are entitled to have an economic compensation, based on the formulas in Art. 6, 570/2012/R/efr.
LV	Net-metering	There is no direct financial compensation for the injected electricity, but the financial equivalent of the injected kW is deducted from the overall electricity bill. If an installation feeds more electricity into the grid than it has taken from the grid during a billing period, this amount is transferred to the next billing period (§ 30 par. 1 Electricity Market Law)
LT	Net-Metering (Law on Energy from Renewable Sources)	For the self-generated and consumed amount of electricity a prosumer is exempt from paying a Public Service Obligation (PSO) levy. However, he has to pay the fee for the use of electricity grid set by the NCC (Chapter III Art. 20^1 Par. 5 and 8 Law on Energy from Renewable Sources). The Law on Energy from Renewable Sources sets a cap of 100 MW for the installed capacity under the net-metering scheme, of which 70 MW for natural persons, including farmers whose annual income from agricultural activities accounts for less than 50% of the received income, and the remaining 30 MW for legal entities, including farmers whose annual income from agricultural activities accounts for more than 50% of the received income (Chapter III Art. 20^1 Par. 9 Law on Energy from Renewable Sources).
NL	Net-Metering	The exact level of support depends on the amount of electricity fed-in the grid and the client's electricity consumption.

Country	Type	Amount
FR	Tax regulation mechanisms I (Crédit d´impôt pour la transition énergétique)	• Persons that install renewable energy plants at their principal residence may deduce 30 % of the net hardware costs from income tax (art. 200 quater par. 1 c, 5 Code Général des Impôts). • For solar energy installations, the tax credit applies under the following conditions: ○ For hybrid liquid circulation systems, the expenses eligible for the tax credit shall not exceed € 400 per m² of solar collectors, with a maximum surface of 10 m². ○ For hybrid air circulation systems, the expenses eligible for the tax credit shall not exceed € 200 per m² of solar collectors, with a maximum surface of 20 m². • **Caps** for the period from 1 January 2005 to 31 December 2019 per principal residence: € 8,000 for individuals, € 16,000 for married or cohabiting couples (PACS) + € 400 per child; if they both have the duty of care: € 200 per child) (art. 200 quater par. 4 Code Général des Impôts). • In **multi-family houses**, every resident may claim the money he invested (Tit. 28, chap. 1, sec. 1, BOI-IR-RICI-280-20180706). • The **capacity** of the eligible plant shall not exceed 3 kWp. Plants that generate more than 3 kWp are eligible only if the electricity consumption of the building is higher than half of the nominal installed capacity (Tit. 28, chapitre 1, sec. 2, BOI-IR-RICI-280-10-20-20120912).
FR	Tax regulation mechanisms II (Value-added tax reduction)	• **On the French mainland and in Corsica**, the reduced VAT rate is 5.5% (Art. 279 bis, Code Général des Impôts). • **In the overseas departments and regions (DOM-ROM)** of Guadeloupe, Martinique and Réunion, the VAT amounts to 2.10% (Art. 296, Code general des Impôts) • From 1 January 2014, the reduced VAT for photovoltaic installations was increased from 7% to 10% (art. 21, Loi de finances rectificative pour 2013).
GR	Tax regulation mechanism (Development Law)	To be eligible for support, minimum investment should amount to (art.5 par.3 Law No. 4399/2016): • Large enterprises: € 500,000 • Medium enterprises: € 250,000 • Small enterprises: € 150,000 • Very small enterprises: € 100,000 • Social cooperatives/ cooperatives: € 50,000 RES for self-consumption can make up to 15% of eligible regional support. Regional support maximum is stipulated in the Regional Support Map (C (2014) 2642/7.5.2014), which is approved by the European Commission and is available at: http://ec.europa.eu/competition/state_aid/cases/252063/252063_1547272_57_2.pdf. As far as a CHP plant is concerned, eligible costs include (1) additional investments in the installation of an equipment that is needed for a CHP plant to function as a high efficient CHP, as compared to a conventional power plant of the same capacity, or (2) additional investment cost for upgrading the performance of the CHP plant (art.7 par. 7 Law No. 4399/2016). Eligible for support are also investment plans for small-scale hydro-power. In addition, support for RES used for self-consumption only is also foreseen (art.7 par.8 Law No.4399/2016). The Development Law alternatively offers the following types of support (art. 10 Law No. 4399/2016): 1. Income tax relief and 2. Stabilisation of income tax coefficient Eligible for income tax relief for renewable energy projects are: • General entrepreneurship (art.38 Law No.4399/2016) • New independent small and medium enterprises (SMEs) (art.43 Law No.4399/2016) • Supporting innovation for SMEs (art.48 Law No.4399/2016) Major investment plans in RES are eligible for a tax relief that can be provided for 12 years and a stabilisation of income tax coefficient that is provided for 10% of the total investment cost, up to a maximum amount of € 5 million (art.66 Law No.4399/2016). Renewable energy sources are eligible for support, subject to the following limitations (art. 11 par.3 subpar.2h and 2z Law No. 4399/2016): For CHP (art. 11 par.3 subpar. 2z Law No. 4399/2016): • 45% of the eligible expenditure for large enterprises • 55% of the eligible expenditure for medium enterprises • 65%of the eligible expenditure for small enterprises For small-scale hydro-power and hybrid plants there are two options (art. 11 par.3 subpar. 2h Law No. 4399/2016): **Option 1** If extra investment costs necessary to promote the production of energy from renewable sources are eligible costs under art. 41 par. 6 cases a and b of the EU Regulation 651/2014: • 45% of the eligible expenditure for large enterprises • 55% of the eligible expenditure for medium enterprises • 65% of the eligible expenditure for small enterprises **Option 2** If extra investment costs necessary to promote the production of energy from renewable sources are eligible costs under art. 41 par. 6 case c of the EU Regulation 651/2014: • 30% of the eligible expenditure for large enterprises • 40% of the eligible expenditure for medium enterprises • 50% of the eligible expenditure for small enterprises Further support between 5%-15% is foreseen, if the investment takes place in certain regions specified stipulated in the Regional Support Map (C (2014) 2642/7.5.2014), which is approved by the European Commission and is available at: http://ec.europa.eu/competition/state_aid/cases/252063/252063_1547272_57_2.pdf.
IT	Tax regulation mechanisms II (Reduction in real estate tax)	The reduced real estate tax amounts to less than 0.4 percent. The reduction is valid for a maximum period of five years starting at the date of installation of the plant (Art. 1, c.6, l.a. L 244/07). This tax is determined at city council level.
IT	Tax regulation mechanisms I (Reduction in value-added tax)	The reduced value-added tax rate is 10 % (instead of 20 %).
LT	Tax regulation mechanisms (Relief from Excise Duty)	The amount of subsidy is equal to the amount of tax a person is exempt from. The tax on generated electricity is € 1.01 per MWh. Generated electricity used for business purposes is subject to a tax of € 0.52 per MWh (Chapter IV Art. 47 Par. 1, 2 Law on Excise Taxes).
NL	Tax regulation mechanisms I (Reduction of environmental protection tax)	There are several tax bands depending on the level of consumption. The amount of tax payable per 12-month period is as follows: • Consumption of less than or equal to 10 000 kWh: €ct 10.46 per kWh (art. 59 (1) (c) WBM); • Consumption from 10 000 kWh up to 50 000 kWh: €ct 5.27 per kWh (art. 59 (1) (c) WBM); • Consumption from 50 000 kWh up to 10 000 000 kWh: €ct 1.40 per kWh (art. 59 (1) (c) WBM); • Consumption of more than 10 000 000 kWh: €ct 0.12 per kWh (for private use) and €ct 0.06 per kWh (for commercial use) (art. 59 (1) (c) WBM). Electricity from renewable sources is exempt from this tax if it is generated by the consumer himself (art. 64 (1) in conjunction with art. 50 (4), (5) WBM).
NL	Tax regulation mechanisms II (Energy Investment Allowance, EIA scheme)	The amount of tax credit may be up to 54.5% of the total investments made in renewable energy or energy-efficiency technologies within one year (art. 3.42 (3) Wet IB 2001). The eligible technologies are published in the Energy List, which is updated on an annual basis. The maximum project costs per company are € 121 million per calendar year (art. 3.42 (4) Wet IB 2001). Investments of less than € 450 are not eligible for the tax credit (art. 3.45 (1) (a) Wet IB 2001). The total sum of investments in eligible projects shall reach at least € 2,300 within one year (art. 3.41 (2) Wet IB 2001). The Minister of Finance may reduce the amount of tax credit or reject applications if the expenses threaten to exceed the budget provided. His decisions are published and do not affect tax credits already granted.
PL	Tax regulation mechanism	The amount of subsidy is equal to the amount of taxes entitled persons are exempt from. At the moment, the consumption tax on electricity amounts to PLN 20 (approx. € 4.66) per MWh (Art. 89 par. 3 Excise Tax Act).
SK	Tax regulation mechanisms (exemption from excise tax)	The amount of tax allowance is equal to the amount of tax entitled persons are exempt from. The amount of tax is calculated on the basis of the amount of electricity in MWh and the corresponding tax tariff (§ 5 Act No. 609/2007). Since 1 January 2010, the tax on electricity has been € 1.32 per MWh (§ 6 par. 2 Act No. 609/2007).
SE	Tax regulation mechanisms II (Energy tax reduction)	**The energy tax is 34.7 öre per kilowatt hour (€ct 3.4 per kWh) (Chapter 11 § 3 par. 1 Act No. 1994:1776). For the calendar year 2020, the tax rates are multiplied by a factor based on the difference between the applicable electricity price of June the previous year and the price as of June 2018 (Chapter 11 § 3 par. 2 Act No. 1994/1776). By the end of November, the Government will determine the recalculated tax amount to be levied for the upcoming year (Chapter 11 § 3 par. 3 Act No. 1994/1776).** Electricity produced in electricity generators with a capacity lower than 50 kW is not taxable. In case of electricity generated from wind, wave and solar this capacity margin is higher (Chapter 11 § 2 Act No. 1994:1776).
SE	Tax regulation mechanisms III (Tax reduction for micro production of renewable electricity)	The tax reduction amounts to 60 öre (€ct. 6.3) per kWh of renewable electricity fed into the grid at the access point during the calendar year. However, the tax reduction may not exceed 30,000 kWh or the amount of electricity withdrawn from the electricity grid at the access point during the same year per natural person / legal entity or per connection point (Chapter 67 §§ 30, 31 Act No. 1999:1229).

Country	Type	Amount
HR	Loan (The Environmental Protection Programme of the HBOR)	According to the HBOR Programme for Environmental Protection, the terms and conditions of loan are as follows: ● The minimum loan amounts to HRK 100,000 (approx. € 13,200). ● The amount of loan is not subject to a maximum and depends on: 1. the HBOR's financing capability, 2. the specific investment programme, 3. the creditworthiness of the end borrower(s), and 4. the value and quality of the security offered. ● Before applying for a loan exceeding HRK 37 million (approx. € 4.9 million), borrowers / commercial banks are obliged to obtain a written consent from the HBOR to submit their loan applications. However, the approval of the application does not mean that a loan will be granted. ● The HBOR will cover up to 75% of the estimated investment value without VAT. ● The interest rate (currently 4%) is variable and mainly subject to the decision of the HBOR. The rate may also be agreed to be set at the three-month EURIBOR + 2% per year. ● If the investment meets the eligibility criteria of the Environmental Fund and is approved by it, the loan interest rate can be reduced by a further 2%. (Point 4 and 5 HBOR Programme for Environmental Protection)
HR	Loan (Environmental Protection and Energy Efficiency Fund)	The amount of the loan is specified in the tender (Art. 8 Nr. 6 Fund Criteria Rulebook).
DK	Loan (Loan guarantees for local initiatives for the construction of wind-energy plants	Danish Ministry of Energy, Utilities and Climate has to work within a budget of 10 million DKK (approx. € 1.34 million) for guarantees. Each guarantee will cover most of the loan in question. The maximum guarantee is 500,000 DKK (approx. € 67,260) per project (§ 21 par. 5 VE-Lov).
DK	Loan (Loan guarantees for local initiatives for the construction of wind-energy plants	Danish Ministry of Energy, Utilities and Climate has to work within a budget of 10 million DKK (approx. € 1.34 million) for guarantees. Each guarantee will cover most of the loan in question. The maximum guarantee is 500,000 DKK (approx. € 67,260) per project (§ 21 par. 5 VE-Lov).
DE	Loan (KfW Renewable Energy Programme – Standard)	Up to 100% of the investment costs eligible for financing (without VAT), however, not more than EUR 50 million per project. It is a long-term and low-interest (1,05 %) loan with a fixed interest period of 5 or 10 years including a repayment-free start-up period. A fixed interest period of up to 20 years is granted if technical and economic duration of co-financed investment is longer than 10 years. Moreover, a commitment fee of 0.25 % per month is charged.
DE	Loan and Subsidy (BMU – Innovation Programme)	The support scheme offers low-interest loans for up to 70 % of total investment costs or a subsidy of up to 30 % of total investment costs. The long-term and low-interest loan has no cap and needs to be repaid within a maximum period of up to 30 years including a maximum 5- year repayment-free start-up period. The fixed interest rate is renegotiated after 10 years. Moreover, a commitment fee of 0.25% per month is charged.
DE	Loan (KfW Renewable Energy Programme Storage)	Up to 100% of the net investment value is eligible for financing. Different kind of maturities are possible: 5, 10, or 20 years with a maximum repayment free period of one year, two or respectively three years. For credits up to 10 years, the interest rate is fix. For credits over more than 10 years the interest rate can be fixed either for the first 10 years or for the whole period of time. The installed capacity of the PV power station must not exceed 30 kWp and the feed-in to the grid is limited to 50% of the plant's capacity. It is a long-term and low-interest loan during a period of 5/10/20 years including a 1/2/3-year repayment-free start-up period. The fixed interest rate is renegotiated after 10 years. Moreover, a commitment fee of 0.25% per month is charged. The share of investment costs eligible for support is gradually reduced every quarter year: ● 1.3.2016 - 30.6.2016: 25% ● 01.07.2016 - 31.12 2016: 22% ● 01.01.2017 - 30.06.2017: 19% ● 01.07.2017 - 30.09.2017: 16% ● 01.10.2017 - 31.12 2017: 13% ● 01.01.2018 - 31.12 2018: 10%
LT	Loan (Climate Change Special Programme)	All loans granted shall be financed partly from the programme's budget and partly from the funds of a credit institution. The loan is paid out by a credit institution on behalf of the Ministry of Environment. No maximum has been set for the total amount of a credit per applicant. The amount to be provided by the credit institution shall be at least 20% of the loan (Chapter III Items 14, 17 Order No. D1-275/2010).
NL	Loan	In practice the declaration on the basis of RGP 2016 will result in a reduction of the interest rate in the order of 1%. Minimum project costs are € 25,000 (art. 15. 1. (e), RGP 2016) unless the project is related to art. 7.d. & e. or art. 8.a. RGP 2016.
PL	Loan (National Fund for Environmental Protection and Water Management - Stork)	The overall budget of the programme is PLN 570 million (€ 132.7 m) for the timeframe 2015-2023 (3 Priority Programme RES Stork). The loan shall cover max. 85% of investment's eligible costs (7.2 Priority Programme RES Stork). The loan amounts to PLN 40 million (€ 9.31 m) (7.3.1 Priority Programme RES Stork). Interest rate of the loan is: WIBOR (Warsaw Interbank Offered Rate) 3M – 100 base points but at least 2% (7.3.2 Priority Programme RES Stork). The maximal duration of loan support is 15 years (7.3.4 Priority Programme RES Stork).
SI	Loan (Eko Fund)	The amount of credit must be determined in line with the provisions of § 11 of the Terms and Conditions of the Eco Fund. According to these provisions, the amount of credit depends on the following factors: ● the amount of eligible costs, ● the type of investment, ● the evaluation of the environmental criteria, ● the credit rating of the eligible party and the debt insurance, ● the total budget available for a specific call, as defined in the public call document, and the relevant state aid and "de minimis" limits. **MAXIMUM LOAN AMOUNT** The calls currently open provide respectively a total of € 6 million for residents (Call No. 59OB17), € 5 million for corporations (Call No. 56PO16) and 5 million for local communities (Call No. 60LS17). **PERIOD** The maximum credit period is 10 years for private individuals – residents (item 3 par. D) b) Call No. 59OB17) and 15 years for environmental investments (Call No. 56PO16 and Call No. 60LS17). **INTEREST RATE** The minimum interest rate for residents and corporations is the three-month EURIBOR rate plus 1.3 percentage points (item 3 par. D a) Call No. 59OB17, item 4 § a) Call No. 56PO16). For local communities, the minimum interest rate corresponds to the three-month EURIBOR rate plus 1.0 percentage points (item 4 a) Call No. 60LS17).

Country	Type	Amount for Solar energy
CZ	Premium tariff: Green Bonus	Since 1 January 2014, the premium tariff for new PV installations has been abolished. Tariffs for PV installations put into operation before 31 December 2013 depend on the date of commissioning and are set as follows: ● From 1 January – 31 December 2010 up to 30 kW: CZK 13,456 (€ 517) per MWh. ● From 1 January – 31 December 2010 above 30 kW: CZK 13,500 (€ 519) per MWh. ● From 1 January – 31 December 2011 up to 30 kW: CZK 7,597 (€ 292) per MWh. ● From 1 January – 31 December 2011 from 30 to 100 kW: CZK 5,886 (€ 226) per MWh. ● From 1 January – 31 December 2011 above 100 kW: CZK 5,414 (€ 208) per MWh. ● From 1 January – 31 December 2012 up to 30 kW: CZK 5,887 (€ 226) per MWh. ● From 1 January – 30 June 2013 up to 5 kW: CZK 2,650 (€ 102) per MWh. ● From 1 January – 30 June 2013 from 5 kW to 30 kW: CZK 1,998 (€ 77) per MWh. ● From 1 July – 31 December 2013 up to 5 kW: CZK 2,177 (€ 84) per MWh. ● From 1 July – 31 December 2013 from 5 kW to 30 kW: CZK 1,549 (€ 60) per MWh (No. 1.10. Price Decision of the Energy Regulatory Office No. 3/2018). The green bonus for PV installations put into operation between 1 January 2010 and 31 December 2010 is subject to a tax of 11% (except for building-integrated installations with a capacity of up to 30 kW) (§ 17 in conjunction with § 18 Letter b Act No. 165/2012). The tax applies to all electricity generated in the respective plants from 1 January 2014 (§ 14 Act No. 165/2012).
DK	Premium tariff (Law on the Promotion of Renewable Energy)	The Danish Ministry of Energy, Utilities and Climate may grant support for electricity produced in PV-installation for a pool of 20 MW per year from 2013 until 2017. In 2016 and 2017 only PV-installations with installed capacity of less than 500 kW are eligible. For projects where the decision on commitment for tariff was met on 01.01.2017 or later, the total aid per project may not exceed an amount equivalent to € 15 million (§ 47 par. 8 VE Lov). Following installations may receive the support (§ 47 par. 7 VE Lov): ● Installations with an installed capacity of max. 6 kW per household and connected to self-consumption installation: maximum subsidy (bonus plus market price) of 1.30 DKK (approx. €ct 17) per kWh, applicable for 10 years after the grid connection. For plants connected on or after 01.01.2014 the bonus will be reduced annually by 0.14 DKK (€ct 2) (§47 par. 7 No. 1 VE-Lov). The maximum subsidy in 2018 is 0.60 DKK/kWh (approx. €ct 8) and in 2019 0.46 DKK/kWh (approx. €ct 6). ● Common PV installations established on the roofs of buildings or integrated into buildings that are not built with the purpose of mounting solar cells: maximum subsidy (bonus plus market price) of 1.45 DKK (approx. €ct 19.5) per kWh, applicable for 10 years after the grid connection. For plants connected on or after 01.01.2014 the bonus will be reduced annually by 0.17 DKK (€ct 2) (§47 par. 7 No. 2 VE-Lov). The maximum subsidy in 2018 is 0.60 DKK/kWh (approx. €ct 8) and in 2019 0.43 DKK/kWh (approx. €ct 6). ● Common PV installations, which are not connected to self-consumption installation: maximum subsidy (bonus plus market price) of 0.90 DKK (approx. €ct 12) per kWh, applicable for the 10 years of operation. For plants connected on or after 01.01.2014 the bonus will be reduced annually by 0.06 DKK (€ct 0.8) (§47 par. 7 No. 3 VE-Lov). The maximum subsidy in 2018 is 0.60 DKK/kWh (approx. €ct 8) and in 2019 0.54 DKK/kWh (approx. €ct 7).
EE	Premium tariff	€ 0.0537 per kWh
DE	Premium tariff (Market Premium)	The amount of tariff depends on the site of production and the installed capacity. ● **specific building-mounted systems** (e.g. roofs, facades, noise barriers, other building) EUR ct 8.91 – 12.70 per kWh (§ 48 par. 1 and 2 EEG 2017).
GR	Premium tariff (Feed-in Premium)	CSP: 257-278 €/ MWh PV ≤500 kW: 1,2* MASPv-1 (MASPv-1= Marginal Average System Price of the previous year (art.4 par.1b Law No.4414/2016).
HU	Green Premium (Premium Tariff)	General information on tariffs: ● There are three different tariff rates depending on the time of day (peak, valley and deep-valley period except for solar power which is subject to a single tariff). ● These time periods are defined by decree (Decree 299/2017), depend on the area the electricity is generated in and vary for weekdays and weekends/holidays as well as for summer and wintertime. ● There are three tariff areas according to the areas of opera-tion of the six distribution grid operators (Annex 3 Decree No. 299/2017). ● The tariff level also depends on a plant's installed capacity and the generation technology employed. Premium Tariffs for the green premium: All eligible technologies receive the same basic tariff (Annex 1. De-cree 299/2017) ● peak period (basic tariff): HUF 31.77 per kWh (approx. € 0.0989) ● valley period (basic tariff): HUF 31.77 per kWh (approx. € 0.0989) deep-valley period (basic tariff): HUF 31.77 per kWh (ap-prox. € 0.0989)
LT	Sliding feed-in premium (Law on Energy from Renewable Sources)	• Tariff rate for building-integrated solar power installations with installed capacity of up to and including 10 kW: € 0.169 per kWh (Item 1.1. Resolution No. O3E-171/2018) • Tariff rate for solar power installations not integrated in buildings with the installed capacity of up to and including 10 kW: € 0.136 per kWh (Item 2.1. Resolution No. O3E-171/2018)
NL	Premium tariff (SDE+)	Photovoltaic solar cells ≥ 15 kWp and connection > 3*80A (maximum 950 FLH) ● Phase 1: €ct 9.0 per kWh ● Phase 2: €ct 10.6 per kWh ● Phase 3: €ct 10.6 per kWh Photovoltaic solar cells ≥ 1 MWp ● Phase 1: €ct 9.0 per kWh ● Phase 2: €ct 9.9 per kWh ● Phase 3: €ct 9.9 per kWh

Annex C: Solar Power Potential

Country	Total area [km2]	Evaluated area [km2]	Population [millions]	Electricity consumption per capita [kWh/per capita/year]	Total electricity consumption [TWh/year]	PV installed capacity [MWp]	Average practical potential [kWh/kWp]	PV equivalent area	Electricity production [MWh/day]	Electricity production [TWh/year]	Electricity produced by solar	Location
LV	64490	64141	2	3507	7	7	2,853	0,30%	20	0,01	0,1%	North
IE	70280	69540	5	5672	28	40	2,513	0,94%	101	0,04	0,1%	North
HR	56590	56366	4,1	3714	15	85	3,631	0,29%	309	0,11	0,7%	South
EE	45340	33976	1,4	6732	9	130	2,873	0,69%	373	0,14	1,4%	North
LT	65286	64500	3	3821	11	148	2,87	0,40%	425	0,16	1,4%	North
LU	2590	2578	0,7	13915	10	195	2,948	5,68%	575	0,21	2,2%	Central
MT	320	318	0,5	4925	2	184	4,562	4,87%	839	0,31	12,4%	South
SI	20675	20209	2,1	6728	14	267	3,425	0,84%	914	0,33	2,4%	South
CY	9250	8659	1,2	3625	4	200	4,698	0,29%	940	0,34	7,9%	South
FI	338455	98467	5,5	15249	84	391	2,783	2,05%	1088	0,40	0,5%	North
SK	49030	48805	5,5	5137	28	593	3,266	0,83%	1937	0,71	2,5%	Central
DK	42920	42770	5,8	5859	34	1300	2,843	2,11%	3696	1,35	4,0%	North
BG	111000	110672	7	4709	33	1073	3,703	0,30%	3973	1,45	4,4%	Central
SE	447430	142277	10,2	13480	137	1417	2,873	1,94%	4071	1,49	1,1%	North
PT	92226	91678	11	4663	51	1025	4,316	0,38%	4424	1,61	3,1%	South
RO	238400	237547	20	2584	52	1387	3,524	0,26%	4888	1,78	3,5%	Central
CZ	78870	78501	10,7	6259	67	2073	3,048	1,37%	6319	2,31	3,4%	Central
HU	93030	92654	10	3966	40	1953	3,44	0,54%	6718	2,45	6,2%	Central
AT	83879	83600	8,5	8356	71	2220	3,257	1,25%	7231	2,64	3,7%	Central
PL	312680	310310	38	3972	151	3936	2,984	0,90%	11745	4,29	2,8%	Central
GR	131960	131843	10,8	5063	55	3247	4,143	0,32%	13452	4,91	9,0%	South
BE	30530	30526	11,5	7709	89	5646	2,916	5,03%	16464	6,01	6,8%	Central
ES	505935	505040	47	5356	252	4744	4,413	0,35%	20935	7,64	3,0%	South
NL	41540	35115	17	6713	114	10213	2,865	6,65%	29260	10,68	9,4%	North
FR	549087	547573	67	6940	465	11733	3,386	1,05%	39728	14,50	3,1%	Central
IT	301340	300651	60,5	5002	303	21600	3,993	0,92%	86249	31,48	10,4%	South
DE	357580	355807	83	7035	584	53783	2,961	2,95%	159251	58,13	10,0%	North
CH	9562910	9348718	1400	3927	5498	250000	3,883	0,46%	970750	354,32	6,4%	

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