

**European Potential of Solar Technologies for
Electricity Generation under Project Drawdown
Framework**

Luiz Fernando Teixeira da Silveira

Thesis to obtain the Master of Science Degree in
Engineering and Energy Management

Supervisors: Dr. João Pedro Costa Luz Baptista Gouveia
Prof. Carlos Augusto Santos Silva

Examination Committee

Chairperson: Prof. Luís Filipe Moreira Mendes
Supervisor: Prof. Carlos Augusto Santos Silva
Member of the Committee: Prof. Maria Júlia Fonseca de Seixas

January 2021

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Bachelor's in environmental engineering

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Acknowledgments

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Additionally, I must show appreciation for Project Drawdown, more specifically, to Drawdown Europe Research Association (DERA) for allowing me the opportunity to contribute somehow to a real project that addresses such important causes as Climate Change and Energy Transition.

Finally, I would also like to thank my home university, UFRJ and its Environmental Engineering course, because, if it weren't by them, I would not have pursued continued education in the energy field as I did. Free higher education is an important part of fighting social inequality that traps Brazilian development for decades, and it must be preserved.

Abstract

The emergency associated with the climate crisis demands immediate action. All economic sectors need to decarbonize in order to fight Climate Change. The Power Sector is strategic whether it be by its massive contribution in greenhouse gases emissions or for its intrinsic capacity to decarbonize other energy-consuming activities in a transversal way. The Energy Transition era will be filled with various complex and interlinked challenges but, at least on the technological domain, there are good solutions to build a future energy mix that can combine security of supply, environmental protection, and economic performance both for investors and consumers.

Within the regionalization phase of Project Drawdown in Europe, this work collects several recent projections for the European Electricity Sector, from 2020 to 2050, in order to evaluate the contributions of solar solutions, more specifically, photovoltaic in centralized scale (U-PV), distributed photovoltaic (D-PV) and solar thermoelectricity (CSP), for both electricity generation and avoidance of GHG emissions, using the Drawdown model and methodology. Results suggest that European electricity sector of 2050 will produce (3,732 - 10,455 TWh/y), with U-PV adoption of (146 - 2,181 TWh/y), D-PV adoption of (93 - 901 TWh/y) and CSP adoption of (33 - 372 TWh/y). Together, solar based solutions can account for (7% to 33%) of total electricity generation in 2050. Over the next decades, they can avoid (1.32 - 26.31 Gt CO₂e) GHG emissions and require investments in between (233 - 2.230 billion €).

Keywords: Solar Power, Long Term Projection, Greenhouse Gases Emissions, European Union, Drawdown, Renewable Energy.

Sumário

A emergência da crise climática exige ação imediata. Todos os setores econômicos precisam se descarbonizar para combater as mudanças climáticas. O setor elétrico é estratégico, seja por sua massiva contribuição em emissões de GEE, seja pela capacidade intrínseca de descarbonizar outras atividades consumidoras de energia de forma transversal. A era de transição energética será marcada por vários desafios complexos e interligados, mas, pelo menos no domínio tecnológico, existem boas soluções para construir uma futura matriz energética que pode conjugar segurança de abastecimento, proteção ambiental e desempenho econômico para investidores e consumidores.

No âmbito da fase de regionalização do Projeto Drawdown na Europa, este trabalho visa recolher projeções recentes para o Setor Elétrico Europeu, de 2020 a 2050, a fim de avaliar as contribuições das soluções solares, mais especificamente, fotovoltaica em escala centralizada (U-PV), fotovoltaica distribuída (D-PV) e termoeletricidade solar (CSP), tanto para a geração de eletricidade quanto termos de emissões GEE evitadas. Resultados deste trabalho projetam que o setor elétrico europeu de 2050 terá um tamanho aproximado de (3,732 – 10,455 TWh/y) com adoção U-PV de (146 – 2,181 TWh/y), adoção D-PV de (93 - 901 TWh/y) e adoção CSP de (33 - 372 TWh/y). Ao longo das próximas três décadas, conjuntamente, essas soluções solares podem abater (1.32 – 26,31 Gt CO_{2e}), correspondendo a (7% a 33%) do parque gerador e demandando investimentos da ordem de (233 – 2,230 bilhões €).

Palavras-Chave: Energia Solar, Projeções de Longo Prazo, Emissões de Gases de Efeito Estufa, União Europeia, Drawdown, Energia Renovável.

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List of Acronyms

APEC – Asia-Pacific Economic Cooperation

ASSET – Advanced System Studies for Energy Transition

CCUS – Carbon Capture Usage and Storage

CSP – Concentrated Solar Power

DERA – Drawdown Europe Research Association

D-PV – Decentralized Photovoltaic

ECF – European Climate Foundation

EDP – Energias de Portugal

ESS – Energy Storage Systems

ETP – Energy Technologies Perspectives

EU – European Union

EUREF – European Union Reference Scenario

EWG – Energy Watch Group

FOM – Fixed Operating and Maintenance Costs

GHG – Greenhouse Gas

GP – Greenpeace

GRO – Global Renewables Outlook

IEA – International Energy Agency

IEEJ – The Institute of Energy Economics, Japan

IRENA – International Renewable Energy Agency

JRC – European Commission Joint Research Centre

LUT – Polytechnic University of Lappeenranta

NDC - Nationally Determined Contributions

NIMB – Not In My Backyard

OECD – Organization for Economic Cooperation and Development

PHS – Pumped-Hydro Storage

PV – Photovoltaic

RES – Renewable Energy Sources

RRS – Reduction Replacement Solutions

SDG – Sustainable Development Goals

SDS – Sustainable Development Scenario

SPE – Solar Power Europe

STEPS – Stated Policies Scenario

TAM – Total Addressable Market

UNEP – United Nations Environmental Programme

UNFCCC - United Nations Framework Convention on Climate Change

U-PV – Utility-Scale Photovoltaic

VMA -- Variable Meta-Analysis

VOM – Variable Operating and Maintenance Costs

VRE – Variable Renewable Energy

WEC – World Energy Council

WEO – World Energy Outlook

Glossary

ADPT: This acronym is sometimes used throughout this work in reference to the projections about the adoption of solar technologies for electricity generation, expressed in TWh.

TAM: The Total Addressable Market in the context of this work refers to the total amount of electricity generated during a given year, also expressed in TWh.

VMA: Variable Meta-Analysis refers to a set of technical and economic features that characterizes technological solutions. Some of them are First Cost (or Installation Cost), Lifetime Capacity, O&M Costs and Emission Factors.

Implementation Unit: Is the unit in which one can express the acquisition, the installation, or the implementation of the given solution. Since solutions in this work relate to electricity generation the Functional Unit is TW, referring to the installed capacity.

Functional Unit: Is the unit in which one can express the intended outcome produced by the solution, or the function of the solution. These two units are closely related, is only thru the implementation of the solution that it can deliver its function. Since solutions in this work relate to electricity generation the Functional Unit is TWh, referring to the amount of electricity generated.

1 Introduction

A common and trending way of perceiving human history is through the lens of technological innovation. One can describe and divide human evolution in chapters, each one of them corresponding to a technological advancement. Fire, for instance, allowed for enhanced vision at night, heating, protection, and some rudimentary form of cooking. The innovation brought up by farming probably have triggered the first human settlements reshaping society and the human relation towards land and property. Such perspective is only possible due to a human trait that distinct us from other species: the ability to create new ways to alter the space we live in, intentionally, according to our needs.

This previous statement might have been too generic. It may be possible to argue that other species can also alter their environment, but there is no doubt that only humans can impact and change the whole planet as a consequence of its own doing.

The newness of present times is that, maybe for the first time, technological development will be directed to address the consequences of our interference over the planet. Over the next decades we will try to reduce the magnitude of impacts when possible while adapting for the ones that are unavoidable effects of Climate Change. Probably this will define the times we live in and when future historians look back at the present, they may label it in a reference to the technological breakthroughs that allowed us to reduce the impacts of human development on the planet, the era of climate change and energy transition.

1.1 The Era of Climate Change and Energy Transition

We already live in the era of Climate Change. Much of the technological and cultural production of the present and next decades will be related to this goal. But the realization of this fact, in a historical perspective at least, is somewhat recent. For too long it was considered that human activity could not significantly impact the planet [1], or if it could, it was not a worry [2].

The grassroots of environmentalism dates back to 1960's symbolized with Rachel Carson's Silent Spring publication. In the 1970's the environmental cause has been formally institutionalized with the creation of the Environmental Protection Agency (1970) in the United States, and the United Nations Environmental Programme (UNEP), right after the Stockholm Conference (1972). Another important chapter happened in Rio de Janeiro in 1992 when it was negotiated the creation of the United Nations Framework Convention on Climate Change (UNFCCC).

Since its creation, the UNFCCC has become the main reference body for climate change relative negotiations and debates with almost universal membership at 197 parties. According to its own website

[3], its ultimate goal is to “stabilize greenhouse gas concentrations in the atmosphere at a level that will prevent dangerous human interference with the climate system, in a time frame which allows ecosystems to adapt naturally and enables sustainable development.”

It was also under the UNFCCC framework that both Kyoto Protocol and Paris Agreement were celebrated. The later, being the currently most important, ambitious and recent environmental treaty of global relevance, aimed at limiting the average global temperature rise to 2 °C above pre-industrial levels in this century and better empower countries to deal with the various impacts of climate change [4].

In order to achieve that ambitious goal, countries need to curb their current greenhouse gasses (GHGs) emissions. The Paris Agreement was built upon the premise that each country would voluntarily self-impose a target known as “nationally determined contributions” or NDCs. Unfortunately, data gathered by Climate Action Tracker shows that only a handful of countries are on track with their self-imposed goals [5].

Climate Change is a transversal threat meaning that it will impact many different sectors of human life and economy. But reducing emissions is itself a transversal challenge since almost every human activity is a net emitter [6]. Looking at the bright side, it also means that there are also various opportunities to abate emissions across the entire economy.

As a matter of fact, some sectors are easier to decarbonize than others. This usually means having developed technological alternatives that can be scalable to substitute polluting old ones, preferably at competitive costs. Others still, are strategic in the sense that once they become carbon neutral many other activities that rely upon them will also reduce their carbon footprint. And some sectors should be prioritized due to its large share of emissions [7].

The power sector satisfies all these conditions. Is one of the biggest carbon emitters [8]. Renewable energy such as wind and solar power are already cost-competitive technologies and actually in many regions of the globe data acquired from newly power auctions suggest solar as being the cheapest form of electricity generation [9]. And with increased electrification many daily activities that once emitted GHGs would cease to pollute if power is supplied with carbon neutral mix.

That is why the Climate Change Era should start with the Energy Transition Period.

1.2 Topic Relevance and Motivation

It is clear the emergency of the topic. Most of society, but primarily the younger generation, recognizes the need to take immediate action. It was made clear in last year's series of demonstrations all across Europe, and other parts of the world as well, in the movement called "Fridays for Future" [10]. The media also recognizes the momentum of pressure for environmental action so much so that 2019 TIME's "Person of the Year" award was given to Greta Thunberg [11]. Even the political sphere recognizes it, and the recent declaration of Climate Emergency from European Parliament exemplifies that [12]. All happened in 2019, including an important milestone in terms of curbing GHG emissions: for the first time emissions from the energy sector remained flat, even as global GDP grew by 2.3% [13].

United Nations current 2030 Sustainable Development Goals (SDG) are also energy related. The SDG framework provides the blueprint for an achievable future when humanity places peace, people, prosperity, and the planet at the core of our collective development [14]. SDG number seven addresses the need "to ensure access to affordable, reliable, sustainable and modern energy for all" in which solar and wind power technologies have a leading role. And renewable energy development contributes indirectly to many other SDGs.

In the current time and age of post-truth we live in, despite the overwhelming amount of evidence and scientific agreement over this matter there are still some that denies the issue completely, including some top-tier world leaders. The challenge of Climate Change and is hands-down one of the most complex problems ever to be solved and executed by humanity: it is, all at once, technological, political, international, inter-generational, cross-industry, stochastic, future-oriented, resulting in a unique complexity.

These two factors, the emergency, and the planetary scope, are probably the two greater motivations for dealing with Energy Transition and Climate Change. Especially in Europe, when the old continent set sail to become world leader in sustainability, already with ambitious self-imposed goals for carbon neutrality in 2050, and plans to recover from a pandemic over a greener route [15]. These unprecedented challenges are also an invaluable opportunity to reshape society, correct flaws of the economic model, becoming better stewards of the planet and of ourselves.

More specifically to solar power technologies, the main motivations are the exciting record breaking news whether relative to its staggering declining costs [16][17][18] or to its efficiency (just recently perovskite/silicon tandem solar cell technology reached 29,15% efficiency [19]). All things considered the huge potential that is still untapped ahead of them is an invitation to study this field. The well-known-to-the-public Photovoltaic (PV) technology has the ability to be embedded in almost any building or product if there is the need to produce energy, with no moving parts and no noise. The somewhat recent Concentrated Solar Power (CSP) is one of the few renewable power solutions that offers some degree of dispatchability and energy storage. In their own ways, both of them have specific traits that can be useful to transition to a cleaner energy mix.

1.3 Work Objectives

The general purpose of this work is to contribute towards the solution of the technical aspect of the puzzle. The primary goal is to assess the potential of solar technologies for electricity generation to abate CO_{2e} emissions from 2020 to 2050 at European level.

There are some pre-requisites for achieving this goal, that will serve as secondary objectives, such as: assessing the projected size in TWh of the total generation of electricity in Europe, the penetration of solar technologies in the 2050's European energy mix, the associated costs demanded by them. Then it is also necessary to size the individual contribution for each one of the solar technologies under analysis, namely, Utility-scale photovoltaic generation (U-PV), Decentralized photovoltaic generation (D-PV) and Concentrated Solar Power (CSP).

Moreover, it is important to highlight that this work is part of the Project's Drawdown regionalization process to study in greater detail the many different regions of the globe, their differences, potential opportunities, deficiencies, and similarities. This is the reason why this work will be oriented to European level.

1.4 Work Structure

In the second chapter of this work, a core aspect of this work will be addressed: Project Drawdown and its three solar-based technology solutions for energy generation. Then a short comparison of the current status of solar technologies in Europe and over the world is followed by the literature review highlighting the most important publications found during the stage of data gathering, whether it be due to the variety and scope of the scenarios projected or the relevance/uniqueness of a certain publication and some distinctive topics that are very relevant to the future of the energy sector.

The third chapter provides an overview of the Drawdown model used for the three solar solutions, run scenarios, and evaluate the results on electricity generation, associated investment and operation costs, and environmental impacts through GHG emissions avoided up to 2050. This chapter also contains a detailed walk-through of the methodology adopted, and all the intermediate steps that transform a big collection of data into a useful format to feed the model.

The different stages of this work have yielded different types of results. Some of them are the product of gathering, curating, and organizing data from the various sources consulted, others were obtained after running project Drawdown's Reduction and Replacement Solutions (RRS) Model with several scenarios. Every result produced in this work will be exposed in Chapter four.

Next, on the fifth chapter, the discussion of results will take place via a combination and comparison of individual results previously addressed. Moreover, there are also specific sections dedicated to comparing these obtained results to the ones previously published by Project Drawdown and a final one for assessing the impacts that varying Variable Meta-Analysis (VMA) parameters will produce over model's results in a sensitivity analysis. The final chapter presents the conclusions of this work, opportunities for improvement and suggestions of future related work.

2 Solar Technologies, Project Drawdown and Literature Review

This chapter will be dedicated to presenting the most important solar technologies at the present and the Project Drawdown. The first section presents Project Drawdown “The world Leading’s resource for Climate Solutions”, its development, results, and the characteristic holistic approach that considers multiple sectors and technological solutions that can contribute to reduce GHG by avoiding emissions and/or by sequestering carbon dioxide (CO₂) already in the atmosphere. Afterwards, a quick comparison of how these technologies take part in the European and global energy mix, followed by detailed comments about the most important sources that supported this study.

2.1 Project Drawdown and Prominent Solar Technologies

Founded in 2014, Project Drawdown is a non-profit organization whose mission is to help the world stop global warming by reaching Drawdown. The project’s name refers to the future point in time when levels of greenhouse gases in the atmosphere stop climbing and start to steadily decline. This is the point when we begin the process of stopping further climate change and averting potentially catastrophic warming. It is a critical turning point for life on Earth. Currently, the project is funded by individual and institutional donations [20].

To achieve Drawdown, the Project has shed light over many, if not every, aspects of the climate equation reducing sources - bringing emissions to zero, supporting sinks - uplifting nature’s carbon cycle and improving the society - fostering equality for all. Nested within each action area, there are sectors and subgroups of different solutions. These solutions are based on practices and technologies that can help the world to stabilize and then start to reduce the levels of greenhouse gases in the atmosphere Together, they make up the Drawdown Framework for climate solutions, published in 2017 as the projects’ inaugural work in print publication. The variety of covered sectors is shown in Figure 2-1 exemplifying the holistic approach that has characterized this initiative since the beginning.

To face the climate crises, the world must change in many ways and in many multiple sectors like technology, politics, business models and behavior. Almost daily, there is a new promising evolution and/or acceleration of climate solutions, as seen in each of these sectors. Although very the general scope of Project Drawdown is very broad, it is composed of a combination of smaller parts. This work will be part of the *shifting production* class of solutions aimed in replacing traditional fossil fuel-powered thermal plants for clean and environmentally friendly alternatives. Thus, this work is focused on solar based solutions for power generation, namely Concentrated Solar Power (CSP), Decentralized Solar Photovoltaics (D-PV) and Utility-Scale Solar Photovoltaics (U-PV).

DRAWDOWN FRAMEWORK FOR CLIMATE SOLUTIONS

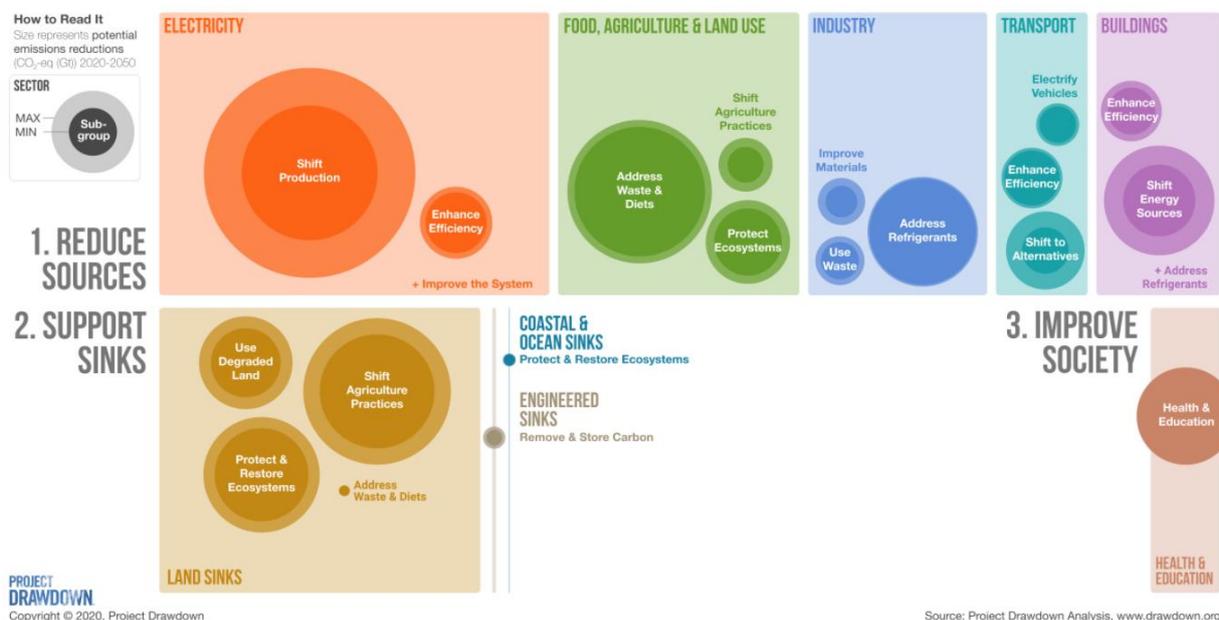


Figure 2-1: Project Drawdown holistic approach of considering multiples sectors and over 80 technological solutions to achieve climate neutrality [21]

It is also important to highlight that Project Drawdown has entered a regionalization phase. As a consequence, the Drawdown Europe Research Association (DERA) was created to apply the project’s methodology to the European reality [22]. And is in this context that the present work is inserted, to study the most prominent solar technologies within European geography, for the first time being developed as part of the fellowship program associated with the production of a master thesis.

2.1.1 Decentralized Solar Photovoltaics (D-PV)

The distributed solar photovoltaic systems are commonly found in residential and commercial systems. Whether grid-connected or part of standalone systems, they offer hyper-local, clean electricity generation based on solar panels with no moving parts.

There are many technologies for solar panels, but the most common technology uses thin wafers of crystalline silicon. These thin film modules are constructed by depositing extremely thin layers of photosensitive materials onto a substrate such as glass, stainless steel, or flexible plastic. As photons strike them, they knock electrons loose and produce an electrical circuit.

Grid connected arrays are the most popular type of solar PV systems for homes and businesses in the developed world. Connected to the local grid, they allow any excess power produced to be sold to the utility. When solar energy is not available, electricity can be drawn from the grid. In rural areas or in of

low-income countries, they can leapfrog the need for large-scale, centralized power grids, and accelerate access to affordable, clean electricity.

Standalone systems have no connection to a grid. An off-grid system usually has batteries, so power can still be used at night or after several days of low sun. An inverter is needed to convert the DC power generated into AC power for use in appliances.

Drawdown's world results are assent over a projection that, in 2050, from 6,235 to 10,000 TWh of annual electricity generation can be originated in decentralized PV panels.

2.1.2 Utility-Scale Solar Photovoltaics (U-PV)

Solar photovoltaics can also be used at utility-scale with hundreds or thousands of panels. A large industrial PV system can produce enormous quantities of electricity at a single location. Such power plants have outputs ranging from hundreds of kilowatts (kW) to hundreds of megawatts (MW). The solar panels for industrial systems are usually mounted on frames on the ground, in single purpose sites. However, they can also be installed on large industrial buildings, such as warehouses, airport terminals and railways stations. These systems can make double use of an urban space and put electricity into the grid where energy-intensive consumers are located.

It will be important to differentiate utility-scale photovoltaic (U-PV) generation from decentralized photovoltaic generation (D-PV) as being two different technological solutions. However, drawing the line between U-PV and D-PV can be tricky sometimes but is typically a matter of system size and ownership (by a power company or not).

This differentiation makes sense in the perspective of market evolution and projection of adoption of these technologies since inhabits different markets and agency levels. Generically speaking, D-PV are composed by a handful of PV-modules, funded by individuals or small companies, installed at the top of a pre-existing building many times inside the urban areas. In contrast, U-PV projects are developed by energy companies, typically acquiring new land under advantageous solar resources, creating panels with thousands of modules with multi-million budgets. Thereby, it is clear that although they share the same technological component (PV-Module) their markets and development will be tread differently.

Drawdown's global results for U-PV rely on projections that by 2050 this solution will account for 20-25% of total electricity generation, a huge depart from the current 2%. Solar PV is shrouded in high expectations.

2.1.3 Concentrated Solar Power (CSP)

Concentrating solar power (CSP) technologies, also known as solar thermal electricity, uses sunlight as a heat source and generate electricity by concentrating direct-beam solar irradiance to heat a medium

that is then used in a downstream process for electricity generation. This solar irradiance is called ‘beam radiation’ or direct normal irradiation – sunlight not dispersed by clouds, fumes, or dust in the atmosphere.

These solar thermal power plants obtain their energy input by concentrating solar radiation through large curved or angled mirrors angles to concentrate sunlight into a single point and converting it to high temperature steam or gas to drive a turbine or motor engine.

The most distinctive feature of CSP is, unequivocally, the ability to store energy, present in most plant designs. Heat is actually the primary product form CSP power plants and such heat can be stored in various ways. Most commonly found storage solutions are equipped with molten salt tanks, so CSP plants can continue to produce electricity well after the sun goes down. Other advantages are that it can integrate thermal storage for peaking loads (less than one hour) and intermediate loads (three to six hours); it can be used of desalination to produce drinking water; it has modular and scalable components, and it can provide industrial process heat in synergetic arrangements [23].

When compared to PV technology, concentrated solar power (CSP) has a much shorter development history, but offers greater diversity in the way power plants are designed, some of them being shown in Figure 2-2, being a group with internal sub-classes. The internal differences within these CSP classes are beyond the scope of this work. But a quick overview can be handy. All systems require four main elements: a concentrator, a receiver, some form of transfer medium or storage, and power conversion. Many different types of system are possible, including combinations with other renewable and non-renewable technologies.

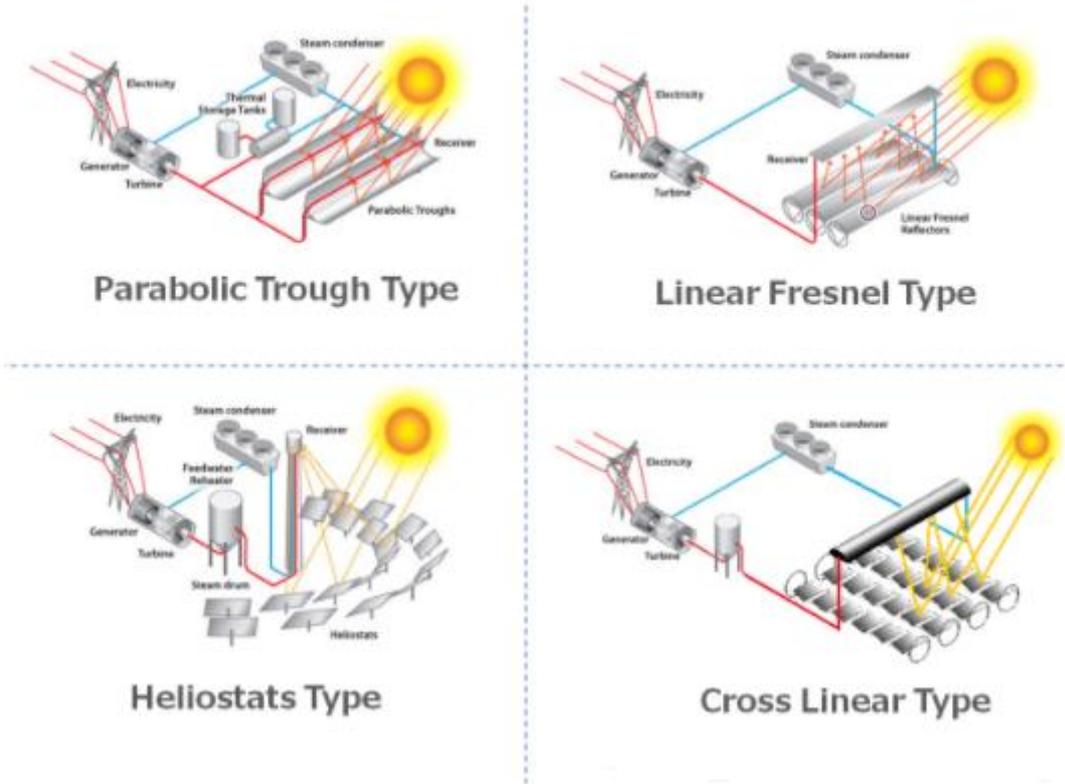


Figure 2-2: Typical CSP power plant arrangements [24]

The Parabolic trough design uses rows of parabolic trough collectors, each of which reflect the solar radiation into an absorber tube. The troughs track the sun around one axis, with the axis typically being oriented from north to south. As the synthetic oil passes through the troughs, it gets hotter and then it passes through a heat exchanger to generate steam for a conventional steam turbine generator to generate electricity.

With long lines of flat or nearly flat Fresnel reflectors this other arrangement of CSP technology forms a field of horizontally mounted flat mirror strips, collectively or individually tracking the sun to generate power. Although this alternative is cheaper to install than trough systems, typically attained efficiencies are lower [25].

Central receivers are maybe the most well-known CSP arrangement to the general public. This point-focused design makes use of a circular array of mirrors (heliostats) that tracks the sun, reflecting the light onto a fixed receiver on top of a tower. A heat-transfer medium absorbs the highly concentrated radiation reflected by the heliostats and converts it into thermal energy to be used for the subsequent generation of superheated steam for turbine operation.

Another alternative is the dish-shaped reflector that is used to concentrate sunlight on to a receiver located at its focal point which also moves with the dish. The concentrated beam radiation is then absorbed by a fluid or gas that is used to generate electricity via turbines in a very similar way as other thermal power plants generate electricity.

The global study carried by Project Drawdown yielded three classes of results: environmental, economic and energy production ones. The key results are permanently available on the internet and are based on a projection that by 2050, 5.9-7.3 percent of global world electricity generation will come from CSP. Current adoptions are very limited, just four gigawatts globally representing 0,05% of global power mix.

2.2 Current Status and trends of Solar Technology in the world and in Europe

Probably the earliest register of photovoltaic effect was when Alexandre Becquerel first observed it via an electrode in a conductive solution that has been exposed to light, in 1839. Several decades have passed since until another milestone has been achieved, in 1904, when Wilhelm Hallwachks makes the first semiconductor-junction solar cell with copper and copper oxide [26].

Maybe as important as the scientific achievements, political support is also a major driver for technological development. Solar photovoltaic technology has experienced such political boost for special purposes in the 1960s and 1970s during the space race, creating a positive feedback to more scientific discoveries [26].

Since then, solar technologies for power generation have evolved and improved enormously. Steady declines in costs have produced a surge of new projects, especially PV ones. Still, only a minor share of global energy mix is generated by solar power. Data from World Energy Outlook 2019 depicts in

Figures 2-3 and 2-4 the current shares of the most common technologies for energy generation for the world and for Europe, respectively.

One can observe that CSP is unable to complete a full 1% of total electricity generation in the world, and not even in Europe. Even PV, despite impressive growth in last decades, has still marginal participation, with 2% and 4% of the global and European mix. Direct comparison shows that Europe share of fossil fuel powered energy generation is lower than global one, partially compensated by increased shares of nuclear power and bioenergy.

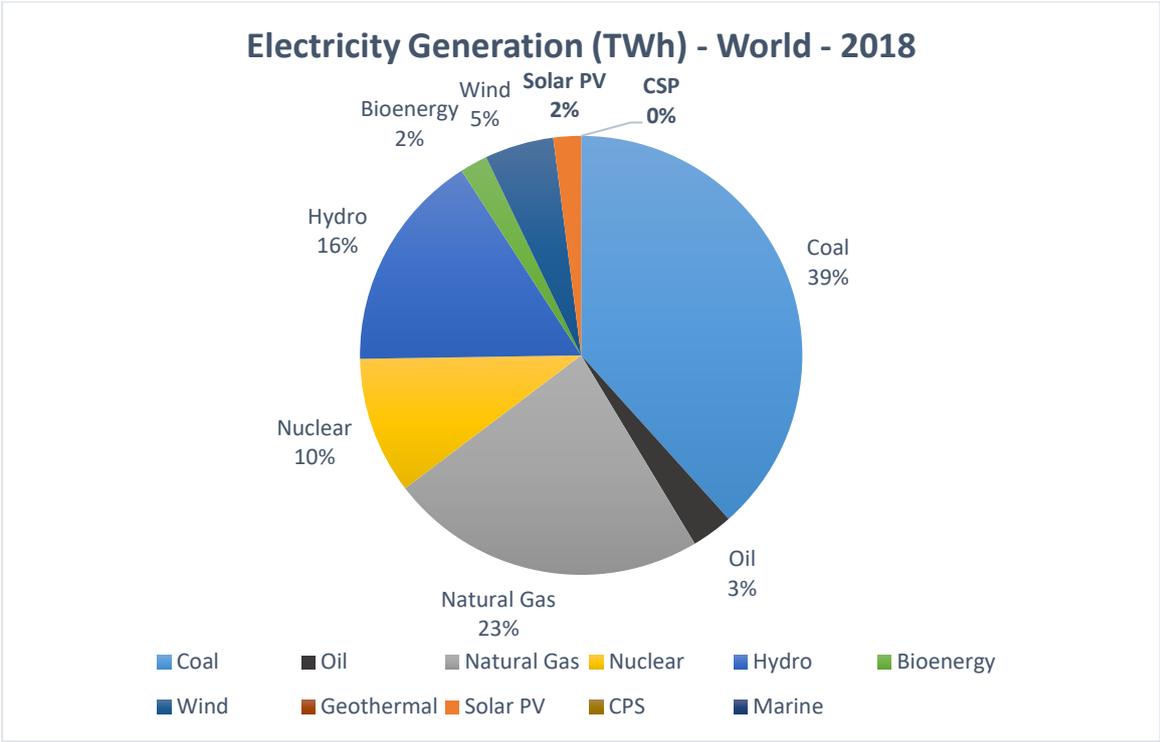


Figure 2-3: World Electricity Mix by technology in 2018 based on WEO 2019 [27] data.

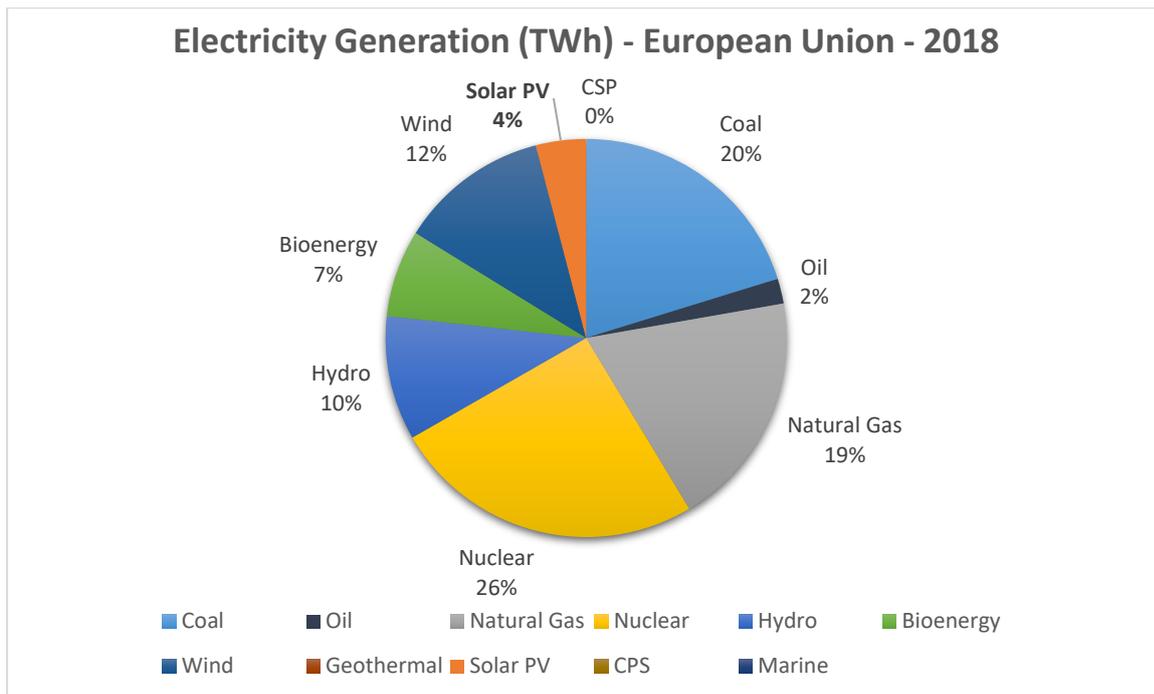


Figure 2-4: European Electricity Mix by technology in 2018, based on WEO 2019 [27] data.

Certainly, there are still scientific breakthroughs to be achieved relative to the discovery of new materials, improving the efficiency, reducing costs or environmental production-related impacts but there is also another sort of innovations that flies under the radar receiving less attentions than it was due.

PV systems that float in water bodies, sometimes referred as “*Floatovoltaics*”, are a recent trend in PV development [27]. This idea can provide many interesting advantages for the installation and operation of PV projects especially when placed on hydroelectric reservoirs. Firstly, the costs for new transmission lines are greatly reduced since they could share the already existing transmission infrastructure for the hydropower plant. Costs related to land procurement are eliminated, and this type of costs are representing an increasingly bigger share of total PV project costs as PV-modules and inverter prices continue to drop. These advantages can be strategic to regions with high-priced lands, and in that sense, South Korea implemented economic incentives for floating PV systems, in which it can earn twice the revenue than a ground-mounted free-field PV system would produce [27].

Apart from installation costs, there are also efficiency gains regarding the operation of floating PV systems. One cause of efficiency loss is the overheating of solar panels but by placing the PV array over the water body it benefits from its cooling effect and the reduced temperature favors greater energy generation. Another source of greater electricity yield is the reduced soiling effect over the panels that is much smaller over water. The floating solar panels in the Alto Rabagão dam in northern Portugal were a pioneering project at European level composed of 840 solar modules with an installed capacity of about 220kWp. Developed by EDP in 2016 served as a proof of concept for testing and measuring these advantages [28].

Even stronger synergies happen when floating PV is coupled with pumped hydropower energy storage sites. Thus, they can be used to pump water upwards during the daytime or to complement the energy generation portfolio, rendering the hybrid power plant more flexible. Under these a much larger *Floatovoltaic* project is under development, this time in the Alqueva Dam, one that could benefit from the pumping feature, with an installed capacity of 4MWp [29].

Another recent concept made possible by the ever-decreasing costs of solar modules, is *Agrivoltaics*. Some other common denominations include *agrophotovoltaic* and *agri-PV* referring to PV systems that are mounted over crops in farmlands sharing the same land and the sunlight resource.

The added value of co-producing food and electricity on the same site can be advantageous for both activities. Due to partial shading, agricultural activity can achieve higher crop yields or enable the use of different crops (especially in semi-arid areas) and thanks to the evapotranspiration of plants PV panels benefit from cooling effect, favoring higher efficiencies in electricity generation [30]. Additionally, it counters the land-intensiveness that characterizes ground-mounted standalone PV solar farms and tackles two current challenges: sufficient food production and decarbonization of the economy.

These are both great examples that disruption not always comes from science labs and new discoveries but rather, in a greater sense, from innovative thinking and holistic perspective. They also tap one of the greatest advantages of solar PV technology that is the potential of integration in existing buildings/sites, allowing for new synergies and hybridization of projects. Sure, a noteworthy distinctive feature.

2.3 In Depth Analysis of Key Publications

This section presents considerations and thoughts about the publications and reports that supported the production of the present study, giving evidence to the ones that were more instrumental. The first step of this work consists of a broad data collection from recent publications related to energy sector. The sources from these documents were deliberately chosen in order to portray the diversity of players in the energy transition.

Were included the perspectives not only from of authoritative agencies of the energy sector (International Energy Agency- IEA, International Renewable Energy Agency- IRENA), but also from other entities that deal with the reduction of GHG emission like the ones from ONG's (Greenpeace, Energy Watch Group – EWG, European Climate Foundation - ECF), or sectoral agencies (Solar Power Europe -SPE), Universities (LUT), technical reports for the European commission issued by Joint Research Centre (JRC) and oil companies (BP, Shell, Equinor). The reasoning is that by having a diverse pool of sources, it would prevent bias from over relying onto a single source, since many of these players are sometimes either too conservative or too ambitious in its projections with different set of assumptions and modelling constraints. Another important reason was to accommodate the results from a different set of model types used (bottom-up and top-down models, simulation, and optimization models, technologically detailed or of general equilibrium which might also result in significantly different expectations for technologies development in the long term.

Besides data relative to electricity generation and long-term pathways, other aspects are also of the interest in this work, such as market-oriented reports that are specialized in costs or technical aspects. In total, more than 50 publications have been researched, while looking for scenario projections and techno-economic data. A total of 53 different scenarios were identified, from which 37 of them were usable in the sense of having at least Total Addressable Market (TAM)¹ at European level², more details in section 3.2.3. These 37 scenarios were obtained from a set of 15 most useful reports. Table 2.1 lists all these 37 serviceable scenarios along with its 15 source documents, the issuing body and year of publication. Scenarios derived from publications marked with an asterisk have suffered a geographical harmonization process that is explained in detail over Section 3.2.1.

¹ Total Addressable Market or TAM is the summation of all demanded functional units for a given region at a certain period. In this case, the total electricity generation, in TWh, from 2020 to 2050.

² For the scope of this study whenever more than one geographical definition of European data was available it was always made the option to use European Union or EU 28 data. This comprises the following countries: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxemburg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden. The inclusion of other third countries could result elimination of a given scenario if there is no way of extracting their data and it clearly compromises projections. When only a larger definition was available, then it was attempted to extract these extra countries from data. Details about this in section 3.2.4.

Table 2-1: Publications that provided usable scenario projections for TAM and/or for Adoption of Solar Technologies, their respective scenarios, issuing body and year of publication

Source Document Name	Organization	Scenario Name
World Energy Outlook (WEO) 2019 [31]	International Energy Agency (IEA)	IEA Stated Policies Scenario (EU)
		IEA Current Policies Scenario (EU)
		IEA Sustainable Development Scenario (EU)
IEEJ Outlook 2019 [32]	The Institute of Energy Economics of Japan	IEEJ Reference Scenario (EU)
		IEEJ Advanced Technologies (EU)
Energy Tech. Perspectives (ETP) 2017 [33]	International Energy Agency (IEA)	IEA Reference Technology Scenario (EU)
		IEA 2°C Scenario (EU)
		IEA Beyond 2°C Scenario (EU)
Shell Sky Scenario 2018 [34]	Shell	Shell Sky Scenario (Europe)
Decarbonization Pathways Full Study Results 2018 [35][36]	Eurelectric	Eurelectric Scenario 1 80% Decarbonization (EU)
		Eurelectric Scenario 2 90% Decarbonization (EU)
		Eurelectric Scenario 3 95% Decarbonization (EU)
Net Zero by 2050 From Whether to How 2018 [37]	European Climate Foundation (ECF)	ECF EUREF 16 (EU)
		ECF Shared Effort (EU)
		ECF Demand-Focus (EU)
		ECF Technology (EU)
Deployment Scenarios for Low Carbon Technologies 2018 [38]	EU Joint Research Centre (EU JRC)	JRC Baseline Scenario (EU 31)
		JRC Diversified Scenario (EU 31)
		JRC ProRES Scenario (EU 31)
		JRC ProRES Near Zero Scenario (EU 31)
Decarbonization Pathways 2020 [39]	Navigant	Navigant Current EU Trends Pathway
		Navigant Accelerated Decarbonization Pathway (EU)
		Navigant Global Climate Action Pathway (EU)
Vision Scenarios for European Union 2017 Update [40]	Oeko Institute	Oeko Reference Scenario (EU 28)
		Oeko Vision Scenario (EU 28)
Global Renewables Outlook (GRO) 2020 [41]	International Renewable Energy Agency (IRENA)	IRENA Planned Energy Scenario (EU) Adjusted
		IRENA Transforming Energy Scenario (EU) Adjusted
Achieving Paris Agreement Goals 2019 [42]	Sven Teske *	Sven Teske 5°C Scenario ("EU")
		Sven Teske 2°C Scenario ("EU")
		Sven Teske 1.5°C Scenario ("EU")
Energy Revolution 2015 [43]	Greenpeace *	GP Energy Revolution ("EU")
		GP Reference ("EU")
		GP Advanced energy Revolution ("EU")
Full Study Energy Transition Europe 2018 [44]	LUT University & Energy Watch Group (EWG) *	LUT & EWG 100% Renewable Energy ("EU")
100% Renewable Europe 2020 [45]	Solar Power Europe (SPE) & LUT University *	SPE & LUT Laggard ("EU")
		SPE & LUT Moderate ("EU")
		SPE & LUT Leadership ("EU")

2.3.1 International Energy Agency (IEA) World Energy Outlook 2019

The IEA's World Energy Outlook is probably the most complete and authoritative annual publication in the energy sector. Published since 1977, and annually since 1998, this report attempts to cover not only the energy theme but also its many different interfaces. The WEO, as many other publications in this sector, offers a scenario-based approach. These scenarios are not future predictions, but portraits of some possibilities founded on key-choices, technology developments, political and economic trends. Moreover, the report offers increasingly more space for the energy-environment interface and highlights the importance of sustainability, security, and affordability of energy in a clear reference to sustainability's tripod.

In last years, the document is divided in parts. Starts with global energy trends, ends up with some insights, besides some worth- delving-in-detail, topics in the middle part. The so called "Part B" typically hosts this special topic that, in alternating manner, addresses geographical and sectorial subjects. The 2016 edition had shed light over "Renewable Energy", in 2018 "Electricity" was chosen. In 2015 we had "India's Energy Outlook" explored, in 2017 was the time for "China's Energy Outlook". Finally, in its most recent issue, 2019, Africa's Energy trends were studied.

The 2019 edition of WEO is composed by three scenarios that serve as backbone for the report's discussion. The Current Policies Scenario (IEA-CPS) is the most conservative scenario when it comes to the achievement of environmental goals. It represents the of present state of countries energy policies, including laws and regulations that have already been translated into operational laws and regulation.

Occupying the middle ground in terms of "environmental ambition" the Stated Policies Scenario (IEA-STEPS) replaces the previously called "New Policies Scenarios". It represents the possible outcome of announced policies and other governmental plans and goals that are still not operational. In the lack of explicit announcement future plans, this scenario adopts a conservative approach, assuming them to be replaced by measures of similar intensity. The document also emphasizes that is rare that intended policies become fully converted into legislation or regulation.

Lastly, there is the Sustainable Development Scenario (IEA-SDS) that represents the high of IEA environmental ambition. It was inspired in the United Nations Sustainable Development Goals and is totally aligned with Paris Agreement. This scenario was built a little bit differently. It was designed having the intended outcomes in mind and then selecting suitable set of actions to achieve them.

In the Annex A of WEO one can find all the numeric results of these scenarios. All three of them offer specific data for projections of solar technology in electricity generation expressed in TWh at European level. Therefore, all scenarios in this report were selected to be further analyzed. The only down-side of scenarios from this publication is that data only covers the year 2040, so in order to include in this study they were extrapolated using a built-in tool in Drawdown model.

2.3.2 Institute of Energy Economics of Japan (IEEJ) Outlook 2019

This publication from IEEJ brings another perspective to the energy transition. Like WEO, it offers a broad view of the sector and the many sub-sectors such as industry, residential, transportation and others. As one could expect, this report focusses heavily on fossil fuel flows, security of supply and Asian markets, offering great amount of detail for many nations in this region.

In a relatively long executive summary, presents some trends for energy sector, for instance, the prevalence of non-OECD countries in the future energy demand growth and the long-lasting global dependence on fossil fuels for their Reference Scenario. This report also increases the number of publications that expect heavy increments in Natural Gas and Electricity as Primary and Final forms of energy, respectively.

This is also a scenario-based publication. The “Reference Scenario” (IEEJ REF) reflects the current state of policies with no aggressive measure to transition to a low-carbon economy. The “Advanced Technologies Scenario” (IEEJ ADV) relies on a powerful promotion of environmental policies and the utmost adoption of low-carbon alternatives. Lastly, the “No New Coal-Fired Power Plant” is hypothetical scenario that assumes, with no exception, from 2020 onwards no new coal-fired power plant would be built. This leads into a discussion about the impacts of that on emissions and the energy mix, especially in Asia, and the substitution alternatives with Natural Gas or Renewables.

Unfortunately, it was only possible to access Europe level projections of solar energy for the first two scenarios, therefore they were included in this study while the very interesting scenario that discards new coal-fired power plants couldn't make it.

2.3.3 Shell Sky (2018)

From all the sources consulted in order to produce this work the longest time series of projections was found in Shell Sky Scenario from 2018. This publication contains only one scenario supported by a solid a backtrack (since 1980) and have projections until the end of the present century, 120 years in five-year intervals. Projections include metrics like population, Total Final Consumption of Energy by Carrier and by Source, specific table for Electricity Final Consumption by Source. The richness of details in energy data is also present when it comes to environmental metrics such as Net CO₂ Emissions that are categorized by point of emission (19 different ones listed) and even Emission Captured by CSS with seven different classes. Hydrogen is present in most of these tables. And it is also one of the few that have a breakdown between D-PV and U-PV. Unfortunately, it has no specific data for CSP.

Sky scenario is the follow up work that was designed to be more ambitious than the previous predecessors, Mountains and Oceans scenarios. Oceans scenario almost reaches carbon neutrality by 2100, Mountains scenario attains it by 2100 and Sky scenario, the most ambitious one, by 2070 and is satisfies Paris Agreement goals. Although it is the most ambitious scenario from this Shell it is much less ambitious than some scenarios published by other entities. This exemplifies the difficulties in

bundling scenarios in tiers when they are designed by bodies that have different understanding of what is an ambitious energy scenario.

Like other oil company's reports Shell Sky publication addresses the energy theme in a broad perspective but with no excessive focus on fuels. In this sense Shell differs from their peers in the oil sector in a good way. This distinction makes itself evident even in the smallest details such as the choice of energy units. While BR and Equinor prefer using energy metrics related to oil industry such as Ton of Oil Equivalent (toe), Shell adopts Exa-Joules (EJ) a more versatile and neutral metric for energy projections.

2.3.4 LUT & Energy Watch Group Full Study Energy Transition Europe (2018)

This report is one of the most important references for this work. Despite having a single scenario, a very ambitious one, the amount of detail and additional data included elevates the value of the report. The study developed by Energy Watch Group (EWG) and the Lappeentanta Polytechnic University (LUT) is the most comprehensive one due to the scope of the work that addresses not only the Power but also, Heat, Transport and Desalination Sectors.

It is distinguished by having the most extensive list of renewable power sources differentiating D-PV from U-PV and CSP, Hydro run-off river from Hydro reservoirs and Wind onshore from wind offshore among other 22 renewable and traditional power sources. There are also projections for nine distinct Energy Storage solutions and for various technical and economic data. Another unique feature is the almost country-by-country detail shown over the European map for both capacity and electricity generation in 2050. This level of detail was then re-edited over another publication from LUT University in partnership with Solar Power Europe (SPE) for other types of data like energy Storage, LCOE and even electrolyzer capacity.

The way Europe was defined was also different from most other publications. Its Europe definition includes Turkey and Ukraine but provided a good way of extracting the influence of these two big countries from the data, further discussed in section 3.2.4.

2.3.5 Greenpeace Energy Revolution (2015)

The oldest source to contribute to this work is only five-years old. The 2015 Energy Revolution Report is also one of the most complete and long studies that has been reviewed in this work. Its projections were among the most ambitious in its time but in this work, it ranks on the upper end of Intermediate scenarios for Solar technology adoption. There are sections with detailed technical explanation of many power generation alternatives, energy and climate policy, societal impacts such as expected new employment, financing, and some sectoral overviews. It was possible to extract scenario projections as well as some VMA cost related data.

On its fifth chapter it also contains an interesting comparison of short-term prognosis versus real development of Solar photovoltaic in terms of cumulative installed capacity where Greenpeace's own projections are compared to, IEA's WEO's shorter projections, the European Photovoltaic Industry Association (EPIA) projections and the real development of the sector. In a similar fashion several of these projections are plotted over the same chart for a longer timeframe until 2030.

This publication is made of three scenarios Greenpeace Reference Scenario (GP REF), Greenpeace Energy Revolution (GP ER) and Greenpeace Advanced Energy Revolution (GP Adv ER), in increasing order of ambition. Just to give a sense of the ambition level in these scenarios, the GP REF projects that in 2050, 41% will come RES. GP ER point to 95 % and GP Adv ER, attains 100% by 2050 and 83% already in 2040.

Some other characterizing features is the inclusion of Hydrogen in its predictions with a separate class for renewable hydrogen, phasing out of Nuclear power in Europe in all scenarios except for the GP REF and a breakdown of CO₂ emissions by economic sector from 2020 to 2050.

Geographically, its definition of Europe is OECD Europe (just like Sven Teske's) and had to be adjusted to remove the influence of Turkey in its data. More information about this process of "geographical harmonization later in section 3.2.4.

2.3.6 Other Publications

Many other publications have contributed somehow to this work whether by providing technical details or just some specific projection. In the attempt of mentioning all of it should be mentioned Equinor Energy Perspectives 2018 [46] and 2019 [47] with its three scenarios that explicit the importance of international political collaboration; The European Climate Foundation [37] that among its four scenarios, includes the "Demand-Focus" one where there is so much focus on energy efficiency that European TAM in 2050 has followed a declining trend and is supported by a very helpful web database.

Additionally, among other important works are IRENA Global Energy Transformation 2018 [48] and 2019 [49]; ECOFYS Energy Transition Within 1,5°C 2018 [50]; BP Energy Outlook 2019 [51]; WEC World Energy Scenarios 2019 [52], [53] and two more JRC reports, the 2018 Global Energy and Climate Outlook [54] and the 2020 Towards Net Zero Emissions in the EU Energy System in 2050 [55].

2.3.7 Distinctive Topics

After reviewing several sources looking for information about projections and other important variables for characterizing the European energy mix of the future, it became apparent that some relevant topics within the energy sector were not always considered or have been treated differently across these several publications. These called topics are actually great sources of uncertainty that can completely reshape not only the power and energy sectors but the entire economy as a whole. These topics are, namely: Nuclear Power, Carbon Capture Usage and Storage (CCUS), Hydrogen and Energy Storage.

Probably the less transforming topic among the ones previously mentioned but certainly the most polarizing one. Nuclear Power has always been intensively criticized by its detractors and defended by its supporters. Anti-nuclear movement has been historically associated with environmental groups and an important part of green parties' political agenda in Europe notably during the 1980s [56]. Still today Nuclear Power carries a lot of stigma and a NIMB (not in my backyard) sentiment with the general public, recently reinforced by Fukushima Daiichi Nuclear Disaster in 2011. The fact of the matter is that Nuclear Power plants are designed to operate at stable outputs, offering little of the so needed flexibility for future power grid with great penetration of variable renewable energy sources.

Stabilization or slight decline of European Nuclear Power output is the most commonly observed projection across the scenarios reviewed in this work. Some examples are IEA's Stated Policies Scenario; IEA's Current Policies Scenario; IEA's Sustainable Development Scenario; IEEJ's Reference Scenario; Equinor Reform; Equinor Rivalry; Equinor Renewal; Greenpeace Reference Scenario; SPE & LUT Laggard; WEC Jazz; WEC Symphony; WEC Rock; Eurelectric 80% Decarbonization; Eurelectric 90% Decarbonization; Eurelectric 95% Decarbonization; ECF EUREF 16; JRC Baseline; JRC Diversified; Oeko Reference and Sven Teske 5°C.

There is also a sizeable group of scenarios that project huge reduction or even a total phase-out of Nuclear power plants in Europe. In this class of scenarios are IRENA's Planned Energy Scenario; IRENA's Transforming Energy Scenario; Solar Power Europe Moderate; Solar Power Europe Leadership; ECF Shared Effort; ECF Technology; ECF Demand Focus; JRC Pro RES and JRC Near-Zero Scenarios. Sharper declines can be found in, LUT & EWG's 100% Renewable Energy; Greenpeace Energy Revolution; Greenpeace Advanced Energy Revolution and Oeko Vision Scenarios, where in some cases nuclear phase-out in Europe happens even before 2050.

Nonetheless, some publications rely on the fact that Nuclear Power does not produce GHG emission to include it in the portfolio of options for a carbon-free future. One may consider this as a symbol of the myopic environmental view: we are so desperate to reduce GHG emissions that we are willing to exchange a carbon problem for a radioactive one. Either way, some examples of publications that tread the route of increases nuclear power output are IEEJ's Advanced Technologies Scenario; IEA's Reference Technology; IEA's 2°C Scenario; IEA's Beyond 2°C Scenario and Shell Sky Scenario.

Hydrogen is attracting players from many different sectors because of its capacity to promote multiple-sector-coupling through its notable versatility and for being a solution to decarbonize industrial sectors with high-temperature processes [57].

One of the main promoters of hydrogen economy is Japan. This is probably due to many Japanese car manufacturers promoting hydrogen, making a case for it in transportation sector. Adding to that the fallout from the 2011 Fukushima nuclear accident and the public opinion that pressured the government to shutdown nuclear power plants. [58]. But Japan is not alone in that path. Many other countries, especially in the Asia-Pacific Economic Cooperation (APEC) region, are following the same trend. Currently Japanese companies are partnering with companies from countries as varied as Australia, Brunei, Saudi Arabia and Norway to test production methods and supply chain developments [59].

Hydrogen also starts to gain momentum in the western world. The state of California and many European countries already have or plan on expanding their hydrogen infrastructure. The European National Plans for Energy and Climate have, national documents that envision targets for these sectors, and recognize the role for hydrogen in energy transition. This goes pretty much hand-in hand with policy guidelines proposed earlier this year by IEA in the document “The Future of Hydrogen for G20” [58].

Besides these dedicated publications, most scenarios mention Hydrogen somehow in their future projections such as but few present details. Very brief mentions are found in IEA’s World Energy Outlook 2019 [31] and Energy Technology Perspectives (ETP) 2017 [33]. As expected hydrogen is ranked as an energy generation source in the IEEJ Outlook 2019 [32] publication but is surprisingly not considered relevant in European context. More detailed projections for Hydrogen development at European level including storage needs can be found in both LUT University publication “Full Study Energy Transition Europe 2018” [23] and “100% Renewable Europe 2020” [45] and Shell Sky Scenario [34] also includes hydrogen as an energy carrier.

Albeit the advantages for VRE sources when it comes to emissions, there are also downsides since their energy outputs fluctuate with the natural availability of wind and sunlight allowing Energy Storage technologies to have a pivotal role in future of power systems by increasing operational flexibility and allowing an ever-bigger integration of VREs on the grid, not to mention many other services.

It must be noted, though, that Energy Storage Systems (ESS) are one possible alternative, among others, to render the whole system more flexible, safe and resilient. Other options may be the increment of flexible and dispatchable generation, demand side-management, grid expansion or electricity imports/exports. Not too long ago, the non-storability was considered one important and unique feature electricity as a commodity [61]. In that sense, the possibility of energy storage is a disruptive technology once it calls for a new approach in the operation and planning of future power systems.

Technological alternatives for storage are also very diverse and although this environmental-concern driver is somewhat new, some technologies have already been applied for many decades. Pumped-Hydro Storage (PHS) plants have been operational for about a century and two Compressed Air Energy Storage plants started operating in the decade of 1970 [62]. Recent developments are dominated by large scale Li-ion battery systems influenced by significant spill over from electronics and automotive sectors [63]. The biggest project of that kind in operation was installed in Hornsdale, South Australia with technical specification of 100MW/129MWh [64] and it’s about to be dwarfed by a project scheduled to be delivered in 2020 in Moss Landing, California with 300MW/1.2GWh [65].

As important as the topic is, once again only LUT University publications distinguish themselves from others by providing deeper analysis for Energy Storage Solutions. Full Study Energy Transition Europe 2018 [23] contains specific data for energy storage for many different technologies at European level while 100% Renewable Europe 2020 [45] provides an analysis of energy storage as detailed as for generation with different projections for thermal and electricity storage. Eurelectric Decarbonization Pathways Full Study Results 2018 [35][36] and IRENA Global Renewables Outlook (GRO) 2020 [41] publications have generic global numbers for this topic and other reports not even mention them in any meaningful way.

3 Methodology

This chapter is divided in two sections. The first one provides an overview of Project's Drawdown excel-based Model that was used to model each of the three solar solutions, develop a data meta-analysis of inputs, run scenarios, and evaluate the results on electricity generation, associated investment and operation costs, and environmental impacts through GHG emissions avoided up to 2050. Secondly, a detailed description of all the steps of the present work, the workflow, and the reasoning behind the choices.

3.1 Project Drawdown Model

Project Drawdown describes existing social, ecological, and technological solutions that reduce and sequester GHG emissions in the atmosphere. It aims to provide robust and scientifically-sound projection of the potential impact that climate-positive solutions will have assuming vigorous increases in their adoption. Supporting all this work is the Reduction and Replacement Solutions (RRS) core model, characterized by its bottom-up design, structured in an Excel workbook where all individual data and calculations are made locally in one file [66].

The model's main inputs are TAM and ADPT projections, and some data on various key assumptions such as "First Cost per Implementation Unit", "First Cost Learning Rate", "Lifetime Capacity", "Average Annual Use", "Fixed Operating and Maintenance Cost" (FOM), "Variable Operating and Maintenance Cost" (VOM) and "Indirect Emissions", collectively called Variable Meta-Analysis (VMA) data. There are specific sheets for registering data that will receive statistical treatment for defining mean, high and low values, to make data interpolation, and to organize different TAM and Adoption scenarios in tiers

To determine the impact potential of each solution requires a forecast of implementation based on estimated global functional demand for the period of study (2020-2050). Due to the diverse nature of the many solutions, each one of them will have its own *Functional Unit of Measure* in order to quantify the impacts of the solution, better expressing the outcome produced. Moreover, it is also necessary to select a specific *Implementation Unit of Measure* that will quantify the expansion in the adoption of such technology, measuring the pace of "acquisitions" or "installations" of such solution. The two units are closely related: the implementation unit produces the function that is in demand. Considering the case for electricity generation of solar technologies, the Implementation Unit of Measure will be TWp of installed capacity while the Functional Unit of Measure is annual TWh of electricity generated by them [66].

Each run of the model consists of a selection of a specific TAM and ADPT projection including values for VMA data. Then the performance of each scenario is measured against a Reference Adoption Scenario where the solution share is fixed in time to its current ratio, and the analysis is conducted

comparing the projected solution adoption versus continued use of conventional technologies. That is why VMA data for traditional technologies are also an input, including “Fuel Costs”.

The model presents as results key climate, economic and generation outcomes such as Adoption Estimates, Total CO_{2e} Avoided Emissions, Net First (implementation) Cost, Lifetime Operating Cost/Savings [66]. Originally, as implemented in 2014, Drawdown’s scope was a global one but during this new regionalization stage, focus will be given to specific regions of the globe such as the European continent. It is also possible for users to individually change input values and check how the results are impacted, useful for sensitivity analysis.

Although currently excel-based, a new python-based version of RSS model is under development with the promise of being more user friendly. Online collaborative platform for data inputs, scenario testing and results analysis is another improvement for the following years that will make an easier process for solutions evaluation.

3.2 Research Procedure in Detail

It is also important to clearly state the objectives of this work. The goal is to assess the future total electricity generation in Europe, from 2020 until 2050, along with the estimated penetration of Solar Generation Technologies, namely, Utility-scale photovoltaic generation (U-PV), Decentralized photovoltaic generation (D-PV) and Concentrated Solar Power (CSP), to size their individual and combined contributions relative to GHG abatement and its associated investment costs. Moreover, this work is part of the Project’s Drawdown regionalization process, in this case, analyzing the European context.

In a condensed way the steps of this work can be summarized as follows:

- Literature Review and Data Collection
- Compilation of Historical European Energy Mix evolution and current adoption
- Gathering and treating data about Total Addressable Market (TAM) projections
- Gathering and treating data about Adoption (ADPT) of Solar Technology projections
- Gathering and treating for Variable Meta-Analysis (VMA) of inputs
- Feeding data and Running the Drawdown RRS model
- Perform Sensitivity analysis

3.2.1 Content Control and Classification

After analyzing these reports, an excel sheet was used to curate the content, clearly assigning what type of information was present in which document, and the values obtained for each scenario projection for TAM and for future adoption of the three solar technologies.

Not all publications have every piece of information needed. Some are more complete (Greenpeace [43] and LUT & EWG [44]), but others only provide historical data form past energy mix or projections TAM (Equinor [67])and others are specialized in investment costs and other technical data points such as capacity factors, lifetime capacity and emission factors, like ASSET publication [68]. The established organization can be seen, briefly, in Figure 3-1, that show a sample from the excel file used for this end. Annex D at the end of this work contains more complete information regarding this table.

Content Control																											
	Hist	Project	EU Solar Market			Tech	Scenario Features						Macro EU Elements			Geography		Description of Technology Costs in EU									
SCE Short Name	1	2	3.1	3.2	3.3	4	5.1	5.2	5.3	5.4	5.5	5.6	6.1	6.2	6.3	Ukraine	Turkey	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8		
IEA STEPS	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
IEA CPS	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
IEA SDS	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
IEEJ REF	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
IEEJ ATS	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
IEEJ CB	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
LUT EWG	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
IEA B2DS	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
IEA 2DS	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
IEA RTS	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
EQ Reform	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
EQ Renew	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
EQ Rival	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
IRENA REMAP	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
IRENA PES	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
IRENA TES	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
IRENA PES Adj	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
IRENA TES Adj	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
8	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
9	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
10	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
GP ER	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
GP REF	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
GP ADV ER	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
GP ER Adj	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
GP REF Adj	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
GP ADV ER Adj	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	
BP ET	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	!	

Figure 3-1: Exhibit of content control and data curation excel spreadsheet used to catalog and manage references

However, at this stage an important problem arises. There are many different interpretations of what Europe means. Some publications adopt “EU” or “EU28” labels, other prefer “OECD Europe” or “EU 31” or even just a generic “Europe”. Few are versatile enough to offer different tables, one for “Europe” and another for “European Union” (WEO 2019 [31] from IEA has this approach). However, most publications maintain detailed information about what countries are included in its geographical groupings.

At this point it is worth mentioning that whenever a choice was available “EU28” or “European Union” data was chosen. This option is justified by the political cohesion provided by the EU, and its willingness to become world leader in the Energy Transition and Climate Change action. The rationale behind any given geographical clustering must be the internal similarity of the countries composing the region relative to a given issue, and for solar energy European Union appears as the best choice available.

Another practical advantage of choosing a tighter geographical definition for Europe is the possibility of extracting data from other countries that do not belong to EU when they appear in certain publications. For instance, the Greenpeace's Energy Revolution [43] report from 2015 and Sven Teske's Achieving Paris Agreement Goals [42] from 2019 had a "OECD Europe", a grouping that included Turkey whereas both publications from LUT University, Full Study energy Transition Europe 2018 [44] and 100% Renewable Europe [45] have included both Turkey and Ukraine in its definition of Europe.

Before making any adjustments, publications with broader definitions of Europe tend to rank higher in projected values when scenarios were ordered, and comparison would not be fair nor adequate. The impact of including these two countries are noticeable and should be corrected. Initially GDP or another economic metric have been considered but then it was preferred to use some references with country-to-country data to proceed the removal.

Sven Teske's paper [42], one of the scenarios with "OECD Europe" label, have a breakdown for load and generation for internal regions of Europe such as Iberian Peninsula, Nordic and also a specific one for Turkey detailed for the years 2020, 2030 and 2050. This data was used as proxy to assess the respective share of Turkey within this OECD Europe group that was then discounted both in the adoption as well as for TAM projections. The share seized by Turkey increases in time since it expected this country to grow more than the European average and are, respectively, 6.5%, 7.3 % and 8% for 2020, 2030 and 2050. Greenpeace Energy Revolution [43] report offers no similar way to do so, consequently, the same ratios from Sven Teske were applied to discount Greenpeace's projections for TAM and adoption of solar technologies.

The correction for scenarios that included both Ukraine and Turkey, the ones produced in association with LUT University [44], [45], suffered a similar process. The percentages for discount this time were based on SPE & LUT 100% Renewable Europe publication [45] that depicts electricity generation capacities in 2050 over a map with almost county to county resolution. A 15,5 % ratio, representing the contributions of Ukraine and Turkey, was discounted from TAMs and adoptions for these two references. All scenarios that have suffered adjustments for "geographical harmonization" are marked with an asterisk in Table 2.1 in the previous chapter. The inclusion of other third countries could result elimination of a given scenario if there is no way of extracting their data and it clearly compromises projections This happened with WEC scenarios that had Russian data included as Europe but not straightforward way of extracting it.

In the case of scenarios with the "EU31", as it happens in JRC publications [38], [55], the different grouping of European countries does not increase projections systematically. Objectively, the addition of Iceland, Norway, and Switzerland to the rest of EU28 gets diffused among other small variations in scenario projections and are too small to jeopardize the comparison with other scenarios. Moreover, there was not simple way of extracting these individual countries from the rest, so they were left untouched.

3.2.2 Compilation of Historical European Generation Mix

Before collecting projections about an uncertain future, one must create a solid base about the past. It may be surprising to notice that not every source presents the same figures for past data, but this is a consequence of the various methods used by different organizations to account for electricity generation. At this phase, the goal was to create a historic time-series for the solar power technologies from 2000 until the most recent data available which, at that time, was 2017.

Considering that IRENA keeps a more detailed and, perhaps, more accurate backtrack of Renewable Energy outputs its database, the IRENA downloadable dataset [69], was chosen for renewable sources. This source presents the much-needed breakdown for Concentrated Solar Power (CSP) in the past while also providing a year-by-year timeseries, rendering interpolation unnecessary.

Unfortunately, IRENA's past timeseries only has a single tier for "Solar PV". As aforementioned, for the scope of this work, it is important to discriminate between utility scale and "smaller-scale", decentralized, photovoltaic systems. Throughout this research period only two publications were detailed enough to bring U-PV and D-PV in different classes of their own. These very handy publications were, namely, Shell Sky Scenario [34] and Full Study Energy Transition Europe from LUT University and Energy Watch Group [44]. Their offer variable ratios for U-PV and D-PV through the years and the average ratio from these sources has been applied to IRENA's dataset to produce two tiers for Solar PV technologies.

Parallel to that, IEA's historical data, freshly published in European Union Energy Policy Review [70], was used for non-renewable electricity *i.e.*, nuclear and fossil fuel powered (coal, oil, gas) power plants. Unlike IRENA's data, this one had to be interpolated (2nd degree polynomial interpolation) since it only provides data in intervals of five years. Together they compose the historical dataset for past European generation, and also the original shares that these technologies detain in the base year of 2017, which can be seen in Annex A later in this work.

3.2.3 Total Addressable Market Projections

Regarding projections, in order to become useful in this part of the work, reports must provide at least Total Addressable Market (TAM) projections *i.e.*, figures, in functional units (*i.e.* TWh), for how much electricity the European power sector up to 2050 will generate. Having been able to gather 37 TAM projections from the selected references it is safe to say that this is one of the wide available inputs needed for the modeling efforts within the scope of this work. Despite being somewhat a common feature in most reports, it is not always explicitly published as a number, and sometimes one had to extract data from graphical charts in approximate values such as in Navigant Gas for Climate [39]. Moreover, just like IEA's historical data, these timeseries are not on yearly basis, provided at five years, 10 years or even sparse data points in the future. Scenarios also differ in which year their projection ends. As mentioned previously WEO only goes until 2040 (and had to be extrapolated), ETP an older publication from IEA ranges until 2060 and Shell Sky Scenario stretches until 2100.

Thus, in order to become useful in the Drawdown RRS model, they underwent a best fit interpolation, which in most cases was either 2nd or 3rd polynomial interpolation built in the Drawdown excel-based model. The result of the collected and interpolated set of 37 scenarios, including the polynomial interpolation used, can be verified in Annex B in the later part of this work. Only reports from 2015 on were eligible for this work and for annual report is considered the most recent issue (years always specified in references).

3.2.4 Solution Adoption Projections (ADPT) for U-PV, D-PV and CSP

The collection of data relative to the adoption of solar technologies has faced the same challenges as the ones described for TAM projections, not always explicit numerical values, and the interpolation process for obtaining yearly values. The resulting year-by-year adoption based on the raw data of these scenarios can be checked in Annex C of this work.

Originally only the Shell Sky [34] and LUT & EWG Full Study Energy Transition Europe [44] publications have separate projections for U-PV and D-PV. Most reports only offer a generic “Solar PV” label, sometimes mentioning that this group encompasses both centralized and decentralized variants, but in general there is not much attention to disaggregating one from another. And it is quite understandable after all they share the same technology and only for very specific purposes it would be useful to separate them.

The overall scarcity of native D-PV data motivated the adaptation of data that originally was referred as “Solar PV” to be split into two parts, D-PV, and U-PV. The average present (2020) ratio between D-PV and U-PV from the publications that originally have projections for both classes have been used for defining the ratio to be applied in other projections homogeneously for every year. It may be a rough assumption to guess that these ratios will remain unchanged, but it would take a stronger reason to do it otherwise. Thus, in the absence of any compelling indicator of change, the ratios were kept stable for the future. The resulting ratios were 61% and 39% for U-PV and D-PV, respectively. For the sake of comparison, Project Drawdown 2020 review has adopted ratios of 60% and 40% [71].

3.2.5 Variable Meta-Analysis (VMA) Data

Besides projections themselves, other important pieces of information are needed to properly run the Drawdown models and produce the intended economic and environmental results. The economic variables are: First Costs per Implementation Unit, typically found in (€/kW), Fixed Operating and Maintenance Costs (FOM) also expressed in (€/kW), Variable Operating and Maintenance Costs (VOM) measured in (€/kWh). All the data previously mentioned has been collected for all three solar technologies (*i.e.* U-PV, D-PV and CSP) and also for conventional thermal powerplants which the solutions are replacing. Fuel costs for each fossil have also been cataloged. Raw economic data is found in various different currencies but in order to serve as an input they were all corrected to 2014

USD. Economic results, however, were converted to 2019 Euros so as to better communicate values within the European context.

Along with economic data, some technical ones are also needed such as Lifetime Capacity and Average Annual Use (or capacity factor). All previously mentioned data has been collected from numerous sources from which it is worth mentioning some like: Grantham Institute & Carbon Tracker Initiative's "Expect the Unexpected" 2017 [72]; ASSET "Technology Pathways in Decarbonization Scenarios" 2018 [68]; JRC "Cost Development of Low Carbon Energy Technologies" 2018 [73]; Guidehouse "Gas Decarbonization Pathways" 2020 [74]; REN21 "Renewable Global Status Report 2020" [75]; IRENA "Renewable Energy Statistics" 2019 [76]; IRENA "Renewable Power Generation Costs" 2019 [77]; IRENA "Cost and Competitive Indicators – Rooftop Solar PV" 2017 [17] and IEA "Monthly Oil Price Statistics" 2020 [78].

Data used in VMA were not projections and have been published between 2015 and 2020 and are mostly European specific but sometimes are mingled with global values then detailed regionally explicit data is scarce or not available. Each data-class was added to a table of its own and if relative to conventional technologies, it was submitted to a where a weighting in order to represent the actual mix of these technologies. Then, for each data type, average value is calculated along with one standard deviations margin, calibrated higher and lower values and eliminating outliers. These average, low and high values can be selected to be used as inputs to the model.

3.2.6 Running Drawdown Model

Once all data acquisition and treatment has ended it is time to run the Drawdown model. The way the model is designed in excel currently limits the total amount of TAM scenarios to be used up to 15. This quantity is then divided in four tiers. In this work the labeling for TAM tiers considers the level of electricity generation by 2050 and goes as follows:

- Modest TAM growth, composed by four scenarios (green)
- Intermediate TAM growth, composed by five scenarios (yellow)
- Ambitious TAM growth, composed by five scenarios (blue)
- Very Ambitious TAM Growth, composed by only one scenario (white)

The color arrangement shown in parentheses will be maintained throughout this work especially during the fourth chapter where results are presented. The selection of 15 from the original 37 available was conducted in view of maintaining the diversity of sources and some degree of continuity even across different tiers. TAM tiers are important because the model could be run considering one single source for TAM, for instance, the projected TAM based on the interpolation of the raw data acquired from Sven Teske's 5^o Scenario; or the average projection of all scenarios that belongs to a given tier, in this case, the Moderate one. In this work, the later alternative was preferred, avoiding an over reliance of a single source. TAM projections are common to all solar technology solutions, also bounding the market for all electricity generation technologies.

There were also quantity limitations for solar adoption projections of each single solar technology in order to fit the project Drawdown RRS model structure. The choice of which scenarios to maintain followed the same rationale described previously for TAM, and their arrangement is as follows:

- Modest Tech Adoption growth, composed by four scenarios (green)
- Intermediate Tech Adoption growth, composed by five scenarios (yellow)
- Ambitious Tech Adoption growth, composed by six scenarios (blue)
- Extremely Ambitious Tech Adoption Growth, with one single scenario (white)

Just like TAM can be bundled according to tiers, adoption scenarios can also be averaged within any given tier. There are various possibilities and different set ups for running this model only making the procedural documentation even more important.

As seen before the latest step is to identify Each run of the model was setup with average values for all variables present in VMA and with one selected Adoption Scenario paired with the corresponding TAM of its tier. As an example, for the projected adoption based on the on the interpolation of the raw data acquired from Sven Teske's 5^o Scenario, which is in the Moderate adoption tier for U-PV, the model was run using the average Moderate TAMs projection. In such fashion, a total of 19 runs, one for each of the 16 selected adoption scenarios in addition to the three tier-aggregate ones were executed for every solar technology, U-PV, D-PV and CSP, producing a total of 57 runs.

Each one of these runs produces over 20 different results of economic and environmental nature. An exhibit of such results can be seen in Figure 3-2 where the main ones are highlighted in orange. "Total Emissions Reduction" is the main environmental result communication the amount of CO_{2e} that we avoided emitting to the atmosphere by switching from traditional generation to a given solar solution. "Cumulative First Cost" provides an idea of the total investment needed in the installation of such power plants. "Lifetime Operating Savings" informs whether the operation of such power plants can be a profitable activity and "Average Abatement Cost" attempts to bridge the economic and environmental dimensions.

3.2.7 Sensitivity Analysis

The main results were developed as described above, being the critical factor of change a range of adoption scenarios, but in order to better understand how each VMA input affects the results a new round of model-runs was executed for sensitivity analysis assessment. As discussed before, VMA inputs can be of three different natures, they are either economic, technical or emissions related. The purpose in this section of the work is to understand how each one of these inputs, *ceteris paribus*, *i.e.* changing one thing at a time and making all else constant, will affect the economic and environmental results produced by the model for each solution. This sensitivity analysis cannot impact generation results because they are considered as the key input that changed in the 57 built scenarios.

Most VMA inputs has been tested in this process with the exception of Average Annual Use and Variable Operating and Maintenance Costs (VOM) for different reasons. Firstly, and most importantly, because they are not an independent variable. Many references assume VOM costs as a small percentage of Fixed Operating Cost (FOM) or sometimes evens First Costs (sometimes also called Installation Costs). Beyond that, VOM values tend to be either very small or null with very little variance so it could be safely put aside from the Sensitivity Analysis. Average Annual Use has been excluded because it is used together with Lifetime Capacity to compute the useful lifetime of these solutions, so changing both would duplicate the experiment for no reason.

Namely, new Sensitivity Analysis runs will be performed for First Costs, Fixed Operating Costs, Fuel Prices, Lifetime Capacity and Emission Factors. Considering that the intent is to explore the boundaries of each result, *i.e.*, the upper and lower values they can assume after the meta-analysis conducted, the basis for comparison were the aggregated adoption projected from the Moderate and Ambitious scenarios. Then, a single change in one of the VMA's variables is made, selecting either the lowest or highest value and the setup is ready for a sensitivity analysis run. Each run has only one alteration relative to the base model runs, in the lower end for Moderate Tier Aggregate Adoption projection and at the upper end for the Ambitious Tier Aggregate Adoption projection, resulting in 24 rounds for each technology, totaling 72 rounds.

4 Results

The different stages of this work have yielded different types of results. Some of them are the product of gathering, curating, and organizing data from the various sources consulted, for instance the ones relative to VMA, Total Addressable Market (TAM) or the Adoption of solar technology solutions. Others yet, were obtained after running project Drawdown’s RRS Model with several scenarios. Whatever sort of result may be, this section will be dedicated to presenting them.

4.1 Variable Meta-Analysis Results

The very first type of result from this work is the compilation of Variable Meta-Analysis (VMA) data that serves as inputs to the model. As explained in section 3.2.5 in the previous chapter these are the results of extensive research from various sources. Tables 4-1, 4-2, 4-3 and 4-4 expose the mean, high and low values for VMA data along with their respective units and how many datapoint have been used to arrive to such final numbers for Conventional Technologies, Utility Scale PV, Decentralized PV and Concentrated Solar Power.

Table 4-1: Variable Meta-Analysis Input Data for Conventional Technologies

CONVENTIONAL TECHNOLOGIES					
VMA Parameter	Unit	Data-points	Mean Value	High Value	Low value
First Cost per Implementation Unit	€2019/kWp	33	1 670	2 578	760
First Cost Learning Rate	%	9	2%	2,5%	1,5%
Lifetime Capacity	hours	17	171 728	203 568	139 887
Average Annual Use	hours/a	24	5 014	7 091	2 937
Variable Operating and Maintenance Cost (VOM)	€2019/kWh	17	0,0029	0,0047	0,0013
Fixed Operating and Maintenance Cost (FOM)	€2019/kWp	25	35.69	52.27	18.92
Fuel Cost	€2019/kWh	57	0,022	0,030	0,013

Datapoints for Conventional technologies were submitted to a weighting process in order to ensure that all values reflect the current share of each technology in the energy mix. This weighted average use current shares of coal, gas, and oil-fired power plants to calibrate calculations. These present ratios were considered constant for the whole length of the study, 2020-2050. Although economic inputs were converted to US\$2014 due to constraints of the model design, here they are shown in euros of 2019 in order to maintain homogeneity with economic results that will be later exposed.

Table 4-2: Variable Meta-Analysis Input Data for U-PV

UTILITY-SCALE SOLAR PHOTOVOLTAICS (U-PV)					
VMA Parameter	Unit	Data-points	Mean Value	High Value	Low value
First Cost per Implementation Unit	€2019/kWp	53	1 376	1 882	870
First Cost Learning Rate	%	3	18%	25%	11%
Lifetime Capacity	hours	9	34 986	38 266	31 706
Average Annual Use	hours/a	29	1 312	1 650	974
Variable Operating and Maintenance Cost (VOM)	€2019/kWh	7	0	0	0
Fixed Operating and Maintenance Cost (FOM)	€2019/kWp	16	16.94	21.34	12.54
Indirect GHG Emissions	tCO _{2e} /TWh	11	48 450	78 557	18 345

Table 4-3: Variable Meta-Analysis Input Data for D-PV

DECENTRALIZED SOLAR PHOTOVOLTAICS (D-PV)					
VMA Parameter	Unit	Data-points	Mean Value	High Value	Low value
First Cost per Implementation Unit	€2019/kWp	49	1 764	2 398	1 128
First Cost Learning Rate	%	3	18%	25%	11%
Lifetime Capacity	hours	8	30 523	43 240	17 807
Average Annual Use	hours/a	31	1 252	1 594	910
Variable Operating and Maintenance Cost (VOM)	€2019/kWh	4	0	0	0
Fixed Operating and Maintenance Cost (FOM)	€2019/kWp	10	23.74	30.35	17.13
Indirect GHG Emissions	tCO _{2e} /TWh	42	48 476	72 298	24 654

Table 4-4: Variable Meta-Analysis Input Data for CSP

CONCENTRATED SOLAR POWER (CSP)					
VMA Parameter	Unit	Data-points	Mean Value	High Value	Low value
First Cost per Implementation Unit	€2019/kWp	29	6 347	8 989	3 706
First Cost Learning Rate	%	12	17%	24%	9%
Lifetime Capacity	hours	5	130 358	141 569	119 147
Average Annual Use	hours/a	18	2 879	3 781	1 976
Variable Operating and Maintenance Cost (VOM)	€2019/kWh	21	0,0460	0,102	0
Fixed Operating and Maintenance Cost (FOM)	€2019/kWp	9	86.14	163.08	9.21
Indirect GHG Emissions	tCO ₂ e/TWh	22	54 290	123 070	0

An important remainder is that for all runs of the model to produce base results only mean values of these VMA parameters will be used. In the sensitivity analysis high and low values will replace mean ones in order to assess how they would impact the various results produced by the model. All data is from recent publications ranging from 2015 to 2020, values before that have been excluded and are not accounted in the number of sources. First Costs is the most abundant data for all technologies as well only after Fuel Cost relative to number of datapoints considered.

Some brief observations regarding these values is the already good performance in terms of “First Cost per Implementation Unit” for PV technologies. Conventional technologies present a mean value of 1.670 €2019/kWp and range of (760 - 2.578) while U-PV has a lower mean value of 1.376 €2019/kWp ranging from (870 – 1882). D-PV is not much far behind, with mean value of 1.764 €2019/kWp (1.128 – 2.398). In this perspective CSP is really in disadvantage with much higher 6.347 €2019/kWp. A similar comment can be said about FOM with the only difference that this time, both PV solutions are cheaper than the average European thermal powerplant.

4.2 Total Addressable Market Results

One of driving results obtained in this work are the projections for the European Total Addressable Market (TAM) depicted as total generation of electricity (TWh). In total, 37 different TAM projections were registered in the database which full content can be verified in Annex B: TAM Expanded Results. This result consists of an interpolated timeseries based of the data acquired from each publication in order to have a continuous year-by-year projection from 2020-2050. Figure 4-1 shows a resumed version of such results composed by the final TAM size in 2050.

Consulting the table or the chart, one can verify the broad range of diversity when it comes to European TAM projections. These very significant differences are as a result of type of models used, socio economic pathways sustaining the scenarios, the contrast of assumptions upon which various scenarios are created, technological availability and constraints, and, as well as on the objectives and the agenda of the issuing body.

So as to illustrate the contrast of premises, take for instance the smaller projected TAM of the pool, the interpolated data based on the European Climate Foundation (ECF) Demand-Focus Scenario. The storytelling that embeds this projection is that a huge effort will be made across many economic sectors in order to increase energy efficiency and thus reduce demand. As a result, from 2020 on, the TAM for Europe only gets smaller as time passes by arriving at 2,720 TWh in 2050. On the same document, ECF offers another perspective, one that emphasizes technological advancement and increased renewable generation, producing the 12th largest European TAM projection for 2050 of 5,637 TWh.

This diversity of perspectives, especially when from the same issuing body or the same publication, reinforces the idea that these are not forecasts but possible paths for future development of the power/energy sector.

But sometimes it is possible to get the impression that a scenario is used to prove some point. For example, Solar Power Europe (SPE) and LUT University developed a scenario in which Europe's Energy System becomes climate neutral before 2050. Unsurprisingly, such a feat is heavily reliant on a very ambitious growth of renewables, especially solar technology, resulting in the largest TAM in our pool (17,091 TWh) by a considerable margin of 11%.

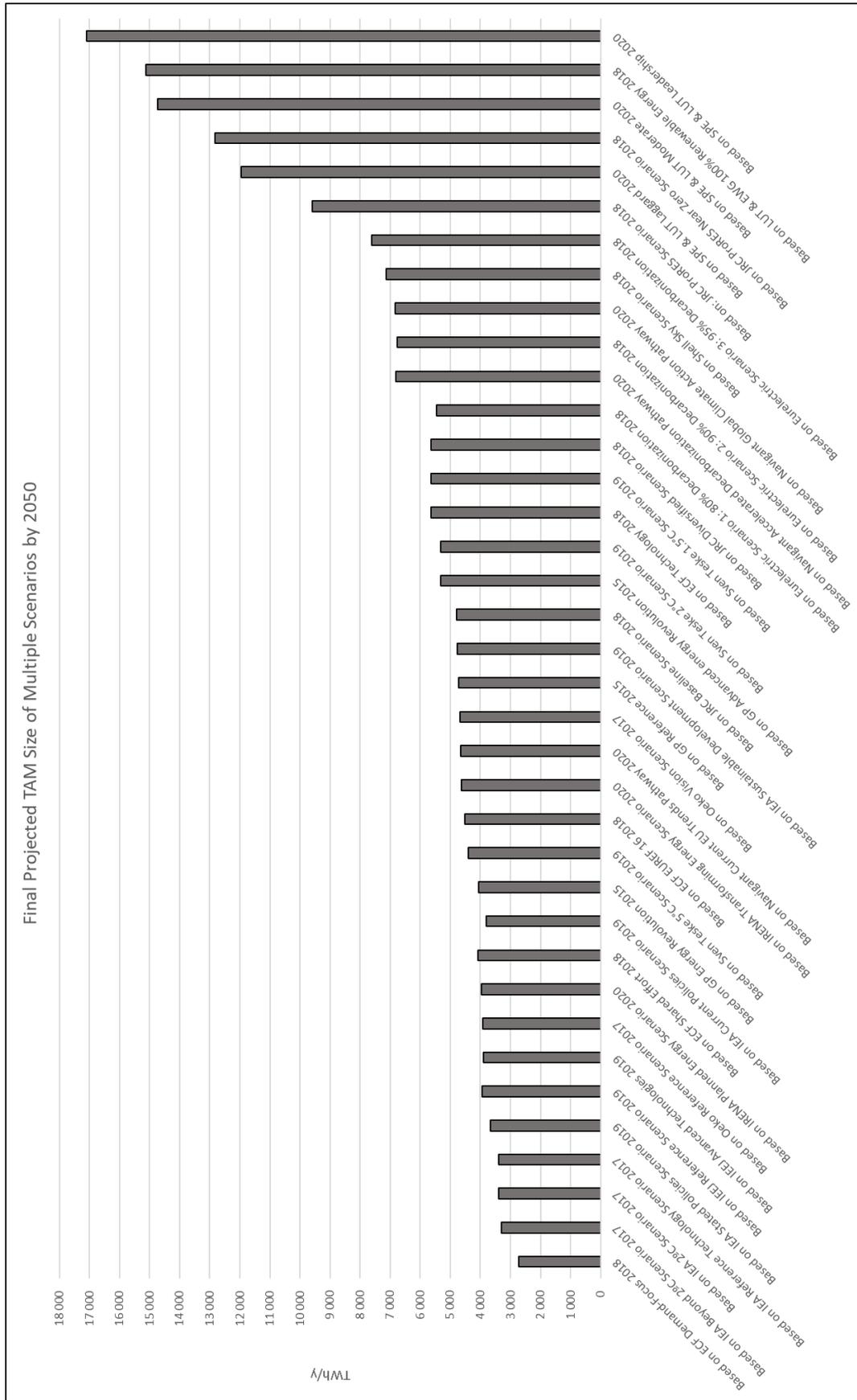


Figure 4-1: Projection of TAM Size of Multiple Scenarios by 2050

A careful observation of this result allows one to conclude that most sources project the European TAM for 2050 to be within the range of 3,500-5,500 TWh. Additionally, some organizations, in its various scenarios and reports, tend to populate one specific end of the spectrum. For instance, the International Energy Agency (IEA) is (unsurprisingly) heavily skewed to the most conservative end of projections while scenarios produced by EWG in partnership with LUT University occupies the bolder, more ambitious side.

A possible explanation for the significant TAM projected by LUT University publications the assumption of having a strong component of electrification and energy storage availability in its scenarios. Certainly, LUT University reports are not the only ones to consider the impacts of energy storage over the energy sector but they are distinguished from the rest by the amount of detail and importance given for this topic.

One could also suspect that most recent publications are skewed to be more ambitious by default, but it would take a larger sample size, with a wider variety of years, to arrive to such conclusion. This can be justified by the fact of having just one single study from 2015, the Greenpeace Energy Revolution [43], that was thought of being very ambitious at its time and most other reports are from 2018, 2019 or 2020, rendering the time-wise comparison uneven.

Still, TAM results are crucial in assessing the projected share of generation that overall electricity generation technologies and future mix will have in the future. As explained previously in the methodology section it was made the option to compare adoption scenarios not against its own TAM, but against an average set of TAMs that are classified in the same level of ambition that it is. Initial (2020) and final (2050) TAM sizes can be seen on Figure 4-2.

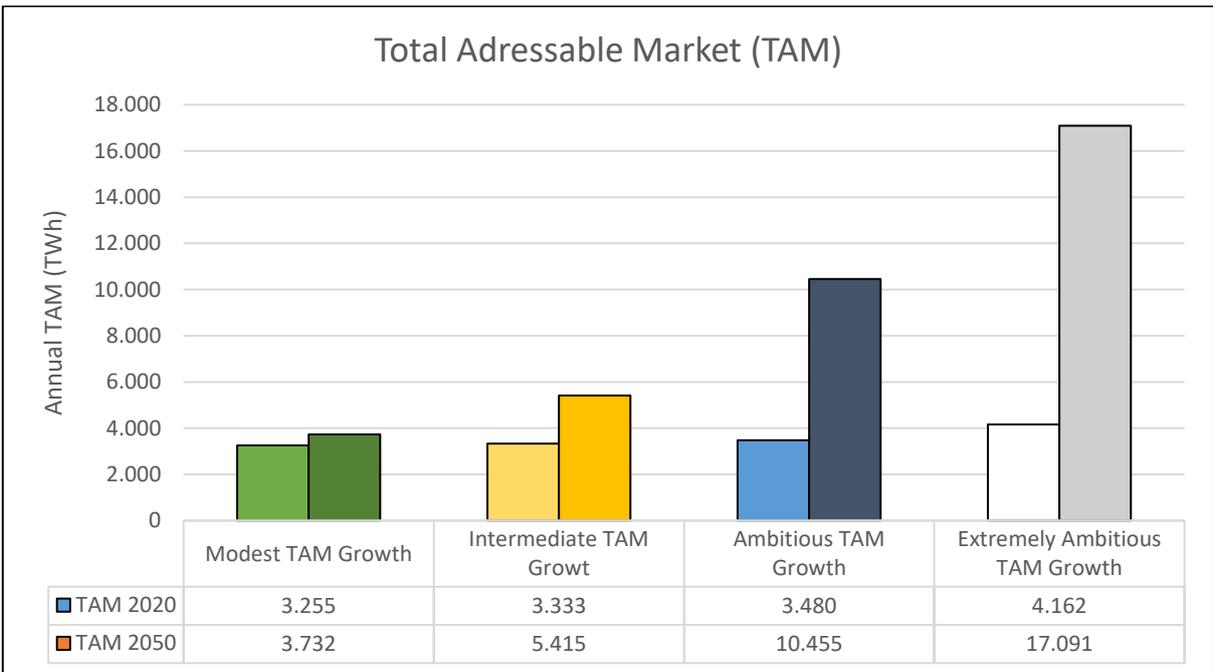


Figure 4-2: Initial (2020) and Final (2050) TAM Sizes for Scenario Tiers. Moderate Tier (14% growth), Intermediate Tier (62% growth), Ambitious Tier (300% growth) and Ext. Ambitious Tier (410% growth)

4.3 Technology Adoption Results

The third set of results produced throughout this work were the projections of solar technologies adoptions, individually, for each one (U-PV, D-PV and CSP) to have a better understanding of the role of each solution/technology in a variety of long-term decarbonization pathways. These were also produced by creating a year-by-year timeseries via interpolation of data acquired from several scenarios in various publications. The methodology section explains in detail how this time-series were created, but it was possible to build 16 time-series for each technology as to be used in Project Drawdown RRS model.

In addition to these sixteen adoption scenarios, three aggregate ones, that represent the average projection of Moderate, Intermediate and Ambitious tiers of adoption have also been added when running the models. In many of the following charts a color scheme will be used to identify these ambition tiers, green for Moderate tier, yellow for Intermediate tier, blue for the ambitious tier. Moreover, the most ambitious scenario is represented in light gray while the aggregate scenarios are in a darker shade of gray.

It may be interesting to register that data for Solar PV was the most abundant one, even though very few publications breakdown between utility scale and decentralized variants as already highlighted above, while data for Concentrated Solar Power (CSP) was scarcer also due to its lower adoption and limited potential future expectations. Detailed data about each adoption projection can be found in Annex C, later in this work.

Figures 4-3, 4-4 and 4-5 portray the 19 European generation projections by 2050, each one of them for U-PV, D-PV and CSP, respectively. One clear takeaway from comparing these figures is the leading role of U-PV among solar technologies. Six scenarios project U-PV generation to be over 1,000 TWh in 2050 while for D-PV there are four scenarios, and for CSP only one. It is interesting to notice that most of the energy sector expects not only the growth of solar-powered technologies for energy generation but also a dominance of PV technology at utility scale.

All adoption results show significant variability between scenarios, a common trend for all technologies. The extreme ambitious scenario (light gray) is more detached from the rest, especially in D-PV. This occurs because the LUT & EWG 100% Renewable Energy Scenario 2018 has native raw data for D-PV that was rather conservative when compared to its other projections, thus producing the big gap. This is one of the few scenarios that present a “non-homogeneous projection for PV technology”, in the sense that it is extremely ambitious with U-PV, not so much with D-PV, ranking almost in the intermediate tier for its CSP projections.

The overall similarity between Figures 4-3 and 4-4, for U-PV and D-PV respectively, was expected since they are both based on the same raw data (*i.e.*, Solar PV adoption) input as explained in the methodology section. As a reminder, only the Shell Sky and LUT & EWG 100% Renewable Energy scenarios have originally discriminated projections for U-PV and D-PV separately.

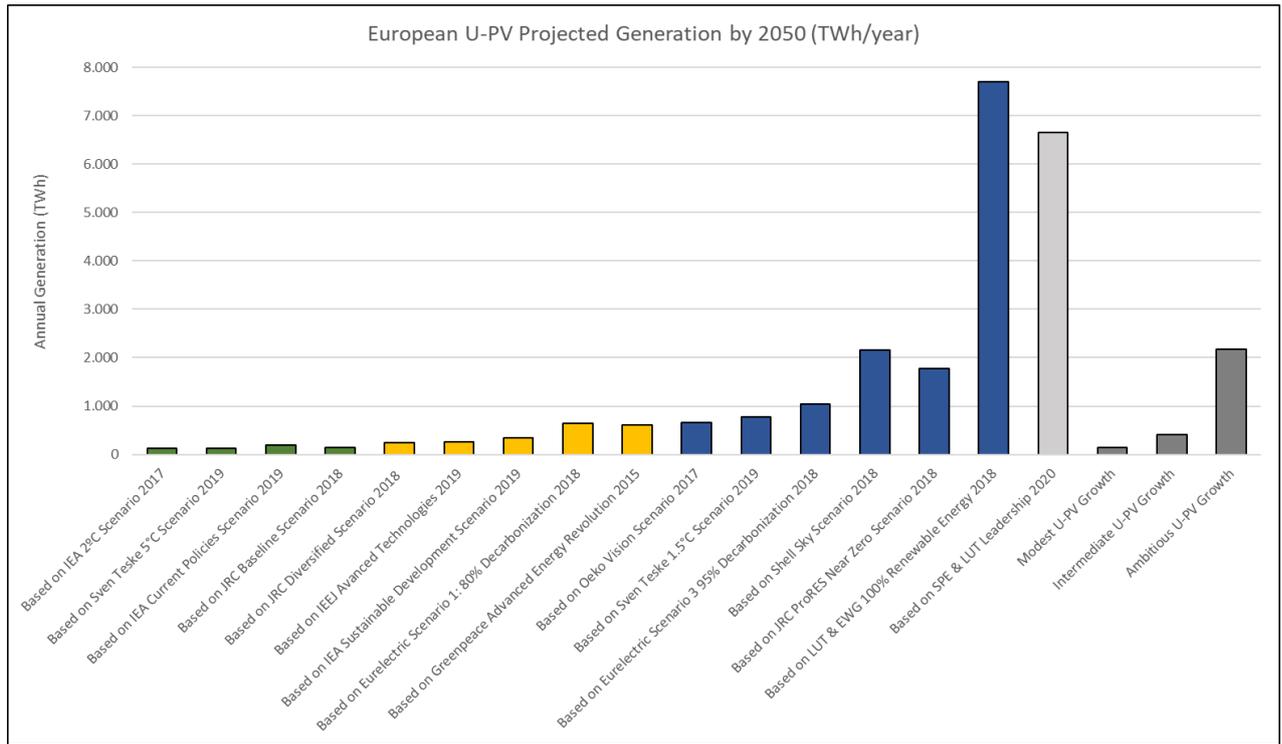


Figure 4-3: European U-PV Projected Generation by 2050 (TWh/y)

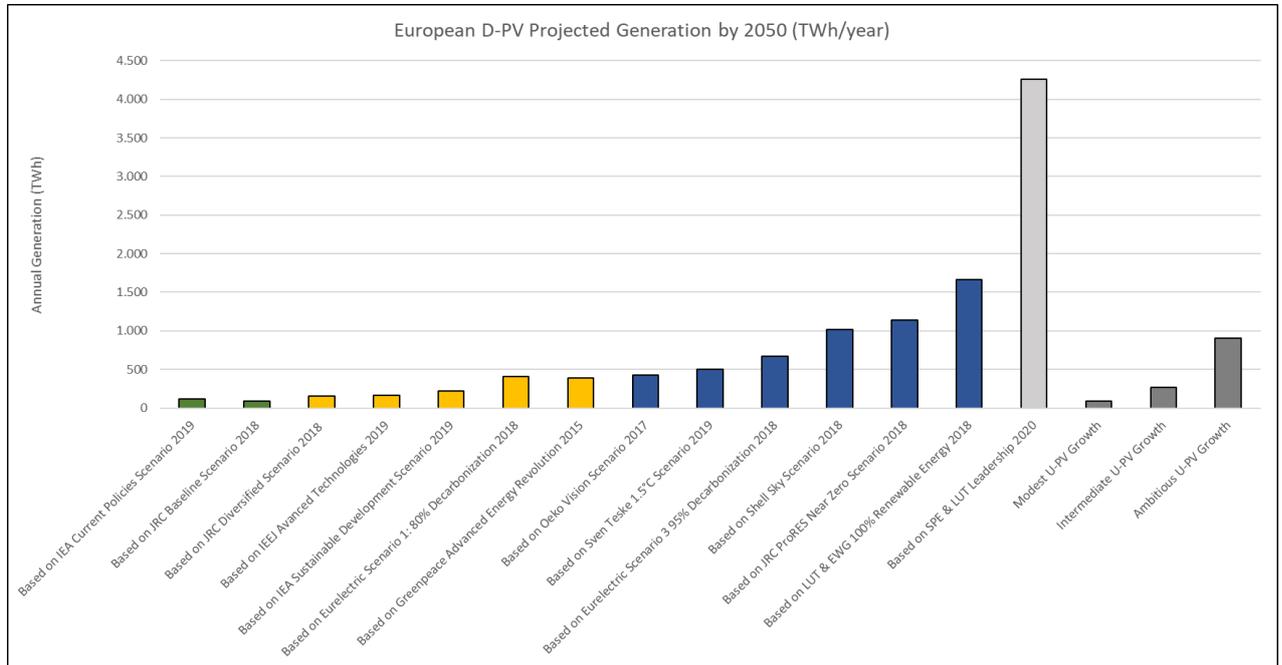


Figure 4-4: European D-PV Projected Generation by 2050 (TWh/y)

The parallel between U-PV and D-PV is only possible because their projections are based in the same scenarios. So, as tempting as it might be, a direct comparison with CSP would not be adequate, for CSP projections come from other publications.

A careful observer could notice that U-PV has four different scenarios within the Moderate Tier (green) while D-PV and CSP have only two and three, respectively. Originally, all technologies have four scenarios in this tier. These “missing-scenarios” were eliminated from the results because they produced near-zero or slight negative results for Emissions Reduction. This is caused by very slow adoption rates combined with near stagnant TAMs and also the way the model is programmed.

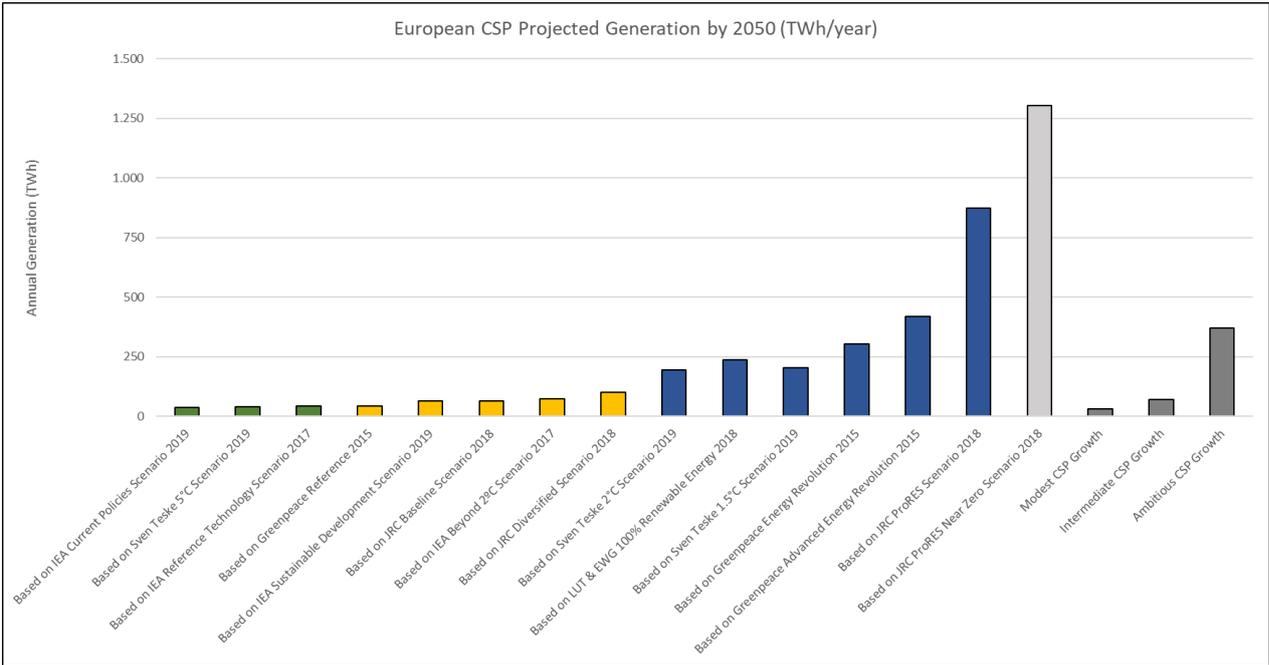


Figure 4-5: European CSP Projected Generation by 2050 (TWh/y)

4.4 Project Drawdown RRS Model Results

The fourth and final set of results are the ones obtained from running the Project Drawdown RRS models for each solar technological solution. For each solar technology there are a total of 19 runs, one for each of the 16 selected adoption scenarios in addition to the three aggregate ones. The outputs from the application of RRS model can be divided in three classes: Emission Results, Economic Results and Adoption Results, the latter already addressed previously, thus, this section will be more focused on Emissions and Economic results.

4.4.1 Utility-Scale Photovoltaic Solution

The result portrayed in Figure 4-6 shows that total emissions reduction via U-PV adoption for most scenarios is below 10 Gt of CO_{2e}, with only some exceptions that are far more optimistic about environmental contributions of utility-scale PV technology. The variability in this result can be better perceived in Figure 4-8, also presenting the normal range for results between 2-10 Gt of CO_{2e}, with an average value that is a little bit shy of 10 Gt of CO_{2e}. It is important to reinforce that such result refers to cumulative avoided emissions during three-decade-period between 2020 and 2050.

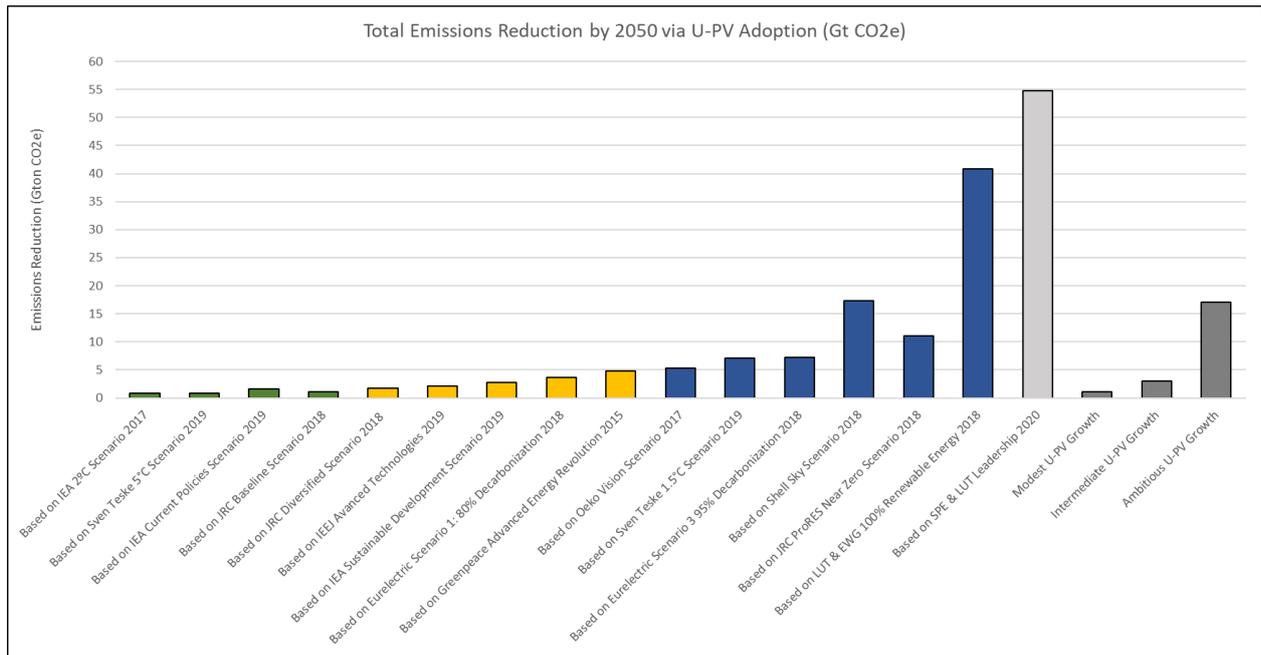


Figure 4-6: Total Emissions Reduction by 2050 via U-PV (Gt CO_{2e})

On the economics part of results, displayed in Figure 4-7, one can appreciate the scale of investment that can be expected for the expansion and renewal of power generation in Europe over the next decade. It is safe to say that Solar PV technologies will be one of the flagships in the energy transition era but to notice that even the most modest projection represents a 100 billion euros worth of investment gives one the sense of the magnitude of investment that the sector is expecting to receive.

Complementarily, Figure 4-8 details once again the variability for this result, with average value just above 600 billion euros, ranging typically within the 150-900 billion euros interval. It is never excessive to remind that all economic metrics throughout this work is measured in euro values of 2019. The detachment of the last Ambitious Scenario (Based on LUT & EWG 100% Renewable Energy) and the Extremely Ambitious Scenario (Based on SPE & LUT Leadership 2020) can be confirmed again in Figure 4-8. These two results fall outside of the normal ranges in every type of result and maybe seen as outliers.

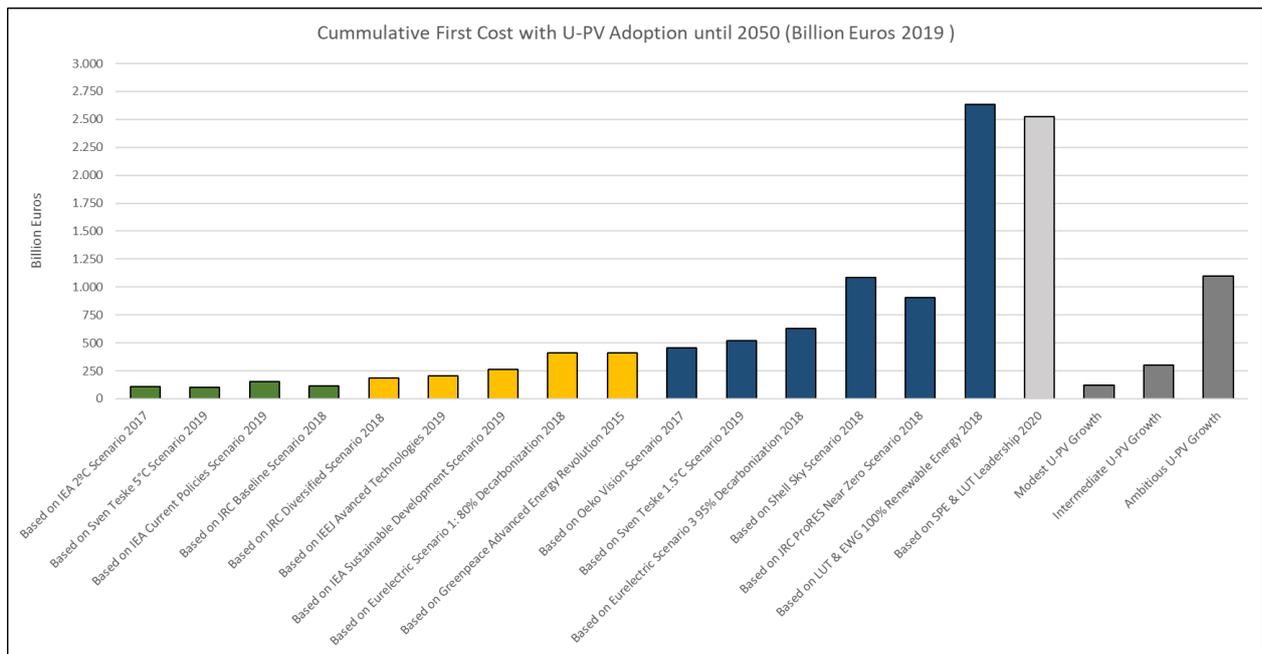


Figure 4-7: Cumulative First Cost with U-PV until 2050 (Billion Euros)

It would have been possible to select other scenarios to compose this 16-scenario-roster in order to attenuate these detachments. However, this would create a more ambitious pool of scenarios that would not better reflect the reality found in publications about the topic. Additionally, it was important to assess the whole range of scenarios found in the revised literature, from the most moderate/conservative to the most ambitious ones, rendering this gap an unavoidable side effect. Still, this is not a particularity of U-PV technology, but rather a consequence of the methodology chosen and model setup, so this pattern will be repeated in the next results for D-PV and CSP.

In addition to Total Emissions Reduction and Cumulative First Cost, Figure 4-8 also exhibits data for two very important results: Average Abatement Cost and Lifetime Operating Savings. The first one is interesting because it bridges economic and environmental results. Low values for abatement cost mean that the technology in question is an interesting candidate to fight climate with economic sense. Moreover, it is one rare metric that can be used to compare technologies across very different economic sectors. Furthermore, Lifetime Operating Savings implies that the technology can be interesting from the investor perspective aiming to generate profit, indicating that possibly the market could push this technology further.

It is interesting to notice that overall, the abatement cost for U-PV is low (average value of 2.7 €/t of CO_{2e}) and some scenarios even present negative values meaning that it can be possible to earn money while reducing emissions via utility-scale PV projects. In the same trend, positive results for Lifetime Operating Savings also suggest that U-PV is a good opportunity for both the environment and the economy, with an average value of 743 Billion € across the many scenarios.

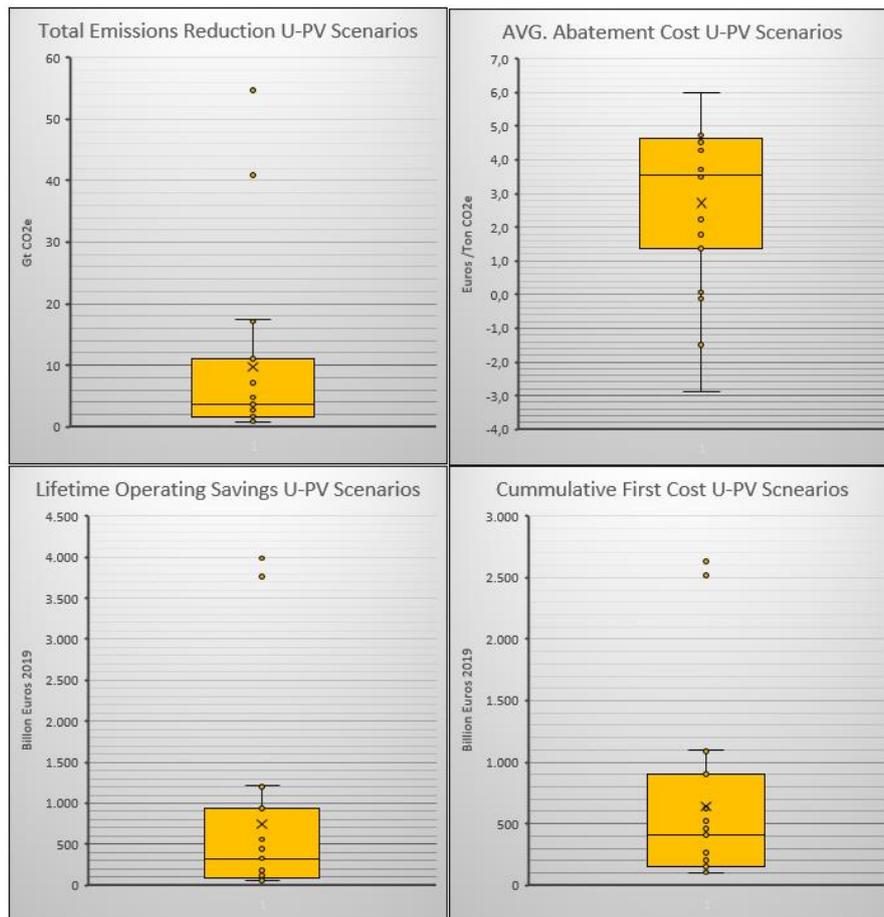


Figure 4-8: U-PV range of Economic and Emission results in detail

4.4.2 Decentralized Photovoltaic Solution

Figure 4-9 presents the results for Total Emissions Reduction achieved via adoption of D-PV. Environmental contributions from this technology branch average around five Gt of CO_{2e}, ranging typically from 0.6 – 6.6Gt of CO_{2e}, as show in Figure 4-11. It needs to be said that such average value has been hugely skewed by the Extremely Ambitious scenario (light gray) shadowing most Moderate and Intermediate scenarios (including the aggregate ones). In great resemblance to U-PV results, most scenarios fall below this average value.

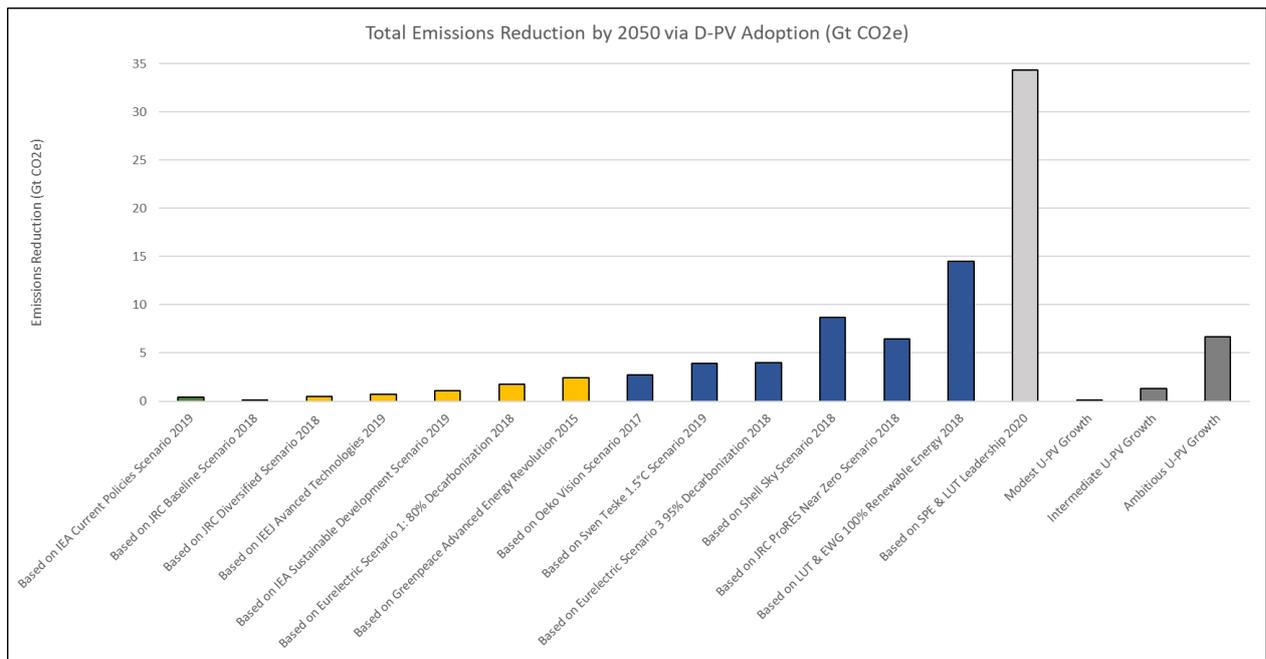


Figure 4-9: Total Emissions Reduction by 2050 via D-PV (Gt CO_{2e})

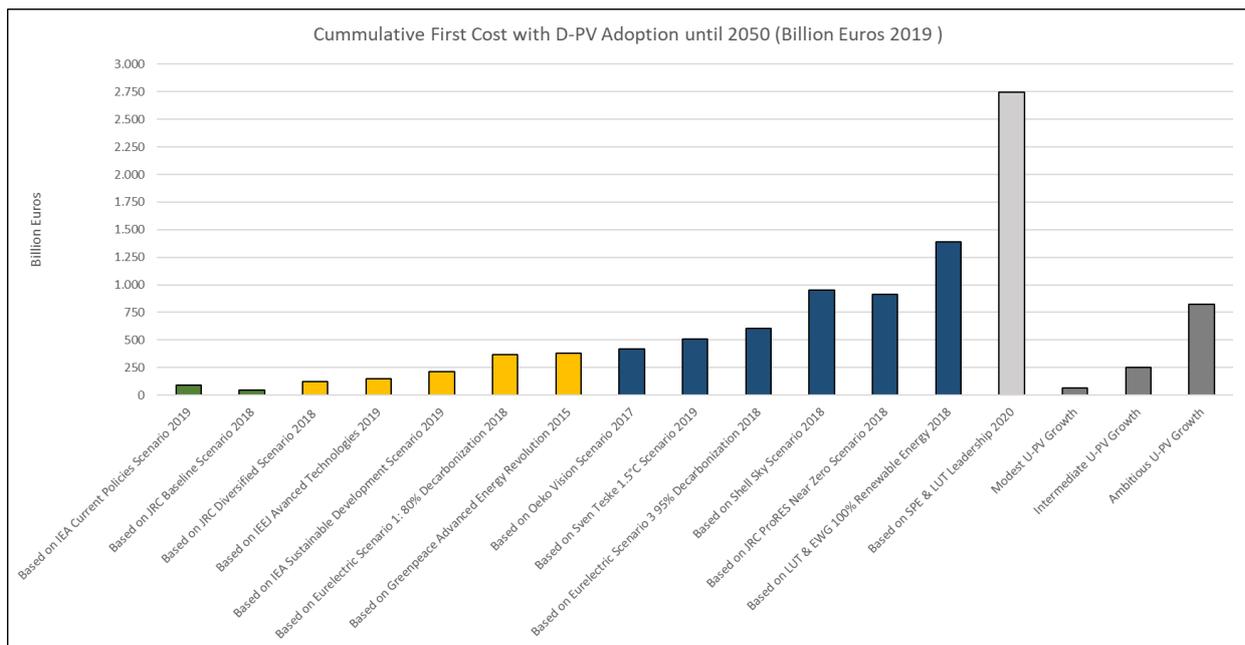


Figure 4-10: Projected Cumulative First Cost with D-PV by 2050 (Billion Euros)

The scenario-by-scenario economic results for D-PV are portrayed in Figure 4-10, accompanied by Figure 4-11 with more details. Data shows that average value for Cumulative First Cost ranges within the 230-830 billion € interval with an average value of 590 billion €. Lifetime Operating Savings average around 240 Billion euros and are more concentrated in a tighter range. Abatement Cost results have an average value of 38 €/t of CO_{2e} in a surprisingly much more variable range.

Also, generically speaking, results for D-PV show a tendency to continuous behavior, with the exception of the Extremely Ambitious Scenario that serves as the single outlier. This continuity could be resultant of wider variability of D-PV inputs when it comes to costs in conjunction with inherently diversity carried

by the concept of “Decentralized PV” itself. Internally the class of D-PV projects can vary a lot. Commercial sized systems are bundled together with residential ones, from different parts of the continent crating a much more heterogeneous group than U-PV or even CSP.

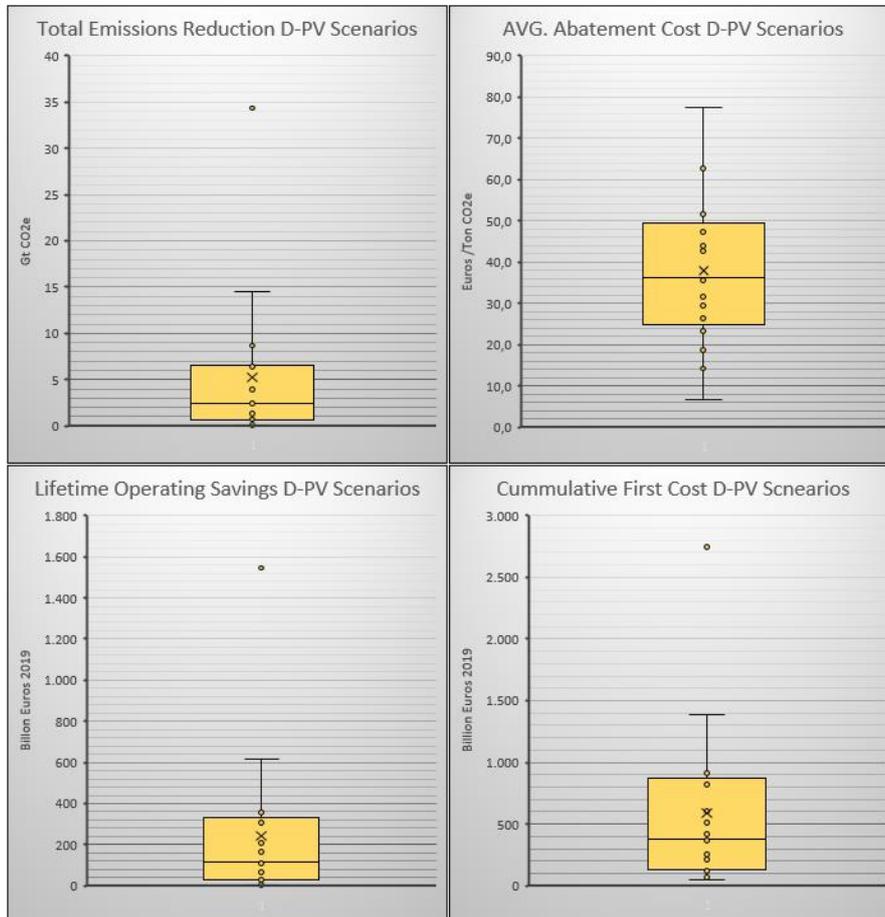


Figure 4-11:D-PV range of Economic and Emission results in detail

4.4.3 Concentrated Solar Power Solution

Finally, emission results for CSP solar technology are depicted in Figure 4-12. They average around 1.6 Gt of CO_{2e}, with a typical range of 0.3 – 2.3Gt of CO_{2e}, as show in Figure 4-14. Cumulative First cost figures, in a scenario-by scenario fashion, are shown in Figure 4-13 having average value of 230 Billion € within a typical range of 65 – 315 Billion €.

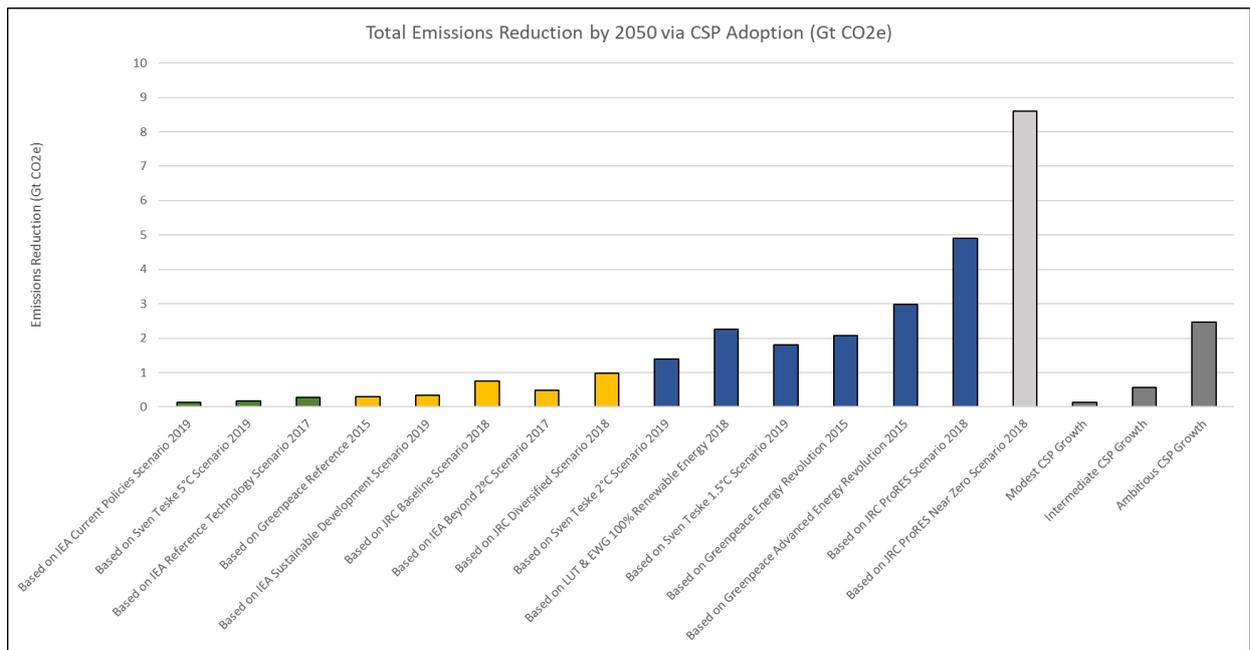


Figure 4-12: Total Emissions Reduction by 2050 via CSP (Gt CO_{2e})

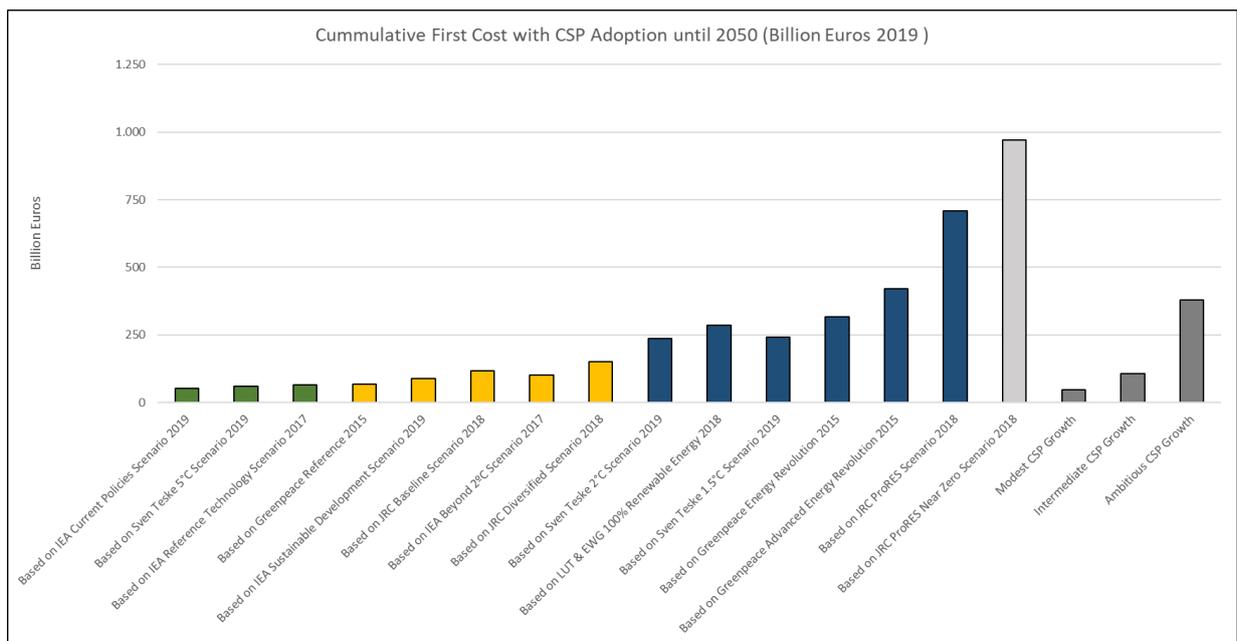


Figure 4-13: Cumulative First Cost with CSP until 2050 (Billion Euros)

Abatement Cost results present an average value of 33 €/t of CO_{2e} and Lifetime Operating Savings are actually negative across all scenarios, suggesting negative cashflows during the operation of a typical CSP project. This is a very important highlight since CSP is the only solar technology displaying this negative economic output, in agreement with previous results of Project Drawdown.

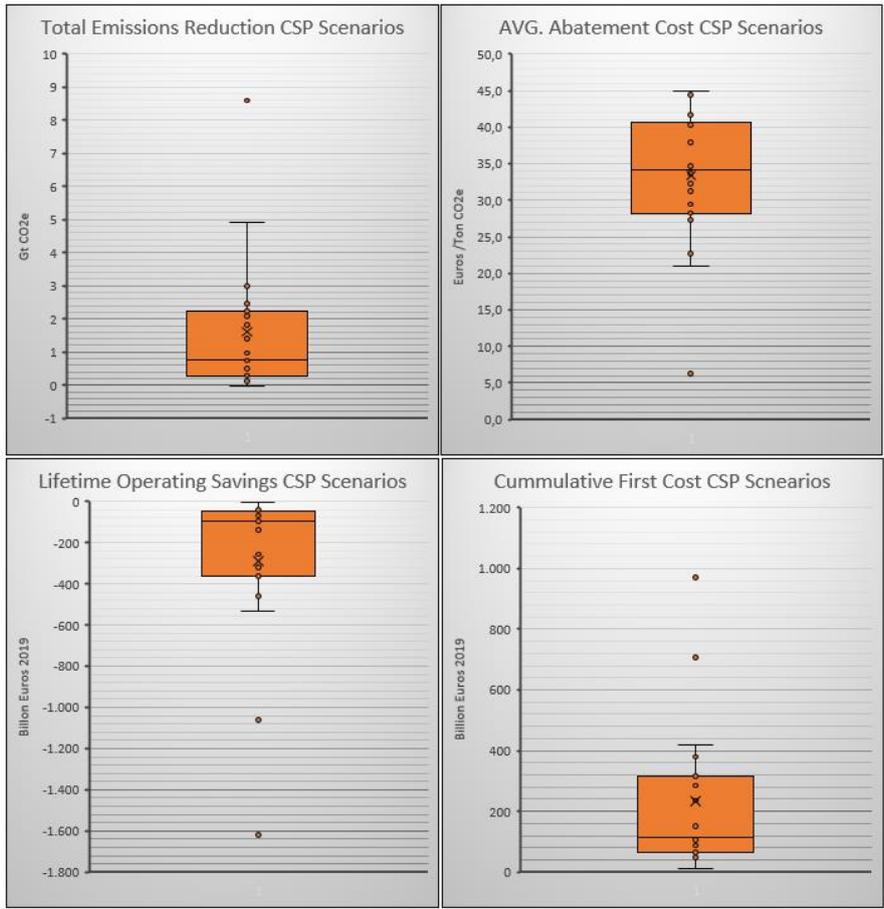


Figure 4-14: CSP range of Economic and Emission results in detail

5 Discussion

In this fifth chapter, obtained results will be contextualized with other important key factors for the future of electricity generation in Europe, providing an enriched interpretation of results, leading to the conclusions in the following chapter.

5.1 Combining and Contrasting Results

Without denying the importance of individual results, many other richer and more meaningful observations can be made when comparing and aggregating these individual pieces of information. Even because, ultimately, these are three solar-based power generating technologies that somehow compete, complement, and contribute to the European power mix of the future.

The preceding chapter was aimed at showing individual results for each technology in charts that were best suited for each individual range of results. This time however, results for each one of the 19 scenarios (16 projections + 3 aggregated-by-tier average projections) for the three technologies U-PV, D-PV and CSP will be compared side-by-side, to better appreciate the relative differences between them. The color scheme established in the previous sections will be continued in the present one, with deep yellow for U-PV, pale yellow for D-PV and light orange for CSP. Moreover, combined results from the three aggregated-by tier average projections, Moderate, Intermediate and Ambitious tiers will be displayed in a cumulative way to better understand the total impact of solar technologies.

Firstly, generation results. Figure 5-1 shows on the left-hand side the results of generation in annual TWh and on the right-hand side, the share of each technology in the European power mix of 2050. Comparing ranges of results, it becomes clear that Utility Scale PV is bound to be the most relevant of Solar Technologies for electricity generation in the future, maybe even, the single most relevant technology for electricity generation due to its elevated share in some scenarios. To realize how projections for U-PV are bold it is interesting to compare it against current total generation numbers in Europe. According to the many sources consulted in this work, in 2017, 3250 TWh of electricity has been generated in Europe while the average projected generation for U-PV in 2050 is around 1380 TWh, just shy of half the current generation, only from U-PV. Furthermore, this also puts in perspective the magnitude of the outlying results that projects around twice as much generation from U-PV than current total energy generation mix.

Another important take away is that CSP technological solution is regarded with more skepticism by most publications. This could be a direct consequence of the fact that CSP is not as matured of a technology as their photovoltaic counterparts. It should be considered that the approach of this work, and of the model used, is a conservative one, meaning that no efficiency improvements are considered as time progresses. Probably some models form source materials don't consider these efficiency gains

either, worsening results for a technology with large room for improvements and such as CSP. Apart from that, unsatisfactory economic results such as seen in the previous section for Lifetime Operating Savings, can be a true warning sign for the future development of this technology branch that is still lagging behind.

In Figure 5-2 one can observe the combined generation from the three solar technologies and how much each one of them contribute to the total, both for 2020 as for 2050. It shows the sum of results for each solar solution for aggregated by tier and the great difference they imply.

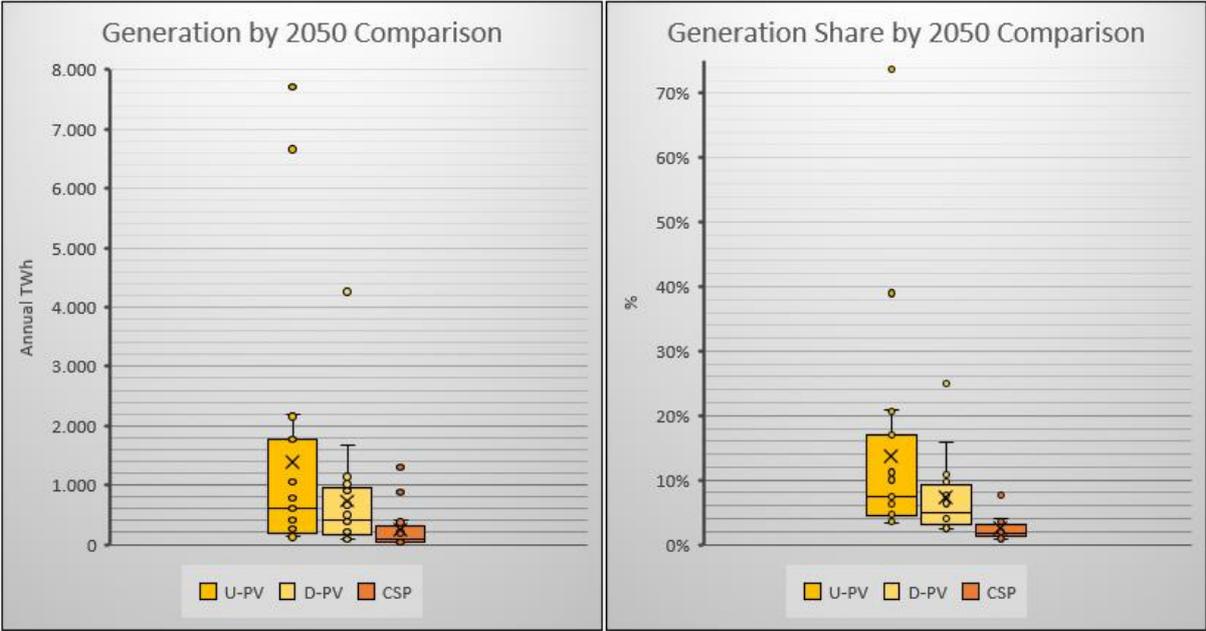


Figure 5-1: Comparison of ranges of projected annual Generation in TWh for U-PV, D-PV and CSP (left hand side) and respective ranges of generation share for these technologies (right-hand side) in 2050.

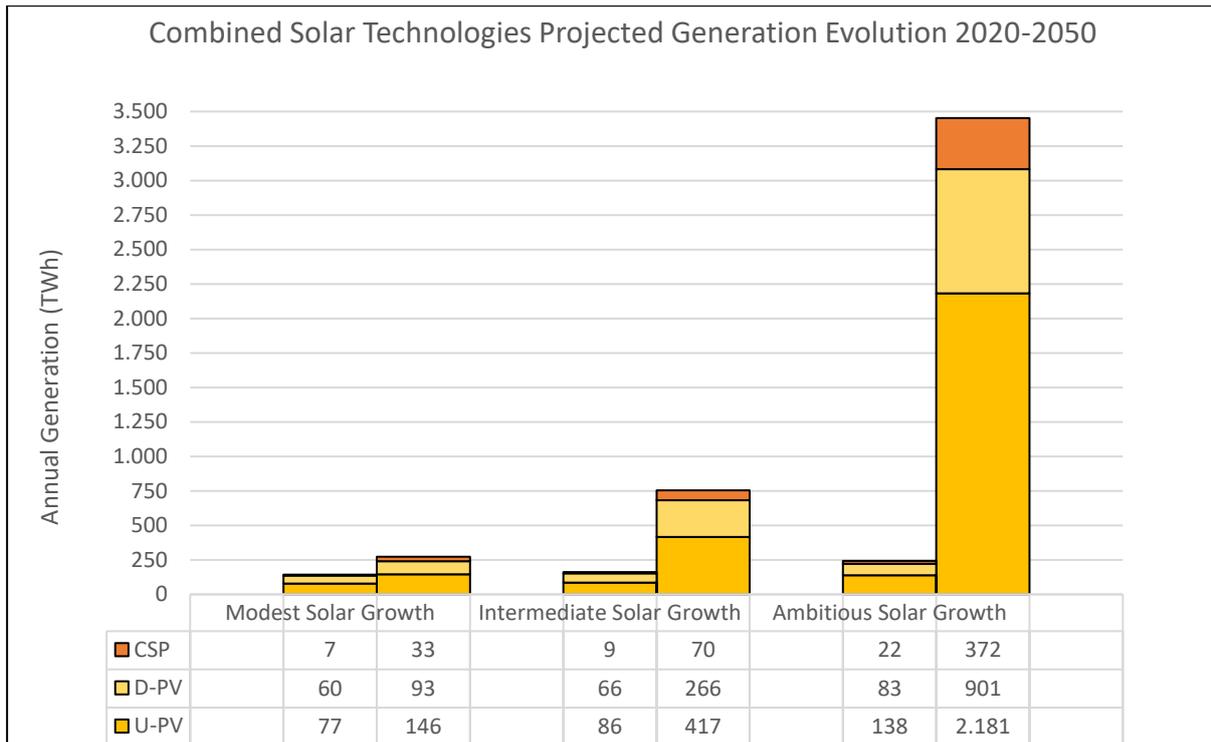


Figure 5-2: Evolution of combined Solar Technologies Annual Generation in 2020 and 2050 considering the Aggregated-by-Tier projections of Modest-Tier Adoption, Intermediate-Tier Adoption and Ambitious-Tier Adoption.

In rough numbers U-PV contribution to total solar generation is a little bit north of 50%, D-PV and CSP, 35% and 12% respectively. The ambitious-tier projects a total solar generation in 2050 equivalent to 2017's total energy generation representing 33% of the electricity generation mix.

Projecting technological development is a multi-metric task. Many factors can influence, such as, government incentives, technology spillover and breakthroughs, regional suitability and synergies play a crucial role in improving or reducing the odds of a technology to prosper. It is known that as Variable Renewable Energy Sources (VREs) increase their penetration in the power network more flexibility is needed to cope with the natural oscillations in instantaneous power outputs [79]. This flexibility can have different forms, wider and more robust interconnection between different regions or storage solutions.

And is in this later aspect, storage, that lies a limitation of comparing costs of U-PV and D-PV with CSP ones. Although they are all possible origins for future kWh in 2050, by definition, CSP offers a degree of dispatchability and of storage that photovoltaic solutions could only deliver when attached to batteries or any other storage solution. During the Energy Transition Era some energy paradigms will end. Energy will be economically stored and not every kWh will be the same. Renewably generated electricity that can be dispatched and/or used later is worth more, and these costs are somewhat being accounted for in CSP while in PV solutions it is not.

Emission results are compared and contrasted in Figure 5-3. On the left-hand side ranges for Emissions Reduction follows the same pattern of generation results. But a very different situation is shown on the right-hand side, where D-PV exhibits a much wider variation in abatement cost than other solutions. This is a consequence of three factors, wider variability of costs, smaller emissions reduction, and higher cumulative first costs when compared specially to U-PV. After all, abatement cost is a measure of

intensity of avoided emissions per each euro invested in a given solution. The indication of a such low abatement costs for U-PV around 4€/t CO_{2e} is a very positive prospect specially when compared to current cost of emissions permit in Europe that in recent years oscillate around 28€/t CO_{2e} [80]. Yet, current estimations for abatement cost in the literature [81] suggest large scale PV to cost 30,3 € for each ton of CO_{2e} avoided. Values found for D-PV average a little below 40 €/t CO_{2e}, more in line with such current values but with very significative variance.

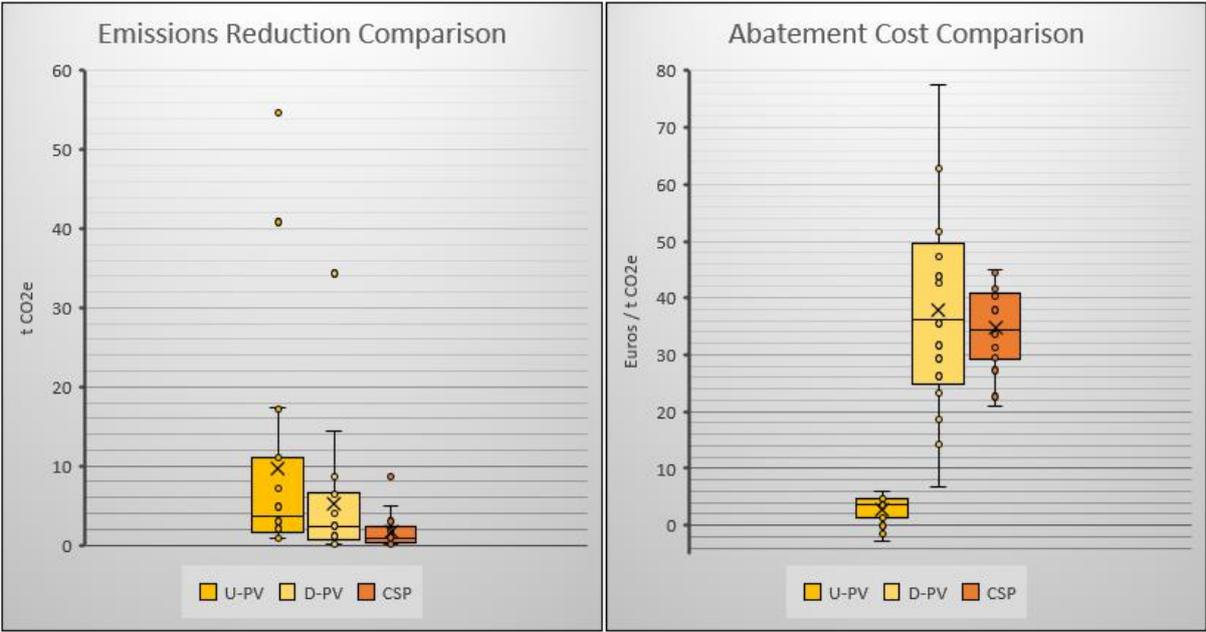


Figure 5-3: Comparison of ranges of projected Emissions Reduction in t of CO_{2e} for U-PV, D-PV and CSP (left hand side) and respective ranges of Abatement Cost for these technologies (right-hand side) in 2050.

The cumulative contributions of U-PV, D-PV and CSP towards emissions reductions is being depicted in Figure 5-4. Once again, the prevalence of U-PV is reassured over all adoption tiers. but it is aggravated in Modest Adoption projections given the timid adoption of other technologies in this setting. For Intermediate tier D-PV and CSP present some contributions that a become really considerable in the Ambitious tier.

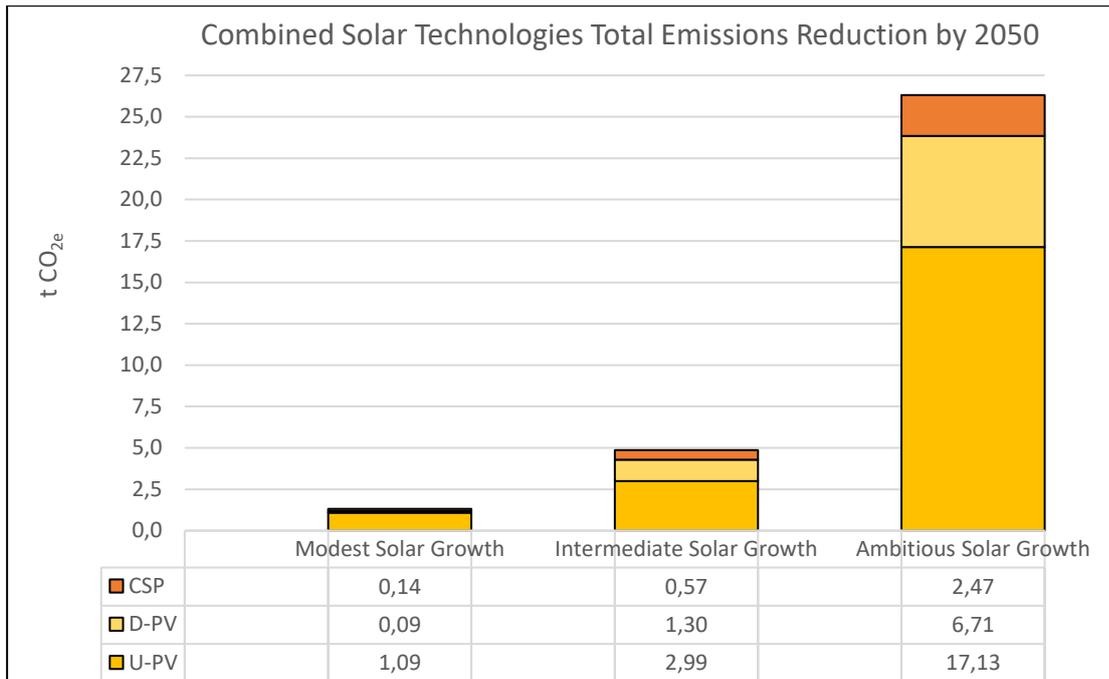


Figure 5-4: Combined Solar Technologies Total Emissions Reduction in t CO_{2e} by 2050 considering the Aggregated-by-Tier projections of Modest-Tier Adoption, Intermediate-Tier Adoption and Ambitious-Tier Adoption.

The contrast of economic results is portrayed in Figure 5-5, in which, on the left-hand side, cumulative first costs are compared side-by-side showing another time that D-PV has a great range of variation when it comes to costs comparable to the one of U-PV even though with much smaller generation figures. Cumulative installation costs for CSP are noticeably smaller as a result of much smaller adoption despite its much higher cost per unit of measure (€/kWp). On the right-hand side, Lifetime Operating Savings are displayed where CSP is detached from PV solutions for having negative results in all projected scenarios. Profitability in D-PV is possible but much smaller than the one from U-PV.

The combined cumulative first cost projected by the average Modest-Tier scenario is a tad shy of 250 billion euros over the next three decades and is represented graphically over Figure 5-6. One can see that for the average Ambitious tier, total investment const in solar technologies will be about 1750 billion euros, a pretty hefty figure.

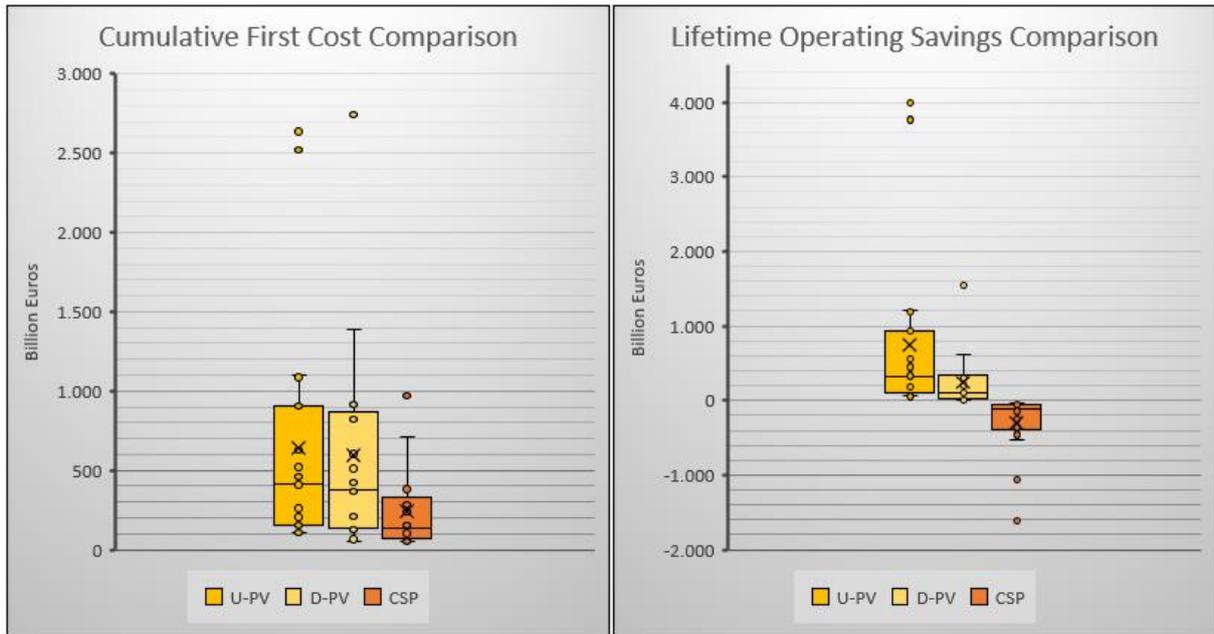


Figure 5-5: Comparison of ranges of Cumulative First Cost in Billion Euros for U-PV, D-PV and CSP (left hand side) and respective ranges of Lifetime Operating Savings for these technologies (right-hand side) until 2050.

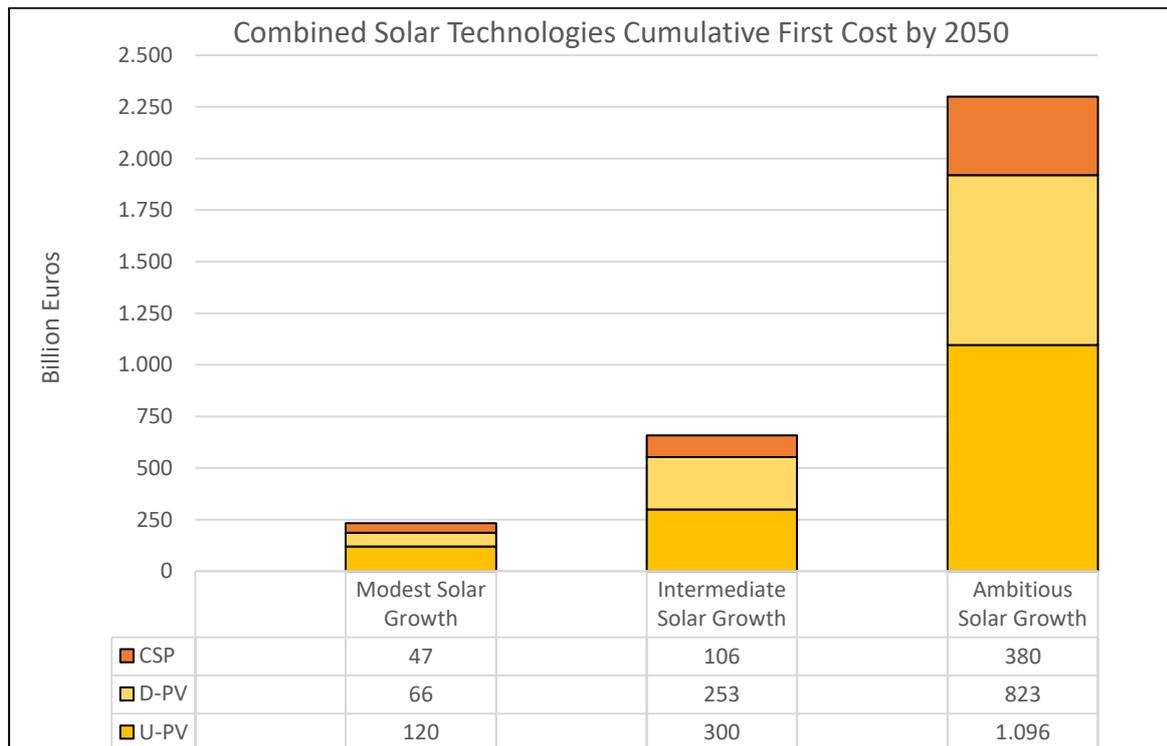


Figure 5-6: Combined Solar Technologies Cumulative First Cost in Billion Euros by 2050 considering the Aggregated-by-Tier projections of Modest-Tier Adoption, Intermediate-Tier Adoption and Ambitious-Tier Adoption.

Other interesting conclusions arise from combining these charts one to another. For instance, looking at the ambitious projections in Figures 5-2 and 5-6 one can realize that the 372 TWh from CSP will cost around 380 billion euros, so an average of one billion euros of investment for each TWh of CSP. The same rationale applied to D-PV or U-PV would result in 910 thousand euros and 500 thousand euros per TWh respectively.

Of course, no projection accounted for the huge disarray caused by COVID-19 pandemic. Many publications issued during 2020 pointed at the decline in electricity consumption delaying new energy investment [13][82]. Renewable energy is not immune to the crisis brought by the global pandemic but they are more resilient [9]. This is due to the increased volatility in prices caused by this global disruption. Fuel prices are the most impacted part of energy sector, oil and coal especially [83].

Energy investments in general are expected to fall by one-fifth in 2020 due to the Covid-19 pandemic. Pre-crisis expectations of modest growth have now become the largest fall in global energy investment on record. The European estimated decline is around 17%, with investments in electricity grids, wind and efficiency holding up better than distributed solar PV and oil and gas. The pandemic might have slowed down but has not stopped renewable power investment. Actually, the European scenario for recovery is expected to follow a green route doubling down on European ambition to lead the globe during the energy transition era with the European Green Deal [84]. Even amid the crisis a proposal for a “European Climate Law” was moved forward, enshrining the 2050 objective for climate neutrality in the law [85].

5.2 Comparison with Project Drawdown 2020 review

Considering that this work is framed within regionalization efforts of Project Drawdown research collaborative into an European context, it is expectable to compare results produced in this study to the ones published earlier by Project Drawdown in order to have a sense of scale and of proportion the Europe Union has relative to the world. One has to bear in mind that this is not an apples-to-apples comparison, though. Global and European projections are very different in numbers and will drift apart even more as Europe’s share of global power sector shrinks with time. IEA’s WEO 2019 data suggest that Europe represents 16% of global power sector in 2018, with a compound average annual growth rate of 07%, representing only 12% in 2040 [31] and probably around 10% in 2050. Other differences in the VMA data can also be the reason for a certain degree of divergence (e.g. lifetime, costs).

Accounting for the asymmetry in the comparison, Figures 5-7 to 5-9 will place side-by-side the most recent Project Drawdown global results, from a 2020 review [21] and this work’s results. These results from this work are expressed in ranges relative to Average Modest Tier and Average Ambitious Tier scenarios results.



Figure 5-7: U-PV Results Comparison. On top of each box is the result name, followed by 2020's Project Drawdown global result [71], and in the bottom, this work's result of Drawdown methodology applied to European context. Ranges shown here are the results of Average Modest U-PV Growth and Average Ambitious U-PV Growth

Drawdown global results suggest that U-PV electricity generation in 2050 will represent between 20.3% and 25% of global electricity generation mix. Results from this work indicate that U-PV will represent from 3.92% to 20.86% of the European power sector mix in 2050. But considering the most optimistic scenario for U-PV adoption, in 2050 it would have a 39% share. The individual and detailed results for every scenario can be found in Annex D. It is interesting to notice that the upper end of global and European results presents a ratio of about ten to one, when it comes to CO_{2e} Emissions Reduction and Projected Generation, which is in line with general expectations.

Although higher end of values is in line with expectations, the lower end ones do not have the 10:1 ratio as expected. It seems that scenarios used to produce the lower end of ranges in this work were much more conservative than the ones in the Project Drawdown 2020 review. This can be confirmed over the adoption scenario part of the technical summary [71], where scenarios one and two are based respectively on ambitious and very ambitious scenarios, while these work's results are from a Modest and Ambitious average scenarios.

Economical results, however, diverge from expectations. This is probably due to differences in VMA data used to feed the model. Higher mean global costs for PV technology in general, or even higher mean fuel costs, would produce bigger results for Lifetime Operating Savings, skewing the proportion of the two compared results to a bigger ratio. Checking the values used on the financial model part of the technical summary available on the internet [71], it is possible to check all these boxes except for the fuel cost. Global meta-analysis produced an 1,803 €/kWp for Total First Cost and FOM of 16.58 €/kWp, values that are a little bit north of the ones used in this work, 1,376 €/kWp and 16,94 €/kWp, respectively (shown in Table 4-2).



Figure 5-8: D-PV Results Comparison. On top of each box is the result name, followed by 2020's Project Drawdown global result [86], and in the bottom, this work's result of Drawdown methodology applied to European context. Ranges shown here are the results of Average Modest D-PV Growth and Average Ambitious D-PV Growth

For D-PV, Drawdown global results remark that it will represent between 13.5% and 14.2% of global electricity generation mix in 2050. Results from this work indicate that U-PV will represent from 2.5% to 8.62% of the European power sector mix in 2050. But considering the most optimistic scenario for U-PV adoption, in 2050 it would have a 25% share.

Generically speaking, all comments from U-PV could be applied also to D-PV. The only noteworthy observation is the Lifetime Operating Savings here are a lot more modest. One of the possible causes behind this is that the two scenarios with native projections for D-PV, once again, LUT & EWG 100% Renewable Energy and Shell Sky scenarios, are more conservative for D-PV than for U-PV projections, resulting in a smaller average adoption in the Ambitious tier they belong to. Another way of putting this, both scenarios suggest that over time D-PV/U-PV ratio will be reduced to 24%, on average, instead of the 40% as of now.



Figure 5-9: CSP Results Comparison. On top of each box is the result name, followed by 2020's Project Drawdown global result [87], and in the bottom, this work's result of Drawdown methodology applied to European context. Ranges shown here are the results of Average Modest CSP Growth and Average Ambitious CSP Growth

In its global results, Project Drawdown points that CSP electricity generation, in 2050, will represent between 7.3% and 9.3% of global energy mix. Results of this work have a much narrower and smaller range of results for CSP in 2050's European power sector Mix, from 0.88% to 3.55%. But considering the most optimistic scenario for U-PV adoption, in 2050 it would have a 7.6% share.

The CSP projections for electricity generation in 2050 show the biggest misalignment between global and European results. First, global results are far more ambitious than the average ambitious European projections. But considering the single most ambitious CSP projection in this work, the 2050's Europe would produce 1,305 TWh from this power source, which is very significant. Despite these differences of projections, this may be due to the fact that other regions of the world (e.g. North Africa) are more suitable to CSP power generation than Europe is, where it is almost constrained to the Iberian Peninsula.

5.3 Sensitivity Analysis

The goal of this section is to present and discuss the Sensitivity Analysis rounds. To better understand how each VMA input affects the economic and environmental results produced by the model, only one of these parameters was changed at a time. Originally, all the runs of the model for generating base results all had average values for VMA parameters. This time they will be altered to their respective minimum and maximum values to assess the impacts produced on each result. Motivated by the intent of exploring the boundaries of results, this sensitivity analysis will be executed for two different references. In the lower end of adoption results, the Average Moderate Tier adoption scenario will be the reference (labelled as "Run 17" in the Tables 5-1, 5-2 and 5-3 on this section); while for the upper end of adoptions, the Average Ambitious Tier adoption scenario will serve as reference (labelled as "Run 19").

The parameters that will have their values shifted to minimum and maximum values are: First Cost, Learning Rate, Lifetime Capacity, FOM, Indirect Emissions Factor and Fuel Costs. Mean values for VMA inputs were used in the base runs while the high and low values were used for sensitivity analysis. All these values were referred in Tables 4-2, 4-3 and 4-4 back in section 4.1 about VMA results. Reminding that VOM and Average Annual Use were left outside of this analysis for not being independent variables.

This systematic approach of testing is methodologically solid, yet it produces some combinations that are very unlikely to make actual sense in the real world. Rounds "AS M1", for instance, couple minimum installation costs for solar technologies with a moderate adoption, which is odd since lower prices would by themselves pressure for higher adoptions and are also a result of economies of scale due to large adoption pathways. The symmetric opposite could be said about rounds "AS A2" where ambitious adoptions are paired to higher First Costs. These and other details are organized in Tables 5-1, 5-2 and 5-3 for U-PV, D-PV and CSP, respectively.

These tables may have a particular way of arranging results for a sensitivity analysis, so a little explanation is due. In the first column of these tables is the “Sensitivity Analysis Round”, with a round identification name sided by the solar technology in question. Then, there is the “Round Description” that explains what change has been made over the reference scenario. For instance, round “AS M10 – Indirect Emission Factor MAX” is nothing more than the Average Moderate Tier adoption scenario paired with the Average Moderate TAM growth the only change being the emission factor that now assumes its maximum value instead of the average one. In the upper rows, in green, are the rounds which reference is the Average Moderate Tier Adoption (“Run 17”), and in the bottom, in blue, the ones which reference for comparison is the Average Ambitious Tier Adoption (“Run 19”).

Remaining columns list results for Total Emissions Reduction, Average Abatement Cost, Lifetime Operating Savings and Cumulative First Cost, always followed by a column to portray the variation relative to the respective base scenarios. If variation is null, then cells are left blank in order to facilitate the visual perception of what variations impact which result. Produced variations are also highlighted in yellow for the same reason.

It is noticeable that the column for “Average Abatement Cost” has received a different formatting. This is due to the fact that this result, in its hybrid environmental-economic nature, is the only one that is always changing, and such formatting would facilitate comparison to reference scenarios. This is an interesting and different Sensitivity Analysis because of its multiple inputs and outputs nature. One immediate take away is that not every change in VMA parameter repercussions in all results. Actually, there is not a single parameter that if altered will impact all these four results selected for these analyses. It is probably worth mentioning that these results were the ones selected for being the most important ones. Together they provide a good insight of economic and environmental aspects of solutions, are the ones most publicized in Project Drawdown website, and thus are the ones already used in previous parts of the work.

Table 5-1: Results of Sensitivity Analysis rounds for U-PV. Reference for comparison are Average Moderate Tier (Run 17) and Average Ambitious Tier (Run 19). Each round had only one single parameter changed.

Sensitivity Analysis Round	U-PV	Round Description	Gt CO2 (2020-2050)	%	Average Abatement Cost 2020-2050	Average Abatement Cost Var	%	Lifetime Operating Savings 2020-2050	%	Lifetime Operating Savings Var	%	Cumulative First Cost 2015-2050	%	Cumulative First Cost Var	%
Run 17		RUN 17	1,09	0%	4,63	0%	0%	68,45	0%	0%	0%	120,28	0%	0%	0%
AS M1		AS 1 - Solution First Costs MIN	1,09		-1,33	-129%		68,45				76,08	-37%		
AS M2		AS 2 - Solution First Costs MAX	1,09		10,59	129%		68,45				164,48	37%		
AS M3		AS 3 - First Costs LR MIN	1,09		6,36	38%		68,45				133,49	11%		
AS M4		AS 4 - First Costs LR MAX	1,09		3,43	-26%		68,45				111,31	-7%		
AS M5		AS 5 - Lifetime Capacity MIN	1,09		5,37	16%		64,84		-5%		127,89	6%		
AS M6		AS 6 - Lifetime Capacity MAX	1,09		4,22	-9%		68,47		0%		114,50	-5%		
AS M7		AS 7 - FOM MIN	1,09		3,60	-22%		80,54		18%		120,28			
AS M8		AS 8 - FOM MAX	1,09		5,66	22%		56,37		-18%		120,28			
AS M9		AS 9 - Indirect Emission Factor MIN	1,16	6%	4,38	-5%		68,45				120,28			
AS M10		AS 10 - Indirect Emission Factor MAX	1,03	-6%	4,91	6%		68,45				120,28			
AS M11		AS 11 - Fuel Costs MIN	1,09		8,14	76%		27,21		-60%		120,28			
AS M12		AS 12 - Fuel Costs MAX	1,09		-2,08	-145%		147,20		115%		120,28			
Run 19		RUN 19	17,13	0%	-0,11	0%		1.211,60	0%	0%		1.096,20	0%		
AS A1		AS 1 - Solution First Costs MIN	17,13		-4,15	3527%		1.211,60				693,25	-37%		
AS A2		AS 2 - Solution First Costs MAX	17,13		3,92	-3527%		1.211,60				1.498,79	37%		
AS A3		AS 3 - First Costs LR MIN	17,13		4,05	-3636%		1.211,60				1.594,32	45%		
AS A4		AS 4 - First Costs LR MAX	17,13		-2,42	2018%		1.211,60				833,82	-24%		
AS A5		AS 5 - Lifetime Capacity MIN	17,13		0,11	-200%		1.146,15		-5%		1.157,69	6%		
AS A6		AS 6 - Lifetime Capacity MAX	17,13		-0,22	91%		1.254,08		4%		1.061,22	-3%		
AS A7		AS 7 - FOM MIN	17,13		-0,86	655%		1.425,44		18%		1.096,20			
AS A8		AS 8 - FOM MAX	17,13		0,63	-655%		997,74		-18%		1.096,20			
AS A9		AS 9 - Indirect Emission Factor MIN	18,12	6%	-0,10	-9%		1.211,60				1.096,20			
AS A10		AS 10 - Indirect Emission Factor MAX	16,13	-6%	-0,12	9%		1.211,60				1.096,20			
AS A11		AS 11 - Fuel Costs MIN	17,13		2,44	-2236%		481,53		-60%		1.096,20			
AS A12		AS 12 - Fuel Costs MAX	17,13		-4,98	4255%		2.605,36		115%		1.096,20			

A closer look at these tables shows that changes in results for Total Emissions Reductions are “*symmetrical*” *i.e.*, in the concrete case of U-PV, the consequence of a minimum value for parameter “Indirect Emission Factors” causes the result of “Total Emissions Reduction” to increase by 6% while the maximum value for “Indirect Emission Factors” causes a reduction of 6% in this same result. They are also “*homogeneous*” in the sense that the very same variations are perceived in both Moderate and Ambitious Tiers. Such symmetry only happens in PV solutions.

Changes caused in “Lifetime Operating Savings” originated from variations in FOM are also both *symmetrical* and *homogeneous* in the sense of previous explanation. Variations caused by different Fuel Costs are only homogeneous, and the ones due to changes in Lifetime Capacity are neither symmetrical nor homogeneous with no consistent trend across the different solar solutions. Overall, variation in Fuel prices of conventional technologies were the ones that most impacted economic results for all solar technologies.

Results for U-PV, in Table 5-1, are unique in the sense of having some configurations in which Abatement Cost becomes negative (and such thing does not occur to neither CPS nor D-PV) up to the minimum value of -4,98 €/t CO_{2e} in the round “AS A12 - Fuel Cost MAX”. This makes sense because of the assumption of replacement that guides the Drawdown RRS model, so if fuel costs for supplying traditional power plants increase twice the current value the economy caused by their replacement is much greater. Generically speaking, abatement costs are fairly low even in for the Moderate scenarios and are almost zero when a more ambitious adoption is considered. Still about negative abatement costs for U-PV, notice that the round “AS S2 – Solution First Costs MIN” also produced the almost same result, which only becomes more interesting for being a setting with reasonable likelihood of happening. The most striking discrepancy probably is the one about Total Emissions Reductions that is about 1 Gt CO_{2e} for the Moderate scenarios and around 17 Gt CO_{2e} for the ambitious one.

Decentralized PV benefits from an even bigger increment in “Lifetime Operating Savings” in the event of high priced fuel. Other noticeable facts brought up by Table 5-2 are the great differences in abatement cost for the two groups, and the fact that D-PV was the technology that was most affected by Lifetime Capacity changes.

The CSP sensitivity analysis results in Table 5-3 presents a behavior a little more diverse than the two previous ones. Being the solar solution with higher First Costs per Implementation Unit this technology was the most affected by changes in this VMA parameter. For a similar reason, it was also heavily affected by variation in FOM. Another significant difference is the fact that abatement costs are high in both groups of scenarios.

Table 5-2: Results of Sensitivity Analysis rounds for D-PV. Reference for comparison are Average Moderate Tier (Run 17) and Average Ambitious Tier (Run 19). Each round had only one single parameter changed.

Sensitivity Analysis Round	D-PV	Round Description	Gt CO2 (2020-2050)	%	Euro / t CO2e	Average Abatement Cost 2020-2050	Average Abatement Cost Var	Lifetime Operating Savings 2020-2050	%	Lifetime Operating Savings Var	Cumulative First Cost 2015-2050	%	Cumulative First Cost Var
Run 17		RUN 17	0,095	0%	151,40	0%	4,66	65,66	0%	65,66	0%	0%	
AS M1		AS 1 - Solution First Costs MIN	0,095		79,46	-48%	4,66	42,04		42,04	-36%	-36%	
AS M2		AS 2 - Solution First Costs MAX	0,095		223,35	48%	4,66	89,26		89,26	36%	36%	
AS M3		AS 3 - First Costs LR MIN	0,095		158,03	4%	4,66	67,68		67,68	3%	3%	
AS M4		AS 4 - First Costs LR MAX	0,095		146,61	-3%	4,66	64,18		64,18	-2%	-2%	
AS M5		AS 5 - Lifetime Capacity MIN	0,095		223,16	47%	3,30	89,69		89,69	37%	37%	
AS M6		AS 6 - Lifetime Capacity MAX	0,095		120,07	-21%	6,29	51,51		51,51	-22%	-22%	
AS M7		AS 7 - FOM MIN	0,095		148,88	-2%	6,56	65,64		65,64			
AS M8		AS 8 - FOM MAX	0,095		153,94	2%	2,76	65,64		65,64			
AS M9		AS 9 - Indirect Emission Factor MIN	0,099	4%	144,72	-4%	4,66	65,64		65,64			
AS M10		AS 10 - Indirect Emission Factor MAX	0,090	-5%	158,74	5%	4,66	65,64		65,64			
AS M11		AS 11 - Fuel Costs MIN	0,095		156,89	4%	0,54	65,66		65,66			
AS M12		AS 12 - Fuel Costs MAX	0,095		140,92	-7%	12,52	65,66		65,66			
Run 19		RUN 19	6,71	0%	23,29	0%	306,79	822,87	0%	822,87	0%	0%	
AS A1		AS 1 - Solution First Costs MIN	6,71		5,21	-78%	306,79	526,82		526,82	-36%	-36%	
AS A2		AS 2 - Solution First Costs MAX	6,71		41,34	78%	306,79	1.118,74		1.118,74	36%	36%	
AS A3		AS 3 - First Costs LR MIN	6,71		36,75	58%	306,79	1.056,22		1.056,22	28%	28%	
AS A4		AS 4 - First Costs LR MAX	6,71		15,22	-35%	306,79	685,53		685,53	-17%	-17%	
AS A5		AS 5 - Lifetime Capacity MIN	6,71		36,86	58%	238,52	1.084,11		1.084,11	32%	32%	
AS A6		AS 6 - Lifetime Capacity MAX	6,71		18,30	-21%	367,26	701,56		701,56	-15%	-15%	
AS A7		AS 7 - FOM MIN	6,71		19,47	-16%	431,88	822,87		822,87			
AS A8		AS 8 - FOM MAX	6,71		27,08	16%	181,69	822,87		822,87			
AS A9		AS 9 - Indirect Emission Factor MIN	7,02	5%	25,90	11%	306,79	822,87		822,87			
AS A10		AS 10 - Indirect Emission Factor MAX	6,41	-4%	28,38	22%	306,79	822,87		822,87			
AS A11		AS 11 - Fuel Costs MIN	6,71		31,53	35%	35,59	822,87		822,87			
AS A12		AS 12 - Fuel Costs MAX	6,71		7,53	-68%	824,51	822,87		822,87			

Table 5-3: Results of Sensitivity Analysis rounds for CSP. Reference for comparison are Average Moderate Tier (Run 17) and Average Ambitious Tier (Run 19). Each round had only one single parameter changed.

Sensitivity Analysis Round	CSP	Round Description	GT CO2 (2020-2050)		Average Abatement Cost 2020-2050		Average Abatement Cost 2020-2050 Var		Lifetime Operating Savings 2020-2050		Lifetime Operating Savings Var		Cumulative First Cost 2015-2050		Cumulative First Cost Var	
			Reduction	Total Emissions	Abatement Cost	Abatement Cost	Var	Savings 2020-2050	Savings Var	Cost 2015-2050	Cost Var					
			%	Euro/t CO2e	%	Billion Euro	%	Billion Euro	%	Billion Euro	%	Billion Euro	%			
Run 17		RUN 17	0,14	0%	40,30	0%	-31,48	0%	47,17	0%	0%	47,17	0%			
AS M1		AS 1 - Solution First Costs MIN	0,14		23,75	-41%	-31,48		27,55		-42%	27,55	-42%			
AS M2		AS 2 - Solution First Costs MAX	0,14		56,86	41%	-31,48		66,81		42%	66,81	42%			
AS M3		AS 3 - First Costs LR MIN	0,14		44,30	10%	-31,48		54,42		15%	54,42	15%			
AS M4		AS 4 - First Costs LR MAX	0,14		36,47	-9%	-31,48		40,49		-14%	40,49	-14%			
AS M5		AS 5 - Lifetime Capacity MIN	0,14		40,65	1%	-29,35	-7%	48,12	-7%	2%	48,12	2%			
AS M6		AS 6 - Lifetime Capacity MAX	0,14		40,04	-1%	-33,29	6%	46,36	6%	-2%	46,36	-2%			
AS M7		AS 7 - FOM MIN	0,14		35,64	-12%	-12,36	-61%	47,17	-61%		47,17				
AS M8		AS 8 - FOM MAX	0,14		44,97	12%	-50,60	61%	47,17	61%		47,17				
AS M9		AS 9 - Indirect Emission Factor MIN	0,15	7%	37,18	-8%	-31,48		47,17			47,17				
AS M10		AS 10 - Indirect Emission Factor MAX	0,11	-21%	50,52	25%	-31,48		47,17			47,17				
AS M11		AS 11 - Fuel Costs MIN	0,14		42,30	5%	-39,67	26%	47,17	26%		47,17				
AS M12		AS 12 - Fuel Costs MAX	0,14		36,49	-9%	-15,85	-50%	47,17	-50%		47,17				
Run 19		RUN 19	2,47	0%	29,43	0%	-461,99	0%	380,04	0%	0%	380,04	0%			
AS A1		AS 1 - Solution First Costs MIN	2,47		17,84	-39%	-461,99		221,90		-42%	221,90	-42%			
AS A2		AS 2 - Solution First Costs MAX	2,47		41,03	39%	-461,99		538,18		42%	538,18	42%			
AS A3		AS 3 - First Costs LR MIN	2,47		40,00	36%	-461,99		576,28		52%	576,28	52%			
AS A4		AS 4 - First Costs LR MAX	2,47		1,41	-27%	-461,99		243,69		-36%	243,69	-36%			
AS A5		AS 5 - Lifetime Capacity MIN	2,47		29,73	1%	-437,63	-5%	391,93	-5%	3%	391,93	3%			
AS A6		AS 6 - Lifetime Capacity MAX	2,47		29,21	-1%	-478,91	4%	369,93	4%	-3%	369,93	-3%			
AS A7		AS 7 - FOM MIN	2,47		23,68	-20%	-181,33	-61%	380,04	-61%		380,04				
AS A8		AS 8 - FOM MAX	2,47		35,19	20%	-742,63	61%	380,04	61%		380,04				
AS A9		AS 9 - Indirect Emission Factor MIN	2,65	7%	26,15	-11%	-461,99		380,04			380,04				
AS A10		AS 10 - Indirect Emission Factor MAX	1,95	-21%	35,51	21%	-461,99		380,04			380,04				
AS A11		AS 11 - Fuel Costs MIN	2,57		30,70	4%	-582,12	26%	380,04	26%		380,04				
AS A12		AS 12 - Fuel Costs MAX	2,57		23,81	-19%	-232,64	-50%	380,04	-50%		380,04				

6 Conclusions

This type work was only possible due to the extensive literature dedicated to the topic of solar energy over the last few years. It is not, by any means, a new topic, but the increasing notoriety of climate emergence and the continued reduction in costs helps to bring solar power technology solutions to the spotlight. Besides, the virtual possibility of integrating any human building and creating multi-purpose projects gives an edge in the potential penetration these technologies can have both in the urban spaces as in the mental space of general public. There is an undeniable sentiment of future and satisfaction when looking at silent and immovable PV panels generating clean energy and realizing that this solution is no more expensive than polluting old ones.

Results from this study point to a significant increase in solar-based power generation, especially for PV class, but also for CSP when compared to present values, but they are unable to give a specific number for how much U-PV, D-PV or CSP generation there will be in 2050. The sources that supported this work were not predictions nor bets, but rather projections based on the various possibilities of technological availability and development, climate mitigation ambition and political choices that lie ahead of us.

Climate change is a global threat, and it must be addressed in global scale, in a coordinated way. Will the pandemic hijack our attention and investment to other more urgent needs? Will the world be less global and nationalist movements become more prevalent in the political arena? Will electrification exceed efforts in energy efficiency? There is no way of anticipating any of these answers but when the world decides to worry again about climate change it is safe to say that there is a solid solution for electricity generation above our heads.

Actually, a part of a solution. Because there will be no single technology, not even a single sector that by itself could solve all intricate challenges of Energy Transition or Climate Change. Some, like the Power Sector, are strategic in the sense of the many integrations and cross-industry repercussions it can unlock. Doubling down the intrinsic transversality of the power sector seems to be an obvious bet because it can decarbonize virtually any other sector that consumes energy if that energy is carbon neutral.

But many others will also be crucial in achieving the Drawdown point, like transportation, buildings, agriculture, forestry, and land use. It will take a combination of many technical solutions to create the future energy mix. The most suitable alternatives will depend on local potentials, development of new technologies and their maturity levels, best fit with other already existing technologies, driven by security of supply, climate mitigation targets, and the technological clusters of each region. And this is the value of initiatives such as Project Drawdown that approaches the challenges of Climate Change and Energy Transition with a holistic perspective as core feature. As daunting as it may be to consider all the small pieces of the puzzle, the “big picture perspective” is an absolute must for studying and solving intricated and complex themes such these ones.

This work is the first step in turning Project Drawdown's approach to a regional European level. This is strategic for supporting the creation of public policies and explore the potential of each region of the globe. Therefore, the continuation of this effort, by considering other technological solutions at European level and/or studying the solar technologies for electricity generation in other geographies is definitely a good option for future work.

There is still some room for improvement in this work, of course. Direct substitution of traditional and dispatchable forms of generating electricity for VREs is a hard assumption with many hidden costs that have not been considered in this work. As mentioned previously, comparing CSP that includes certain degree of dispatchability and storage, to other solutions such as PV that do not, may have been a good first approach. But, perhaps, future works similar to this one should consider an association of PV and batteries (or any given storage solution), at least at the Utility scale level, for leveling the comparison with CSP. It is important to highlight that energy storage along with dispatchability cannot be perceived merely as a desirable feature for power generation solutions since it is already a built-in feature for the pollution fossil fuel fired power plants.

A deep dive into the technical improvements and their respective costs for a future grid with high penetration of VREs, is also certainly a hot topic. Sure, it is hard to prescribe technological solutions for an ever-more interconnected European grid that is managed in a marginalist market rationale. Innovative market regulations and inventive ways of ensuring security of supply with the oscillation of renewable power output would also be welcome.

Furthermore, it could be interesting to extend the pool of scenarios into the past just to have a definitive perception for how the different entities of the sector have evolved in their own projections and how well they could design scenarios that were close to actual development of the sector.

Maybe ranges of results in this work are way too wide to drive public policy but they can be useful to assess the current state of expectations from the many organizations that produce projections for electricity generation. Being a testimonial of the current state of projections, in the future one can look back and understand what our projections for solar technologies were in 2020. Or even, as time goes by and new projections are made public, one can compare where the newer ones sit among those presented here both for TAM and ADPT.

The various results originated in this work through extensive research, *i.e.*, curated values for VMA, TAM and Adoption projections, and the environmental and economic ones provided by the Drawdown RRS model can be very valuable for future reference and comparison with other regions of the globe or even as a testimony of current state of solar technologies. The methodology and sensitivity analysis could also be used to enhance future version of the Drawdown RRS model, that would also benefit from extended capacity both for TAM and Adoption projections and free selection of scenarios on each tier.

If the many decades-long-trend of diminishing solar energy costs will be maintained or not is still uncertain. But a sure thing is that solar technologies, especially the PV branch, has already attained a cost small enough to be competitive against conventional technologies, and in some regions, it already figures as the cheapest form of electricity generation. At the dawn of a new decade, solar powered

technologies, are already poised to play a crucial role in the near future by being the power generation solution that best combines economic performance with overall eco friendliness and an unmatched capacity to become ubiquitous.

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Annexes

Annex A: Historical Dataset for European Electricity Generation Mix

Indicator	Technology	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	
Electricity generation (TWh)	Total Energy	2 939	3 013	3 039	3 103	3 208	3 263	3 318	3 339	3 344	3 311	3 313	3 223	3 222	3 229	3 204	3 190	3 208	3 242	
	Coal	914	930	946	963	979	994	938	902	880	870	864	865	863	856	840	829	738	709	
	Oil	180	174	168	161	155	142	128	115	104	95	87	80	75	71	67	64	65	62	
	Natural Gas	481	519	557	595	633	668	787	843	850	818	764	692	621	561	525	498	612	664	
	Nuclear	944	954	964	974	985	997	978	961	945	931	917	904	892	880	868	858	838	830	
	Sum of all classes of Ren. Energy	420	436	404	410	456	462	487	518	565	598	682	682	772	862	904	940	956	977	
	Hydropower	388	409	354	343	364	349	352	349	365	368	409	342	342	369	405	408	373	382	332
	Renewable hydropower	358	380	320	310	330	314	317	316	333	337	378	314	338	374	377	343	352	302	
	Pumped storage	30	29	34	33	34	35	33	33	32	31	31	28	31	31	31	30	30	31	
	Marine	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	Wind	22	27	36	44	59	70	82	104	120	133	149	180	206	237	253	302	303	362	
	Onshore wind energy	22	27	36	43	58	69	81	102	116	129	143	170	193	219	229	267	264	311	
	Offshore wind energy	0	0	0	1	1	1	1	2	2	3	4	6	10	13	18	24	35	39	52
	Solar	0	0	0	0	1	1	1	3	4	7	14	23	48	72	87	99	109	112	120
	Solar photovoltaic Utility Scale *	0	0	0	0	0	0	0	1	1	2	4	7	14	20	25	28	42	44	47
	Solar photovoltaic Decentralized *	0	0	0	0	1	1	1	2	3	6	11	16	32	48	57	65	61	63	67
	Concentrated solar power	0	0	0	0	0	0	0	0	0	0	0	1	2	4	5	5	6	6	6
	Bioenergy	34	24	42	49	60	70	79	88	98	108	125	134	149	158	168	179	182	186	
	Solid biofuels	28	16	33	39	48	56	61	65	72	76	87	92	99	100	105	112	113	117	
	Bagasse	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Renewable municipal waste	7	8	8	9	10	12	13	15	15	15	15	17	18	19	19	20	21	21	22
	Other solid biofuels	20	8	25	29	38	44	48	50	56	61	70	74	74	80	81	85	91	92	95
	Liquid biofuels	0	0	0	0	1	2	3	2	2	2	4	5	3	4	4	5	6	5	5
Biogas	6	7	9	10	12	13	15	21	24	28	32	38	38	47	54	58	61	63	63	
Geothermal	5	5	5	5	6	6	6	6	6	6	6	6	6	6	6	6	7	7	7	

Annex B: Total Addressable Market (TAM) Expanded Results³

	Based on ECF Demand-Focus 2018	Based on IEA Beyond 2°C Scenario 2017	Based on IEA 2°C Scenario 2017	Based on IEA Reference Technology Scenario 2017	Based on IEA Stated Policies Scenario 2019	Based on IEEJ Reference Scenario 2019	Based on IEEJ Advanced Technologies 2019	Based on Oeko Reference Scenario 2017	Based on IRENA Planned Energy Scenario 2020
	2018	2017	2017	2017	2019	2019	2019	2017	2020
	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly
2010	3 313	3 313	3 313	3 313	3 313	3 313	3 313	3 313	3 313
2011	3 223	3 223	3 223	3 223	3 223	3 223	3 223	3 223	3 223
2012	3 232	3 232	3 232	3 232	3 232	3 232	3 232	3 232	3 232
2013	3 231	3 231	3 231	3 231	3 231	3 231	3 231	3 231	3 231
2014	3 233	3 233	3 233	3 233	3 233	3 233	3 233	3 233	3 233
2015	3 239	3 239	3 239	3 239	3 239	3 239	3 239	3 239	3 239
2016	3 248	3 248	3 248	3 248	3 248	3 248	3 248	3 248	3 248
2017	3 260	3 260	3 260	3 260	3 260	3 260	3 260	3 260	3 260
2018	3 153	3 148	3 202	3 197	3 245	3 274	3 269	3 262	3 262
2019	3 137	3 134	3 195	3 193	3 248	3 292	3 284	3 265	3 264
2020	3 121	3 121	3 189	3 190	3 255	3 311	3 301	3 268	3 267
2021	3 105	3 107	3 184	3 187	3 264	3 333	3 321	3 271	3 271
2022	3 089	3 095	3 180	3 186	3 275	3 357	3 342	3 274	3 284
2023	3 073	3 083	3 175	3 185	3 286	3 382	3 365	3 279	3 299
2024	3 056	3 072	3 172	3 185	3 299	3 409	3 390	3 282	3 315
2025	3 040	3 062	3 169	3 186	3 312	3 437	3 415	3 290	3 332
2026	3 024	3 053	3 167	3 187	3 327	3 466	3 442	3 305	3 351
2027	3 008	3 045	3 166	3 190	3 342	3 496	3 470	3 322	3 371
2028	2 992	3 038	3 166	3 193	3 358	3 527	3 498	3 340	3 392
2029	2 976	3 033	3 166	3 196	3 375	3 558	3 527	3 359	3 414
2030	2 960	3 028	3 167	3 200	3 392	3 590	3 556	3 379	3 437
2031	2 945	3 025	3 169	3 205	3 409	3 621	3 585	3 400	3 461
2032	2 929	3 023	3 171	3 211	3 427	3 653	3 614	3 422	3 485
2033	2 914	3 023	3 175	3 217	3 444	3 684	3 642	3 445	3 510
2034	2 899	3 024	3 180	3 224	3 462	3 714	3 671	3 469	3 536
2035	2 885	3 026	3 185	3 231	3 480	3 743	3 698	3 494	3 562
2036	2 870	3 031	3 191	3 239	3 497	3 772	3 725	3 520	3 589
2037	2 856	3 037	3 199	3 247	3 515	3 799	3 750	3 546	3 616
2038	2 843	3 045	3 207	3 256	3 532	3 825	3 775	3 574	3 643
2039	2 830	3 055	3 217	3 265	3 548	3 849	3 798	3 601	3 671
2040	2 817	3 067	3 227	3 275	3 564	3 871	3 819	3 629	3 698
2041	2 805	3 081	3 239	3 285	3 579	3 891	3 839	3 658	3 726
2042	2 793	3 097	3 251	3 296	3 594	3 909	3 856	3 687	3 753
2043	2 782	3 115	3 265	3 306	3 608	3 925	3 872	3 717	3 780
2044	2 771	3 135	3 280	3 318	3 620	3 937	3 884	3 747	3 807
2045	2 761	3 158	3 296	3 329	3 632	3 947	3 895	3 777	3 833
2046	2 751	3 183	3 313	3 341	3 642	3 954	3 902	3 807	3 859
2047	2 742	3 211	3 332	3 353	3 651	3 957	3 907	3 837	3 884
2048	2 734	3 241	3 352	3 365	3 659	3 956	3 908	3 868	3 909
2049	2 727	3 274	3 373	3 378	3 665	3 952	3 907	3 898	3 932
2050	2 720	3 310	3 395	3 391	3 670	3 944	3 901	3 929	3 955

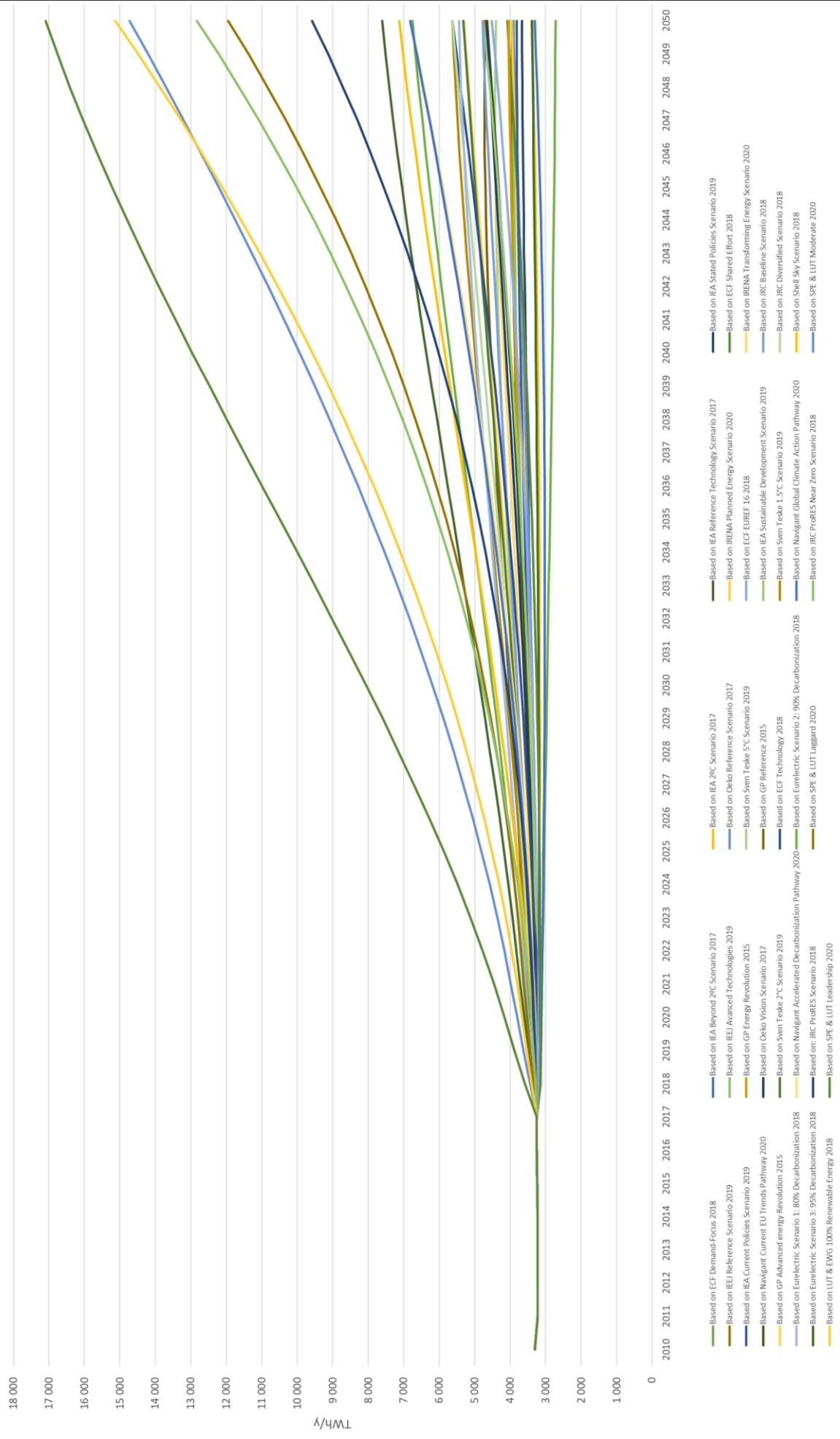
³ Values in these time series are expressed in TWh/y and reflect the projected total amount of electricity generation in Europe for a given year. Each column is the result of the interpolation of projections from a specific publication.

	Based on ECF Shared Effort 2018	Based on IEA Current Policies Scenario 2019	Based on GP Energy Revolution 2015	Based on Sven Teske 5°C Scenario 2019	Based on ECF EUREF 16 2018	Based on IRENA Transforming Energy Scenario 2020	Based on Navigant Current EU Trends Pathway 2020	Based on Oeko Vision Scenario 2017	Based on GP Reference 2015
	2018	2019	2015	2019	2018	2020	2020	2017	2015
	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly
2010	3 313	3 313	3 313	3 313	3 313	3 313	3 313	3 313	3 313
2011	3 223	3 223	3 223	3 223	3 223	3 223	3 223	3 223	3 223
2012	3 232	3 232	3 232	3 232	3 232	3 232	3 232	3 232	3 232
2013	3 231	3 231	3 231	3 231	3 231	3 231	3 231	3 231	3 231
2014	3 233	3 233	3 233	3 233	3 233	3 233	3 233	3 233	3 233
2015	3 239	3 239	3 239	3 239	3 239	3 239	3 239	3 239	3 239
2016	3 248	3 248	3 248	3 248	3 248	3 248	3 248	3 248	3 248
2017	3 260	3 260	3 260	3 260	3 260	3 260	3 260	3 260	3 260
2018	3 150	3 262	3 290	3 335	3 215	3 275	3 262	3 265	3 393
2019	3 147	3 265	3 305	3 367	3 218	3 296	3 264	3 269	3 433
2020	3 146	3 278	3 322	3 402	3 223	3 320	3 266	3 273	3 477
2021	3 148	3 293	3 340	3 440	3 230	3 346	3 268	3 277	3 524
2022	3 152	3 309	3 361	3 481	3 239	3 376	3 287	3 302	3 573
2023	3 158	3 327	3 383	3 524	3 250	3 408	3 309	3 330	3 625
2024	3 166	3 347	3 406	3 568	3 263	3 442	3 334	3 361	3 679
2025	3 176	3 367	3 431	3 615	3 278	3 479	3 361	3 394	3 735
2026	3 189	3 389	3 457	3 663	3 296	3 518	3 391	3 430	3 793
2027	3 203	3 412	3 484	3 712	3 316	3 558	3 423	3 469	3 851
2028	3 220	3 435	3 512	3 762	3 339	3 601	3 457	3 509	3 910
2029	3 239	3 458	3 540	3 812	3 364	3 645	3 493	3 552	3 970
2030	3 259	3 483	3 569	3 862	3 391	3 690	3 532	3 597	4 030
2031	3 282	3 507	3 598	3 912	3 421	3 736	3 573	3 643	4 089
2032	3 307	3 531	3 628	3 962	3 454	3 784	3 616	3 691	4 148
2033	3 334	3 556	3 658	4 010	3 489	3 833	3 660	3 741	4 206
2034	3 362	3 580	3 687	4 058	3 526	3 882	3 707	3 792	4 263
2035	3 393	3 604	3 717	4 104	3 566	3 931	3 756	3 844	4 318
2036	3 426	3 627	3 746	4 148	3 609	3 982	3 806	3 897	4 371
2037	3 461	3 649	3 775	4 190	3 655	4 032	3 858	3 951	4 421
2038	3 497	3 671	3 804	4 230	3 704	4 082	3 912	4 006	4 469
2039	3 536	3 692	3 831	4 267	3 755	4 132	3 967	4 062	4 514
2040	3 577	3 711	3 858	4 301	3 809	4 182	4 024	4 118	4 556
2041	3 619	3 730	3 884	4 332	3 866	4 231	4 082	4 175	4 594
2042	3 663	3 747	3 908	4 358	3 926	4 280	4 142	4 231	4 628
2043	3 709	3 762	3 932	4 381	3 989	4 328	4 203	4 288	4 658
2044	3 758	3 775	3 954	4 400	4 055	4 375	4 265	4 345	4 683
2045	3 807	3 787	3 974	4 414	4 125	4 420	4 329	4 401	4 702
2046	3 859	3 796	3 993	4 423	4 197	4 464	4 393	4 458	4 717
2047	3 913	3 804	4 010	4 426	4 272	4 507	4 459	4 513	4 726
2048	3 968	3 808	4 025	4 424	4 351	4 548	4 526	4 568	4 728
2049	4 025	3 811	4 038	4 417	4 433	4 587	4 593	4 623	4 724
2050	4 084	3 810	4 048	4 403	4 518	4 624	4 662	4 676	4 714

	Based on IEA Sustainable Development Scenario 2019	Based on JRC Baseline Scenario 2018	Based on GP Advanced energy Revolution 2015	Based on Sven Teske 2°C Scenario 2019	Based on ECF Technology 2018	Based on Sven Teske 1.5°C Scenario 2019	Based on JRC Diversified Scenario 2018	Based on Eurelectric Scenario 1: 80% Decarbonization 2018	Based on Navigant Accelerated Decarbonization Pathway 2020
	2019	2018	2015	2019	2018	2019	2018	2018	2020
	2nd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly
2010	3 313	3 313	3 313	3 313	3 313	3 313	3 313	3 313	3 313
2011	3 223	3 223	3 223	3 223	3 223	3 223	3 223	3 223	3 223
2012	3 232	3 232	3 232	3 232	3 232	3 232	3 232	3 232	3 232
2013	3 231	3 231	3 231	3 231	3 231	3 231	3 231	3 231	3 231
2014	3 233	3 233	3 233	3 233	3 233	3 233	3 233	3 233	3 233
2015	3 239	3 239	3 239	3 239	3 239	3 239	3 239	3 239	3 239
2016	3 248	3 248	3 248	3 248	3 248	3 248	3 248	3 248	3 248
2017	3 260	3 260	3 260	3 260	3 260	3 260	3 260	3 260	3 260
2018	3 261	3 330	3 298	3 298	3 261	3 305	3 307	3 336	3 263
2019	3 262	3 356	3 336	3 328	3 263	3 349	3 355	3 412	3 266
2020	3 262	3 386	3 374	3 363	3 264	3 398	3 402	3 489	3 299
2021	3 263	3 418	3 413	3 402	3 266	3 453	3 450	3 565	3 338
2022	3 263	3 453	3 452	3 445	3 268	3 512	3 496	3 624	3 382
2023	3 281	3 490	3 495	3 491	3 327	3 576	3 546	3 687	3 432
2024	3 302	3 529	3 541	3 541	3 368	3 644	3 599	3 752	3 487
2025	3 325	3 571	3 590	3 594	3 413	3 717	3 655	3 821	3 548
2026	3 350	3 615	3 641	3 649	3 462	3 792	3 715	3 891	3 615
2027	3 379	3 660	3 696	3 708	3 515	3 871	3 778	3 964	3 687
2028	3 410	3 707	3 753	3 769	3 572	3 952	3 843	4 039	3 764
2029	3 443	3 756	3 812	3 833	3 633	4 035	3 911	4 115	3 847
2030	3 480	3 805	3 873	3 898	3 697	4 121	3 982	4 192	3 936
2031	3 518	3 856	3 937	3 966	3 765	4 208	4 055	4 270	4 030
2032	3 560	3 907	4 002	4 035	3 837	4 296	4 130	4 348	4 129
2033	3 604	3 960	4 069	4 105	3 913	4 384	4 207	4 427	4 234
2034	3 651	4 012	4 138	4 177	3 992	4 473	4 286	4 505	4 344
2035	3 700	4 066	4 207	4 250	4 074	4 562	4 366	4 583	4 459
2036	3 752	4 119	4 278	4 324	4 159	4 651	4 447	4 659	4 580
2037	3 807	4 172	4 351	4 398	4 247	4 739	4 530	4 735	4 706
2038	3 864	4 225	4 424	4 473	4 339	4 825	4 614	4 809	4 837
2039	3 924	4 278	4 497	4 548	4 433	4 911	4 699	4 881	4 974
2040	3 987	4 330	4 571	4 623	4 530	4 994	4 784	4 950	5 116
2041	4 052	4 382	4 646	4 698	4 630	5 074	4 870	5 017	5 263
2042	4 120	4 432	4 721	4 772	4 733	5 152	4 956	5 082	5 415
2043	4 190	4 482	4 796	4 846	4 838	5 227	5 042	5 143	5 572
2044	4 263	4 530	4 871	4 919	4 945	5 299	5 128	5 200	5 735
2045	4 339	4 576	4 945	4 990	5 055	5 366	5 214	5 254	5 903
2046	4 417	4 622	5 020	5 061	5 167	5 430	5 300	5 303	6 075
2047	4 498	4 665	5 093	5 130	5 282	5 488	5 385	5 348	6 253
2048	4 582	4 706	5 166	5 197	5 398	5 542	5 469	5 387	6 436
2049	4 668	4 746	5 238	5 262	5 517	5 590	5 553	5 422	6 624
2050	4 757	4 782	5 309	5 325	5 637	5 632	5 635	5 451	6 817

	Based on Eurelectric Scenario 2: 90% Decarbonization 2018	Based on Navigant Global Climate Action Pathway 2020	Based on Shell Sky Scenario 2018	Based on Eurelectric Scenario 3: 95% Decarbonization 2018	Based on: JRC ProRES Scenario 2018	Based on SPE & LUT Laggard 2020	Based on JRC ProRES Near Zero Scenario 2018	Based on SPE & LUT Moderate 2020	Based on LUT & EWG 100% Renewable Energy 2018	Based on SPE & LUT Leadership 2020
	2018	2020	2018	2018	2018	2020	2018	2020	2018	2020
	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly
2010	3 313	3 313	3 313	3 313	3 313	3 313	3 313	3 313	3 313	3 313
2011	3 223	3 223	3 223	3 223	3 223	3 223	3 223	3 223	3 223	3 223
2012	3 232	3 232	3 232	3 232	3 232	3 232	3 232	3 232	3 232	3 232
2013	3 231	3 231	3 231	3 231	3 231	3 231	3 231	3 231	3 231	3 231
2014	3 233	3 233	3 233	3 233	3 233	3 233	3 233	3 233	3 233	3 233
2015	3 239	3 239	3 239	3 239	3 239	3 239	3 239	3 239	3 239	3 239
2016	3 248	3 248	3 248	3 248	3 248	3 248	3 248	3 248	3 248	3 248
2017	3 260	3 260	3 260	3 260	3 260	3 260	3 260	3 260	3 260	3 260
2018	3 351	3 270	3 285	3 375	3 288	3 348	3 290	3 441	3 396	3 587
2019	3 443	3 279	3 312	3 490	3 312	3 437	3 344	3 622	3 531	3 876
2020	3 535	3 315	3 379	3 605	3 342	3 525	3 409	3 804	3 667	4 165
2021	3 627	3 356	3 454	3 720	3 379	3 613	3 486	3 985	3 803	4 449
2022	3 707	3 403	3 537	3 823	3 424	3 691	3 576	4 168	3 957	4 773
2023	3 792	3 455	3 628	3 934	3 476	3 779	3 679	4 367	4 128	5 120
2024	3 882	3 513	3 726	4 051	3 536	3 877	3 794	4 582	4 314	5 489
2025	3 976	3 577	3 831	4 173	3 605	3 986	3 924	4 813	4 517	5 878
2026	4 075	3 646	3 941	4 301	3 684	4 107	4 067	5 059	4 737	6 285
2027	4 178	3 720	4 057	4 434	3 772	4 240	4 225	5 321	4 973	6 710
2028	4 284	3 800	4 178	4 572	3 870	4 386	4 398	5 596	5 226	7 149
2029	4 394	3 885	4 304	4 713	3 979	4 545	4 586	5 887	5 495	7 602
2030	4 506	3 976	4 433	4 857	4 099	4 718	4 789	6 191	5 781	8 066
2031	4 621	4 071	4 567	5 004	4 230	4 906	5 009	6 509	6 084	8 540
2032	4 738	4 172	4 703	5 153	4 374	5 108	5 246	6 840	6 404	9 022
2033	4 856	4 278	4 842	5 304	4 530	5 326	5 500	7 185	6 741	9 510
2034	4 976	4 390	4 983	5 456	4 700	5 561	5 771	7 542	7 095	10 003
2035	5 096	4 506	5 126	5 609	4 883	5 811	6 060	7 912	7 465	10 499
2036	5 217	4 627	5 270	5 762	5 079	6 079	6 367	8 294	7 853	10 995
2037	5 339	4 753	5 414	5 914	5 291	6 365	6 693	8 687	8 259	11 492
2038	5 460	4 884	5 559	6 065	5 517	6 669	7 038	9 092	8 681	11 985
2039	5 580	5 021	5 703	6 215	5 759	6 992	7 403	9 508	9 121	12 475
2040	5 699	5 161	5 847	6 363	6 017	7 335	7 788	9 936	9 578	12 959
2041	5 817	5 307	5 989	6 508	6 291	7 697	8 193	10 373	10 053	13 435
2042	5 934	5 457	6 130	6 650	6 583	8 080	8 620	10 821	10 545	13 902
2043	6 048	5 612	6 268	6 789	6 891	8 483	9 067	11 279	11 055	14 358
2044	6 160	5 772	6 404	6 923	7 218	8 909	9 536	11 746	11 583	14 800
2045	6 269	5 936	6 536	7 053	7 563	9 357	10 028	12 222	12 128	15 229
2046	6 374	6 105	6 665	7 178	7 926	9 827	10 542	12 708	12 691	15 641
2047	6 476	6 278	6 789	7 296	8 309	10 321	11 079	13 202	13 272	16 035
2048	6 574	6 456	6 909	7 409	8 712	10 838	11 639	13 704	13 871	16 409
2049	6 668	6 638	7 024	7 515	9 136	11 380	12 224	14 214	14 488	16 762
2050	6 757	6 825	7 133	7 613	9 580	11 947	12 832	14 732	15 123	17 091

Evolution of TAM Projections Based on Consulted Scenarios



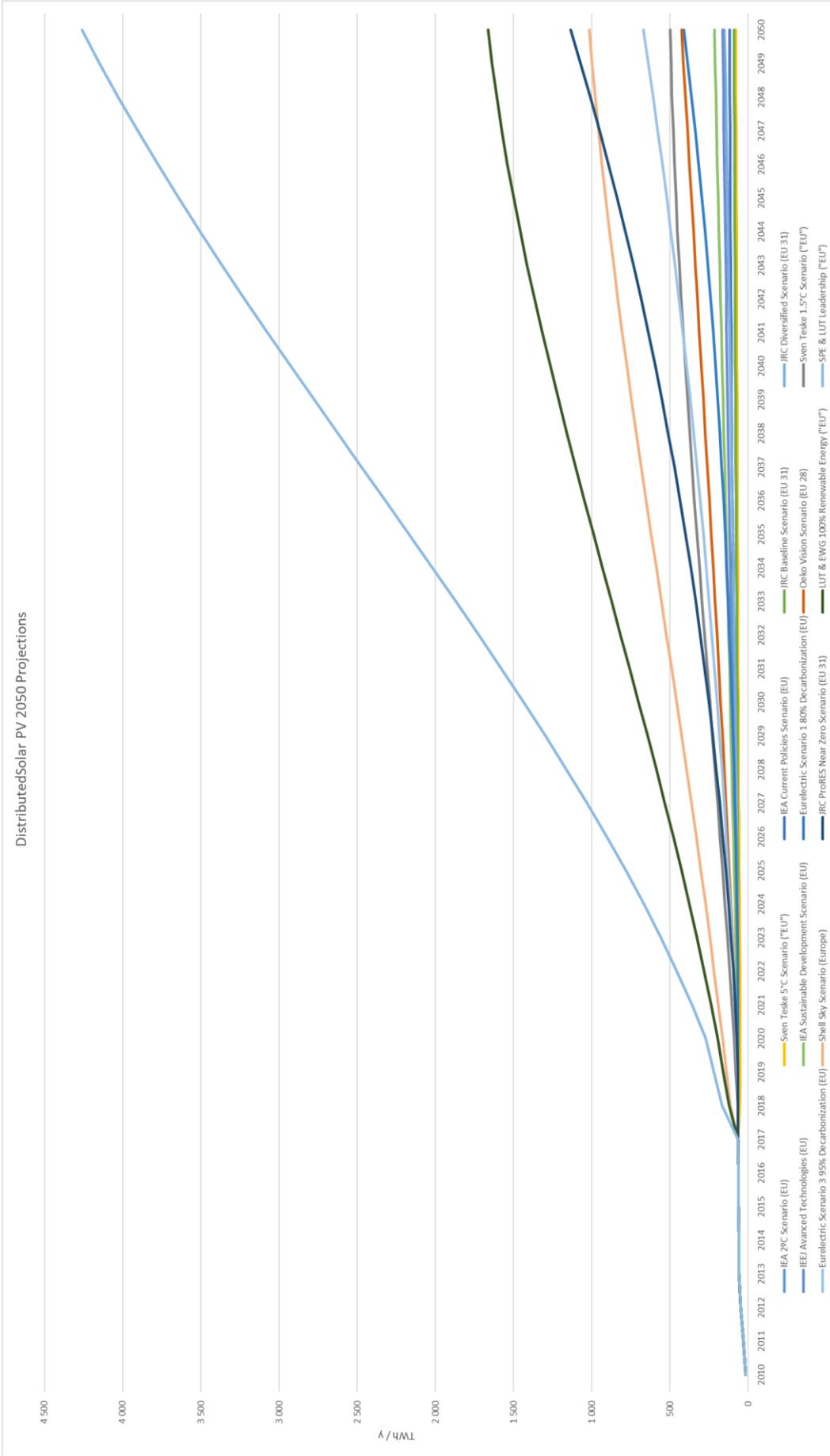
Annex C: Adoption Expanded Results 4

UTILITY SCALE SOLAR PV(U) INTERPOLATED DATA												
EA 2°C Scenario (EU)	2017	2019	2019	2016	2018	2018	2018	2015	2017	2019	2019	2018
	3rd Poly	3rd Poly	2nd Poly	3rd Poly	2nd Poly	3rd Poly	3rd Poly					
	7	7	7	7	7	7	7	7	7	7	7	7
	14	14	14	14	14	14	14	14	14	14	14	14
	20	20	20	20	20	20	20	20	20	20	20	20
	25	25	25	25	25	25	25	25	25	25	25	25
	28	28	28	28	28	28	28	28	28	28	28	28
	42	42	42	42	42	42	42	42	42	42	42	42
	44	44	44	44	44	44	44	44	44	44	44	44
	47	47	47	47	47	47	47	47	47	47	47	47
	60	60	60	62	65	66	66	66	66	66	66	66
	62	60	60	62	65	66	66	66	66	66	66	66
	70	69	78	70	73	76	76	76	76	76	76	76
	77	76	87	77	81	87	86	86	86	86	86	86
	81	80	94	81	87	97	97	97	97	97	97	97
	84	83	99	85	92	104	104	104	104	104	104	104
	87	86	105	89	97	110	105	105	105	105	105	105
	90	88	110	92	102	117	102	102	102	102	102	102
	92	91	114	95	107	123	107	107	107	107	107	107
	94	93	119	98	112	129	108	108	108	108	108	108
	96	95	124	101	116	136	112	112	112	112	112	112
	98	97	128	104	121	142	114	114	114	114	114	114
	99	98	132	106	126	148	117	117	117	117	117	117
	101	100	136	109	130	154	120	120	120	120	120	120
	102	101	140	111	135	160	124	124	124	124	124	124
	104	102	144	113	140	166	127	127	127	127	127	127
	105	104	148	116	144	172	130	130	130	130	130	130
	106	105	151	118	149	177	133	133	133	133	133	133
	107	106	154	119	154	183	136	136	136	136	136	136
	108	107	158	121	159	189	139	139	139	139	139	139
	109	108	161	123	164	194	142	142	142	142	142	142
	110	109	163	125	169	199	145	145	145	145	145	145
	111	110	166	126	174	205	148	148	148	148	148	148
	113	111	169	128	179	210	151	151	151	151	151	151
	114	112	171	129	184	215	154	154	154	154	154	154
	115	114	173	131	190	220	157	157	157	157	157	157
	116	115	175	132	195	225	160	160	160	160	160	160
	118	116	177	134	201	230	163	163	163	163	163	163
	120	118	179	136	206	234	166	166	166	166	166	166
	121	119	181	138	212	239	169	169	169	169	169	169
	123	121	182	139	218	243	172	172	172	172	172	172
	125	123	183	139	225	247	175	175	175	175	175	175
	128	125	184	140	231	252	178	178	178	178	178	178
	130	127	185	142	238	256	180	180	180	180	180	180
2010												
2011												
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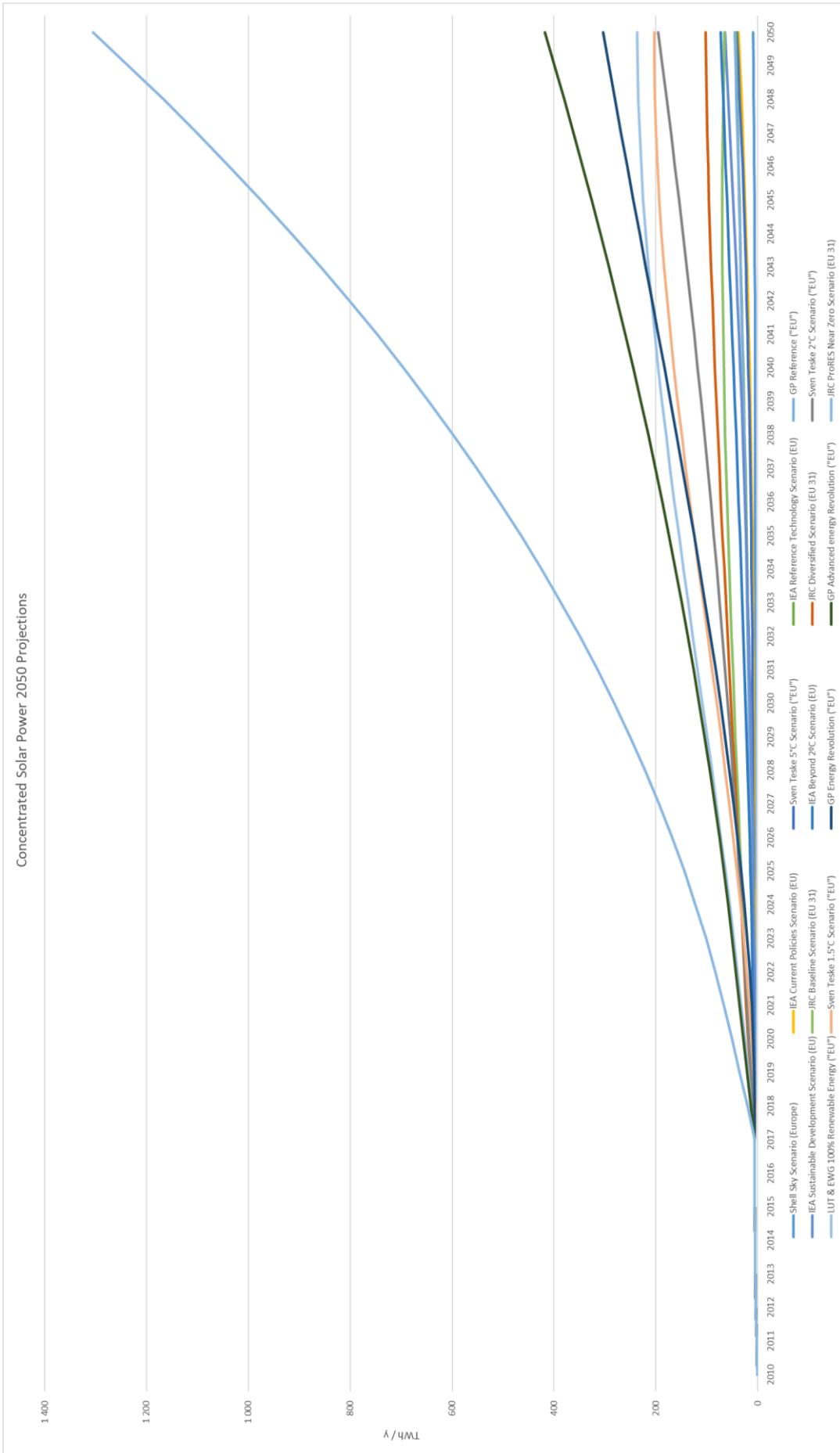
4 Values in these time series are expressed in TWh/y and reflect the projected electricity generation for a certain solar solution in Europe for a given year. Each column is the result of the interpolation of projections from a specific publication.

DISTRIBUTED SOLAR PV (D-PV) INTERPOLATED DATA															
IEA 2°C Scenario (EU)	Sven Teske 5°C Scenario ("EU")	IEA Current Policies Scenario (EU)	JRC Baseline Scenario (EU 31)	JRC Diversified Scenario (EU 31)	IEEJ Advanced Technologies (EU)	IEA Sustainable Development Scenario (EU)	Eurelectric Scenario 1 80% Decarbonization (EU)	Based on Greenpeace Advanced Energy Revolution 2015 ("EU")	Oeko Vision Scenario (EU 28)	Sven Teske 1.5°C Scenario ("EU")	Eurelectric Scenario 3 95% Decarbonization (EU)	Shell Sky Scenario (Europe)	JRC ProRES Near Zero Scenario (EU 31)	LUT & EWG 100% Renewable Energy ("EU")	SPE & LUT Leadership ("EU")
2017	2019	2019	2018	2018	2019	2019	2018	2015	2017	2019	2018	2018	2018	2018	2020
3rd Poly	3rd Poly	2nd Poly	3rd Poly	3rd Poly	3rd Poly	2nd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly	3rd Poly
2010	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
2011	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
2012	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
2013	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
2014	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59
2015	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61
2016	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63
2017	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65
2018	55	55	65	65	65	65	65	65	65	65	65	65	65	65	65
2019	53	52	65	65	65	65	65	65	65	65	65	65	65	65	65
2020	52	53	66	66	66	66	66	66	66	66	66	66	66	66	66
2021	52	53	66	66	66	66	66	66	66	66	66	66	66	66	66
2022	54	53	68	68	68	68	68	68	68	68	68	68	68	68	68
2023	56	55	70	69	69	69	69	69	69	69	69	69	69	69	69
2024	57	57	72	70	70	70	70	70	70	70	70	70	70	70	70
2025	59	58	74	71	71	71	71	71	71	71	71	71	71	71	71
2026	60	59	76	72	72	72	72	72	72	72	72	72	72	72	72
2027	61	61	79	74	74	74	74	74	74	74	74	74	74	74	74
2028	62	62	82	77	77	77	77	77	77	77	77	77	77	77	77
2029	64	63	85	80	80	80	80	80	80	80	80	80	80	80	80
2030	64	64	87	83	83	83	83	83	83	83	83	83	83	83	83
2031	65	65	90	86	86	86	86	86	86	86	86	86	86	86	86
2032	66	65	92	89	89	89	89	89	89	89	89	89	89	89	89
2033	67	66	94	92	92	92	92	92	92	92	92	92	92	92	92
2034	68	67	97	95	95	95	95	95	95	95	95	95	95	95	95
2035	68	68	99	98	98	98	98	98	98	98	98	98	98	98	98
2036	69	68	101	102	102	102	102	102	102	102	102	102	102	102	102
2037	70	69	103	105	105	105	105	105	105	105	105	105	105	105	105
2038	70	70	104	108	108	108	108	108	108	108	108	108	108	108	108
2039	71	70	106	111	111	111	111	111	111	111	111	111	111	111	111
2040	72	71	108	114	114	114	114	114	114	114	114	114	114	114	114
2041	73	72	109	118	118	118	118	118	118	118	118	118	118	118	118
2042	74	73	111	121	121	121	121	121	121	121	121	121	121	121	121
2043	74	74	112	125	125	125	125	125	125	125	125	125	125	125	125
2044	75	74	114	128	128	128	128	128	128	128	128	128	128	128	128
2045	76	75	114	132	132	132	132	132	132	132	132	132	132	132	132
2046	76	76	115	136	136	136	136	136	136	136	136	136	136	136	136
2047	79	77	116	140	140	140	140	140	140	140	140	140	140	140	140
2048	80	79	117	144	144	144	144	144	144	144	144	144	144	144	144
2049	82	80	118	148	148	148	148	148	148	148	148	148	148	148	148
2050	83	81	119	152	163	218	412	386	426	488	670	1 015	1 136	1 663	4 260

DistributedSolar PV 2050 Projections



Concentrated Solar Power 2050 Projections



Annex D: Model Expanded Results

SHEET NAMES	U-PV ADPTION PROJECTION FROM SCENARIO										Total Emissions Reduction	Average Abatement Cost 2020-2050	Lifetime Operating Savings 2020-2050	Cumulative First Cost 2015-2050			
	U-PV Functional Units in 2020	U-PV Functional Units in 2050	TAM 2020	TAM 2050	U-PV Adoption Share - Year 2020	U-PV Adoption Share - Year 2050	%	%	TWh	TWh							
Run 1	77	130	3,255	3,732	2,38%	3,49%	0,89	4,52	58,08	105,79	Based on IEA 2eC Scenario 2017						
Run 2	76	127	3,255	3,732	2,33%	3,41%	0,87	4,66	56,06	102,85	Based on Sven Teske 5°C Scenario 2019						
Run 3	87	185	3,255	3,732	2,66%	4,97%	1,57	4,28	94,94	155,59	Based on IEA Current Policies Scenario 2019						
Run 4	77	142	3,255	3,732	2,38%	3,80%	1,05	4,82	64,74	114,94	Based on JRC Baseline Scenario 2018						
Run 5	81	238	3,333	5,415	2,43%	4,39%	1,70	4,73	117,72	184,66	Based on JRC Diversified Scenario 2018						
Run 6	87	256	3,333	5,415	2,61%	4,72%	2,07	5,99	133,33	203,61	Based on IEEJ Advanced Technologies 2019						
Run 7	97	340	3,333	5,415	2,91%	6,29%	2,72	3,49	183,55	261,42	Based on IEA Sustainable Development Scenario 2019						
Run 8	86	645	3,333	5,415	2,58%	11,92%	3,66	3,56	327,59	409,23	Based on Eureka Scenario 1: 80% Decarbonization 2018						
Run 9	86	605	3,333	5,415	2,58%	11,17%	4,80	3,72	330,12	411,22	Based on Greenpeace Advanced Energy Revolution 2015						
Run 10	141	666	3,480	10,435	4,04%	6,37%	5,28	2,25	366,12	457,28	Based on Oeko Vision Scenario 2017						
Run 11	136	779	3,480	10,435	3,91%	7,45%	7,15	1,91	448,09	518,84	Based on Sven Teske 1.5°C Scenario 2019						
Run 12	141	1,047	3,480	10,435	4,04%	10,01%	7,18	1,78	561,32	627,21	Based on Eureka Scenario 3 95% Decarbonization 2018						
Run 13	162	2,154	3,480	10,435	4,66%	20,60%	17,36	0,07	1,195,22	1,084,89	Based on Shell Sky Scenario 2018						
Run 14	107	1,776	3,480	10,435	3,09%	16,99%	11,07	1,37	934,19	903,96	Based on JRC ProRES Near Zero Scenario 2018						
Run 15	133	7,710	3,480	10,435	3,81%	73,74%	40,87	-1,50	3,988,82	2,634,94	Based on LUT & EWG 100% Renewable Energy 2018						
Run 16	427	6,664	4,162	17,091	10,26%	38,99%	54,72	-2,88	3,764,63	2,521,51	Based on SPE & LUT Leadership 2020						
Run 17	77	146	3,255	3,732	2,44%	3,92%	1,09	4,63	68,45	120,28	Modest U-PV Growth						
Run 18	86	417	3,333	5,415	2,62%	7,70%	2,99	4,33	218,46	299,71	Intermediate U-PV Growth						
Run 19	138	2,181	3,480	10,435	5,33%	20,86%	17,13	-0,11	1,211,60	1,096,20	Ambitious U-PV Growth						

SHEET NAAMES	D-PV ADPTION PROJECTION FROM SCENARIO										Euro / t CO2e	Billion Euro	Billion Euro	Cumulative First Cost 2015 -2050
	TWh	D-PV Functional Units in 2020	TWh	D-PV Functional Units in 2050	TAM 2020	TAM 2050	%	D-PV Adoption Share - Year 2020	%	D-PV Adoption Share - Year 2050				
Run 1	52	83	3.255	3.732	1,60%	2,23%	-0,05	-305,26	-0,36	64,40	Based on IEA 2eC Scenario 2017			
Run 2	53	81	3.255	3.732	1,63%	2,18%	-0,06	-231,20	-1,18	61,18	Based on Sven Teske 5°C Scenario 2019			
Run 3	66	119	3.255	3.732	2,03%	3,18%	0,40	52,23	15,59	91,02	Based on IEA Current Policies Scenario 2019			
Run 4	66	91	3.255	3.732	2,03%	2,43%	0,09	77,51	4,59	48,44	Based on JRC Baseline Scenario 2018			
Run 5	66	152	3.333	5.415	1,98%	2,81%	0,49	51,69	25,19	123,09	Based on JRC Diversified Scenario 2018			
Run 6	67	163	3.333	5.415	2,01%	3,02%	0,72	47,30	31,20	146,37	Based on IEI Advanced Technologies 2019			
Run 7	68	218	3.333	5.415	2,04%	4,02%	1,12	44,30	51,79	211,99	Based on IEA Sustainable Development Scenario 2019			
Run 8	66	412	3.333	5.415	1,98%	7,62%	1,74	42,63	108,84	367,00	Based on Eurelectric Scenario 1: 80% Decarbonization 2018			
Run 9	66	386	3.333	5.415	1,98%	7,14%	2,42	36,32	112,81	380,30	Based on Greenpeace Advanced Energy Revolution 2015			
Run 10	75	426	3.480	10.455	2,15%	4,07%	2,75	35,53	127,64	421,08	Based on Oeko Vision Scenario 2017			
Run 11	92	498	3.480	10.455	2,63%	4,76%	3,95	29,36	163,66	511,71	Based on Sven Teske 1.5°C Scenario 2019			
Run 12	74	670	3.480	10.455	2,14%	6,40%	3,96	31,69	206,54	605,06	Based on Eurelectric Scenario 3 95% Decarbonization 2018			
Run 13	165	1.015	3.480	10.455	4,73%	9,71%	8,68	18,65	370,46	950,08	Based on Shell Sky Scenario 2018			
Run 14	72	1.136	3.480	10.455	2,07%	10,86%	6,46	26,28	358,22	915,18	Based on JRC ProRES Near Zero Scenario 2018			
Run 15	196	1.663	3.480	10.455	5,64%	15,91%	14,47	14,26	614,18	1.388,25	Based on LUT & EWG 100% Renewable Energy 2018			
Run 16	270	4.260	4.162	17.091	6,49%	24,93%	34,36	6,78	1.546,04	2.742,77	Based on SPE & LUT Leadership 2020			
Run 17	60	93	3.255	3.732	1,82%	2,50%	0,09	62,80	4,66	65,66	Modest U-PV Growth			
Run 18	66	266	3.333	5.415	2,00%	4,92%	1,30	43,85	65,97	252,65	Intermediate U-PV Growth			
Run 19	83	901	3.480	10.455	3,23%	8,62%	6,71	23,29	306,79	822,87	Ambitious U-PV Growth			

SHEET NAMES	CSP ADPTION PROJECTION FROM SCENARIO										TWh		%		Gt CO2 (2020-2050)		Euro / t CO2e		Billion Euro	
	CSP Functional Units in 2020	CSP Functional Units in 2050	TAM 2020	TAM 2050	CSP Adoption Share - Year 2020	CSP Adoption Share - Year 2050	Total Emissions Reduction	Average Abatement Cost 2020-2050	Lifetime Operating Savings 2050	Cumulative First Cost 2015 -2050										
Run 1	5	9	3.255	3.732	0.16%	0.25%	-0,01	6,28	-1,85	10,75										
Run 2	6	38	3.255	3.732	0.19%	1.01%	0.13	34,60	-35,71	52,02										
Run 3	7	41	3.255	3.732	0.22%	1.11%	0.17	40,71	-41,83	59,26										
Run 4	7	44	3.255	3.732	0.22%	1.17%	0.27	41,67	-46,51	64,56										
Run 5	9	45	3.333	5.415	0.26%	0.83%	0.29	44,42	-50,19	68,64										
Run 6	6	65	3.333	5.415	0.18%	1.19%	0.34	34,22	-68,05	87,36										
Run 7	18	65	3.333	5.415	0.54%	1.21%	0.75	44,94	-94,33	116,25										
Run 8	8	73	3.333	5.415	0.23%	1.35%	0.49	37,91	-83,18	102,16										
Run 9	19	103	3.333	5.415	0.57%	1.90%	0.97	40,45	-139,81	151,76										
Run 10	18	196	3.480	10.455	0.52%	1.87%	1.40	33,64	-245,91	235,47										
Run 11	25	237	3.480	10.455	0.73%	2.26%	2.25	32,31	-319,05	285,26										
Run 12	12	203	3.480	10.455	0.35%	1.94%	1.81	31,29	-256,06	242,75										
Run 13	9	303	3.480	10.455	0.26%	2.90%	2.08	27,31	-361,93	316,65										
Run 14	28	418	3.480	10.455	0.82%	4.00%	2.98	28,25	-530,26	420,89										
Run 15	37	873	3.480	10.455	1.07%	8.35%	4.90	22,67	-1058,68	707,38										
Run 16	51	1.305	4.162	17.091	1.22%	7.64%	8.60	20,94	-1.617,86	970,32										
Run 17	7	33	3.255	3.732	0.20%	0.88%	0.14	40,30	-31,48	47,17										
Run 18	9	70	3.333	5.415	0.36%	1.30%	0.57	42,24	-87,11	105,72										
Run 19	22	372	3.480	10.455	0.62%	3.55%	2,47	29,43	-461,99	380,04										

Annex D: Content Control in Detail

Most Promising References										Content Control																		
Basic Information										Tech																		
SCE Short Name	SCE ID	Scenario Name	REF ID	Organization	Source Document Name	Hit	Project	EU Solar Market	Tech	Scenario Features	Macro EU Elements	Description of Technology Costs in EU																
						1	2	3.1	3.2	3.3	4	5.1	5.2	5.3	5.4	5.5	5.6	6.1	6.2	6.3	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8
IEA STEPS	1	EA Strated Policies Scenario (EU)	1	IEA	World Energy Outlook (WEO) 2019																							
IEA CFS	2	EA Current Policies Scenario (EU)	1	IEA	World Energy Outlook (WEO) 2019																							
IEA SDS	3	EA Sustainable Development Scenario	1	IEA	World Energy Outlook (WEO) 2019																							
IEEJ REF	4	IEEJ Reference Scenario (EU)	2	IEEJ	IEEJ Outlook 2019																							
IEEJ ATS	5	IEEJ Advanced Technologies (EU)	2	IEEJ	IEEJ Outlook 2019																							
IEEJ CB	6	New Coal PP Ban	2	IEEJ	IEEJ Outlook 2019																							
LUT EWG	7	EWG 100% Renewable Energy (E)	3	LUT & EWG	Fall study Energy Transition Europe 2018																							
IEA RTS	8	Reference Technology Scenario	4	IEA	Energy Tech. Perspectives (ETP) 2017																							
IEA 2DS	9	IEA 2DS Scenario (EU)	4	IEA	Energy Tech. Perspectives (ETP) 2017																							
IEA B2DS	10	IEA Beyond 2DS Scenario (EU)	4	IEA	Energy Tech. Perspectives (ETP) 2017																							
EQ Reform	11	Reform	5	Equinor	Energy Perspectives 2019																							
EQ Renew	12	Renewal	5	Equinor	Energy Perspectives 2019																							
EQ Rivalry	13	Rivalry	5	Equinor	Energy Perspectives 2019																							
IRENA REMAP	14	IRENA REMAP Case (EU)	6	IRENA	Global Energy Transformation (GET) 2018																							
IRENA PES	15	IRENA Planned Energy Scenario (EU)	7	IRENA	Global Renewables Outlook (GRO) 2020																							
IRENA TES	16	IA Transforming Energy Scenario	7	IRENA	Global Renewables Outlook (GRO) 2020																							
IRENA PES-Adj	17	IA Planned Energy Scenario (EU) Adj	7	IRENA / LTS	Global Renewables Outlook (GRO) 2020																							
IRENA TES-Adj	18	IA Transforming Energy Scenario (EU) Adj	7	IRENA / LTS	Global Renewables Outlook (GRO) 2020																							
8		antomining Energy Scenario (EU)	8	CTI	Expect the Unexpected 2017																							
9			9	Eurelectric	Eurelectric Annual Report 2018																							
10			10	ECOPIYS	Energy Transition 2018																							
GP REF	17	GP Reference (OECD Europe)	11	Greenpeace	Energy Revolution 2015																							
GP ADV ER	18	P Energy Revolution (OECD Europ	11	Greenpeace	Energy Revolution 2015																							
19		anced Energy Revolution (OECD I	11	Greenpeace	Energy Revolution 2015																							
GP ER Adj	106	GP Energy Revolution (EU)*	11	Greenpeace / LTS	Energy Revolution 2015																							
GP REF Adj	107	GP Reference (EU)*	11	Greenpeace / LTS	Energy Revolution 2015																							
GP ADV ER Adj	108	Advanced energy Revolution (*)	11	Greenpeace / LTS	Energy Revolution 2015																							
BP ET	20	Evolving Transition	12	BP	BP Energy Outlook 2019																							
BP ME	21	More Energy	12	BP	BP Energy Outlook 2019																							
BP LG	22	Less Globalization	12	BP	BP Energy Outlook 2019																							
BP RT	23	Rapid Transition	12	BP	BP Energy Outlook 2019																							
14 - JRC LCET 2018	24	Shell Sky Scenario (Europe)	13	Shell	Shell Sky Scenario 2015																							
SPE & LUT LAG	25	SPE & LUT Lagardere (Europe)	14	JRC	Cost Development of Low Carbon Energy Tech 2018																							
SPE & LUT LAG	25	SPE & LUT Lagardere (Europe)	15	SPE & LUT	100% Renewable Europe 2020																							
SPE & LUT MOD	26	SPE & LUT Moderate (Europe)	15	SPE & LUT	100% Renewable Europe 2020																							
SPE & LUT LEAD	27	SPE & LUT Leadership (Europe)	15	SPE & LUT	100% Renewable Europe 2020																							
SPE & LUT LAG Adj	110	SPE & LUT Lagardere (EU)*	15	SPE & LUT / LTS	100% Renewable Europe 2020																							
SPE & LUT MOD Adj	111	SPE & LUT Moderate (EU)*	15	SPE & LUT / LTS	100% Renewable Europe 2020																							
SPE & LUT LEAD Adj	112	SPE & LUT Leadership (EU)*	15	SPE & LUT / LTS	100% Renewable Europe 2020																							
16			16	Forme Blank	Solar's Future is Inevitable: Energy 2020																							
17			17	Science	Terawatt-Scale Photovoltaics: Transform Global Energy 2020																							
18			18	CS	CS Energy Outlook 2020																							
WEC LUT	28	WEC Modern bas (Europe/EU)*	19	WEC	World Energy Scenario 2019																							
WEC Synch	29	WEC Modern Synch (Europe/E	19	WEC	World Energy Scenario 2019																							
WEC Rack	30	WEC Modern Rack (Europe/EU)*	19	WEC	World Energy Scenario 2019																							
20 - Under the Hood	20	Under the Hood	20	Elevance Energy Journal	Looking Under the Hood																							
21			21	McKinsey	Climate math: What a 1.5-degree pathway would take																							

Most Promising References				Content Control																									
Basic Information				EU Solar Market			Tech			Scenario Features			Macro EU Elements			Description of Technology Costs in EU													
SCE Short Name	SCE ID	Scenario Name	REFID	Organization	Source Document Name	1	2	3.1	3.2	3.3	4	5.1	5.2	5.3	5.4	5.5	5.6	6.1	6.2	6.3	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	
22				IEA	World Energy Investment 2020																								
23				WFEF	Fostering Effective Energy Transition 2020																								
24	JRC	Towards Net Zero 2050	24	JRC	Towards Net Zero 2050 in EU Energy System in 2050																								
25	IRENA	IRENA PTC 2016	25	IRENA	Power to Change 2016																								
26	IRENA	IRENA PGC 2019	26	IRENA	Power Generation Costs 2019																								
27	ASSET	ASSET	27	ASSET	Technology Pathways																								
28	IRENA	IRENA Full Solar PV	28	IRENA	The Future of Solar PV 2019																								
29			29	Springer Nature	Exploration of Divergence in EPBT and EROI for Solar PV																								
30			30	Energy Sciences	Assessing the PV Tech Landscape																								
31			31	IRENA	Renewable Energy Market Update 2020-2021																								
32	Eurelet 80%	31	32	Eurelectric	Decarbonization Pathways Full Study Results 2018																								
33	Eurelet 90%	32	33	Eurelectric	Decarbonization Pathways Full Study Results 2018																								
34	Eurelet 95%	33	34	Eurelectric	Decarbonization Pathways Full Study Results 2018																								
35	ECF EUREF16	34	35	European Climate Foundation	Net Zero by 2050 From Whether to How 2018																								
36	ECF Shared Effort	35	36	European Climate Foundation	Net Zero by 2050 From Whether to How 2018																								
37	ECF Demand Focus	36	37	European Climate Foundation	Net Zero by 2050 From Whether to How 2018																								
38	ECF Technology	37	38	European Climate Foundation	Net Zero by 2050 From Whether to How 2018																								
39	JRC Baseline *	38	39	JRC	Global Energy and Climate Outlook 2018																								
40	JRC Diversified Scenario (EU 31)	39	40	JRC	Deployment Scenarios for Low Carbon Technologies 2018																								
41	JRC Div *	40	41	JRC	Deployment Scenarios for Low Carbon Technologies 2018																								
42	JRC ProRES *	41	42	JRC	Deployment Scenarios for Low Carbon Technologies 2018																								
43	JRC ProRES NearZero *	42	43	JRC	Deployment Scenarios for Low Carbon Technologies 2018																								
44	European Commission / JRC	43	44	European Commission / JRC	PV Tech Development Report 2019																								
45	European Commission / JRC	44	45	European Commission / JRC	PV Market Development Report 2019																								
46	European Commission / JRC	45	46	European Commission / JRC	Shielding Crops with PV Panels																								
47	European Commission / JRC	46	47	European Commission / JRC	CSP Tech Development Report 2019																								
48	European Commission / JRC	47	48	European Commission / JRC	Gas for Climate																								
49	European Commission / JRC	48	49	European Commission / JRC	Gas for Climate																								
50	European Commission / JRC	49	50	European Commission / JRC	Decarbonization Pathways 2020																								
51	European Commission / JRC	50	51	European Commission / JRC	Decarbonization Pathways 2020																								
52	European Commission / JRC	51	52	European Commission / JRC	Decarbonization Pathways 2020																								
53	European Commission / JRC	52	53	European Commission / JRC	Decarbonization Pathways 2020																								
54	European Commission / JRC	53	54	European Commission / JRC	Decarbonization Pathways 2020																								
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58	European Commission / JRC	57	58	European Commission / JRC	Decarbonization Pathways 2020																								
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85	European Commission / JRC	84	85	European Commission / JRC	Decarbonization Pathways 2020																								
86	European Commission / JRC	85</																											

Color Legend:

	Contains Specific Solar Power Generation Data Projections at European/EU level
	Contains at least TAM Projections at European level
	Doesn't contain neither <i>Specific Solar Power Generation or TAM Projections at European level</i>
	Cost-Specialized Publications that maybe useful
	Other Special Publications that may be useful
	Geography Issue not solved
	Original Scenario of some enhanced version
Adj	Original data altered due to Geographical Harmonization
*	Original Data for "Solar PV" split into PVu and PVd

Item Description:

(Symbols indicate if publications contain data relative to the following topics)

1 - Historical Data about Electricity Generation	
2 - Future Projection Total Addressable Market	6.1 – Detailed explanation of Regional definition and countries included (Europe/EU)
3.1 – Future Projection Utility Scale PV	6.2 – Population
3.2– Future Projection Decentralized PV	6.3 – Economic Growth & GDP
3.3 – Future Projection Concentrated Solar Power	7.1 – Fixed O&M Costs
4 - Technological Description of Solar Generation Solutions	7.2 – Variable O&M Costs
5.1 –Nuclear Energy	7.3 – Fuel Prices
5.2 –Carbon Capture, Usage and Storage (CCUS)	7.4 – Capacity Factor
5.3 –Energy Storage	7.5 – Lifetime
5.4 –Hydrogen	7.6 – Learning Curves
5.5 –CO ₂ Emissions	7.7 – LCOE
5.6 –CO ₂ Prices	7.8 –Currency of Reference