Market Uptake of Solar Thermal
Electricity through Cooperation

Updated policy pathways for the energy transition in Europe and selected European countries

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ABOUT THE PROJECT

In the light of the EU 2030 Climate and Energy framework, ***MUSTEC- Market uptake of Solar Thermal Electricity through Cooperation*** aims to explore and propose concrete solutions to overcome the various factors that hinder the ***deployment*** of concentrated solar power ***(CSP)*** projects in Southern Europe capable of supplying renewable electricity on demand to Central and Northern European countries. To do so, the project will analyse the ***drivers and barriers*** to CSP deployment and renewable energy (RE) cooperation in Europe, identify future CSP ***cooperation opportunities*** and will propose a set of concrete ***measures*** to ***unlock the existing potential***. To achieve these objectives, MUSTEC will build on the experience and knowledge generated around the cooperation mechanisms and CSP industry developments building on concrete CSP ***case studies***. Thereby we will consider the present and future European energy market design and policies as well as the value of CSP at electricity markets and related economic and environmental benefits. In this respect, MUSTEC combines a dedicated, comprehensive and multi-disciplinary analysis of past, present and future CSP cooperation opportunities with a constant ***engagement*** and ***consultation*** with ***policy makers*** and ***market participants***. This will be achieved through an intense and continuous ***stakeholder dialogue*** and by establishing a tailor-made ***knowledge sharing network***.

Project information	
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FOREWORD

This Deliverable builds on a previous report from the MUSTEC project (Deliverable 7.2) and the Swiss Competence Centre for Energy Research (SCCER, Deliverable 1) published in February 2019. The present report is an updated version of that text, holding the most up-to-date information about the energy strategies of the investigated EU Member States as expressed in the draft National Energy and Climate Plans, and of the Clean Planet for All proposal of the European Commission. In addition, we updated the minority pathways for all cases based on new information made available since February 2019 and on feedback from project-external readers. The Analytical framework and Method sections were not updated but remain the same as in the previoius report, whereas the Results and the Discussion reflect the most recent developments.

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ABSTRACT

In a decarbonised future electricity system, Europe will rely on fluctuating renewable sources, such as solar PV and wind power, to a much larger extent than today. This means that Europe as a whole and each individual country on the continent must increase the availability of *flexibility* options in order to balance the grid. Such flexibility options include dispatchable renewable sources (e.g. concentrating solar power (CSP) with thermal storage), electricity storage, and demand-response.

We start from the notion that the future does not *happen*, but *it is made* by a series of policy decisions between now and then. If this is true, then the electricity system of 2050 is determined by the sum of all policy decisions affecting the power system – the *policy pathway* – in all legislations in Europe until 2050. In this report, we take the first steps towards identifying the potential future role for dispatchable renewables – specifically CSP with thermal storage – as a function of policy decisions that either increase the need for power system flexibility (e.g. fluctuating renewables) or provide flexibility (e.g. storage, dispatchable renewables, flexible demand).

We draw on the energy transition logics framework developed by Foxon and colleagues. This framework poses that the space of possible energy transition pathways is a triangle with three distinct policy logics in its corners: a state-centred logic, in which the central government leads or carries out the transition; a market-centred logic, in which the government sets the framework but leaves all other decisions to market actors; and a grassroots-centred logic, in which the transition is carried out locally with the resources available to each community. Any transition strategy will consist, in some constellation, of policies from these corner.

We investigate policy strategies in France, Germany, Spain, Italy, Switzerland and of the European Union as a whole. For each case, we define one *dominant pathway*, consisting of currently valid, implemented policies of the current (or newly resigned) government. In addition, we identify up to three *minority pathways* for each case, describing the energy policy visions and strategies of parties that are currently in opposition but could form a government in the future. For each case, we identify pathways representing each of the three logics, both in narrative form and as a set of 41 quantitative variables affecting the need for and provision of power system flexibility.

This report is a primary data source for the power system modelling in the MUSTEC project. This modelling will happen in 2019 and 2020, and will bring detailed, quantitiave insights of how the potential role for dispatchable renewables is affected by energy policy decisions. However, from the data we have derived here, we can draw a number of conclusions.

We show that all countries and the EU as a whole seek to strongly decarbonise their power systems, as a key part of economy-wide decarbonisation efforts. Some countries have plans that would suffice to fulfil the European (Union and national) commitments under the Paris Agreement: net-zero emissions, mainly or exclusively based on renewables. We also show that all countries seek to vastly expand intermittent renewables, which will trigger a greatly increased need for flexibility. However, this is not reflected in the policies we analysed: no pathway, dominant or minority, is specific on how they want to provide flexibility, especially not at the scale and pace needed. This problem will be exacerbated as the climate targets are tightened and fossil fuels – first coal and lignite (mainly in the 2020s) and later gas power (especially in the 2040s) – are phased out: once this happens, the European power system(s) will lose much of its current flexibility, and unless other, carbon-free flexibility options are expanded, it will be increasingly difficult to maintain power system stability.

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1 INTRODUCTION

The European electricity system is changing, both rapidly and profoundly: the climate commitment under the Paris Agreement requires the electricity supply to become completely carbon-neutral by mid-century (IPCC, 2014, 2018a; Patt, 2015). This is a very far-reaching shift of the way electricity is generated and, possibly, consumed: a transition is far more than an adaptation of an existing system – it is the reconstruction of an entirely new system, adapted to the needs of the new technologies and practices (Geels *et al.*, 2017). The transition to a decarbonised power system in Europe is full of unknowns, regarding how to achieve decarbonisation, how to manage a future decarbonised electricity system, and who is going to make the relevant decisions. Some things can however be known already now.

First, any decarbonised electricity future in Europe will be based mainly on renewables, as the other low-carbon options – nuclear power and fossil fuelled power with carbon capture and storage (CCS) – face problems both with costs and public acceptance (EASAC, 2013; GCI, 2015; IAEA, 2015; Metz *et al.*, 2007; Vattenfall, 2014; WNN, 2015a, b, c). The potential for renewable power is sufficiently large, both in Europe as a whole and in every country in isolation, to cover 100% of the demand (Tröndle *et al.*, 2019). We also know that most of that renewable power will be fluctuating, since wind power and solar photovoltaics (PV) are the most mature, lowest-cost technologies available – and as these are the by far largest renewable energy resources available in Europe (IRENA, 2018; IRENA & EC, 2018).

This means that a key challenge for the European energy transition will be to find ways to handle large shares of fluctuating supply – to make the remainder of the system flexible enough to remain stable, and preferably at a reasonable cost. There are many possible ways to achieve this, at least in theory. Such flexibility options include demand-side changes such as making demand flexible and increasing consumer price-responsiveness, and infrastructure adaptations, such as new transmission lines. Increasing flexibility could also mean the large-scale expansion of storage, both decentralised (e.g. batteries) and centralised (e.g. pressurised air storage). Finally, a key measure to increase the level of flexibility in the power system is a targeted expansion of dispatchable renewables, including concentrating solar power (CSP) with thermal storage.

Second, the national power systems in Europe are becoming increasingly integrated, driven both by the development of an internal European power market and by techno-economic efficiencies of sharing capacities across national borders. As long as the Union remains intact, this process is unlikely to be reversed, especially as the internal market is the core rationale and the glue of the European Union. Further, as increased transmission over large distances is a potential key balancing measure for fluctuating renewables, their expansion is an emerging driver for system interconnection that is likely to gain additional importance over time.

This means that both electricity policy and the technical electricity system are increasingly europeanised: national decisions are not the only determinant, and sometimes not even the primary one, of a country's electricity future. Instead, decisions made in Brussels limit the possible decision space for national policy makers and decisions made in neighbouring countries may have great repercussions in one's own country as well. Consequently, the continental power system trajectory is largely determined by the sum of decisions made at especially the European and Member State levels.

In the MUSTEC project, and hence in this report, we investigate the potential future need for and role of dispatchable renewable power sources available in Europe – in particular CSP equipped with thermal storage. We deviate from the mainstream approach of letting energy models search for cost-optimal futures and instead assume that the (electricity) future is the sum of (electricity) policy decisions made between now and then. The future does not "happen", and it is not the result of economic "laws" – it is made by conscious steps taken by human actors, the actions of whom are guided by their collective beliefs and perceptions. Hence, we generate data – which will subsequently be fed into the modelling framework in the MUSTEC project consortium – describing the *policy pathways* of a set of European countries. These policy pathways consist of all (actual or possible) near- to mid-term policy decisions that affect the need for power system flexibility, either by increasing it (e.g. more fluctuating renewables) or reducing it by providing flexibility (e.g. dispatchable sources, storage, interconnections). Each pathway is centred around a certain logic – a worldview, or belief about the type of policies that are (to its proponents) acceptable and beneficial, leading to a desired type of electricity future.

We analyse current and potential future policy decisions in the large western EU countries (Germany, France, Spain, Italy) as well as of Switzerland (as the home of much of Europe's dam hydropower capacity and a key actor for dispatchable renewables) and of the European Union, and bundle them into sets of policy pathways which describe possible trajectories of each country and the EU as a whole. These pathways will be a central data input for the modelling frameworks and shape the scenario construction with the ultimate aim of identifying what the potential role for dispatchable CSP is and on which specific policy decisions this role depends.

2 ANALYTICAL FRAMEWORK

2.1 The use of models in energy policy analysis

The energy transition is an enormously complex matter, with high stakes and a need for urgent decisions. The tool for analysing our energy transition options has been and remains modelling, in particular power system optimisation models. These models have emerged in parallel with the rise in computing power, and are today capable of highly sophisticated techno-economic analyses with high temporal and spatial resolution.

These models provide valuable insights of the space of possible futures and can bring knowledge about trade-offs between different strategies or decisions. For example, we today know that a completely renewable electricity future is technically possible and not necessarily very expensive, in Europe (EC, 2011; ECF, 2010), and single countries (e.g. Denmark (Lund & Mathiesen, 2009), Ireland (Conolly *et al.*, 2011) and Germany (SRU, 2011).

The models used in the project served by this deliverable are part of this literature and have been used to investigate policies and strategy options for high-renewables futures in various geographical settings. For example, *Calliope* has been used to show that high- or all-renewables futures are possible in multiple countries, including the UK (Pfenninger & Keirstead, 2015b), South Africa (Pfenninger & Keirstead, 2015a), Switzerland (Diaz Redondo & van Vliet, 2015), the US and China (Labordena & Lilliestam, 2015). The *Green-X* model (used in MUSTEC) has been used in a large number of EU-funded projects to simulate the effects of different European renewable energy policy choices (e.g. (del Río *et al.*, 2017; Resch *et al.*, 2013)). In particular, Green-X has often been used in conjunction with the *HiREPS* and/or *Enertile* models (both used in MUSTEC), giving insights regarding policy instruments and support (Green-X) and the effects on the physical power system (HiREPS and Enertile) in different contexts, from the national (e.g. Austria (Resch *et al.*, 2017)), to the European Union scale (Held *et al.*, 2018), and cooperation between the EU and neighbouring countries (Resch *et al.*, 2015; Welisch *et al.*, 2016).

Although they differ in the details, state-of-the-art modelling frameworks (including Calliope and Green-X-HiREPS/Enertile) have in common that they seek the least-cost electricity future fulfilling a set of boundary conditions, often a carbon constraint and a system stability criterion (Ellenbeck & Lilliestam, 2019). This optimum marks the lowest possible cost, but can never be achieved in reality, as the models do not include in a rigorous way the "uncertainties" of the future, such as future technology cost and performance trajectories. Hence, the projections coming out of optimisation models do not well represent the actual development (Trutnevyte, 2016). In the past, models have in particular underestimated the growth of renewables (Trutnevyte *et al.*, 2016), as they have consistently underestimated the dramatic reduction in cost of wind power and, especially, solar PV. For example, Creutzig *et al.* (2017), note that past model runs have vastly underestimated the increase of solar PV; after feeding their Integrated Assessment Model REMIND with "recent price information" they find that solar PV could, *in fact*, supply 30-50% of the world's electricity by 2050.

2.2 Pathways: the sum of all decisions between now and then

We believe that economic optimisation is not sufficient to understand how and why the electricity system develops, and why a future looks the way envisioned. In particular, we reject the link of cost and expansion as the main determinant of future system properties, that is central in optimisation models (Creutzig *et al.*, 2017; Ellenbeck & Lilliestam, 2019). In the past, cost has not been a main determinant of the uptake of renewables: if it were, then all countries – as they experience similar technology cost – would have similar shares of renewables, and they do not. Arguably, if cost were the determinant of uptake, there would be no renewables in Europe at all, as they were (and sometime still are) more expensive than their conventional competitor technologies. Instead, what has determined uptake was the presence of an effective support policy and its level of ambition (Grubb, 2014; Patt, 2015).

Further, we question the usefulness of pure optimisation studies, as we reject the absence of humans and their values, beliefs and agency in optimisation models. Past model runs have missed the vast expansion of renewables – not only because they have overestimated their cost but because they have underestimated their political traction and societal attractiveness, resulting in ambitious support schemes in countries around the world.

Instead, we agree with Hughes *et al.* (2013): "technologies and technological systems are evidently not autonomously self-assembling – *they are the result of sequences of actor decisions*" [emphasis added], and these decisions may or may not be cost optimal. In this view, a decision is made because a group of actors deem it to be the *best* option, and "best" goes far beyond its effect on the total electricity system cost and includes a wide range of normative, subjective and discourse-driven views (Ellenbeck & Lilliestam, 2019).

We therefore assume that the future is the sum of all decisions made between now and then, so that the technological power system co-evolves with the social and political systems (Geels, 2002; Geels *et al.*, 2016). For example, it is not correct that a technology has a particular cost or cost trajectory which it will follow: innovation and improvements will be strongest in the technologies we chose to support, and thus the future cost of, say, wind power or PV will be made by our decisions. In this way, the future is not "uncertain", as is the common view in the modelling community: the future is unknown, because it will be defined by not yet made decisions.

In this report, we use the concept of *policy pathways*, which allows us to view the future as the cumulated outcome of adoption and (successful) implementation of sequential sets of policy decisions that influence a particular socio-technical system. In our view, the future is not uncertain – it has just not yet been made. Current, past or future policy decisions may or may not be cost-optimal, or even useful, but they happen, as the dominant political force in a jurisdiction deems it appropriate at a point in time, addressing a problem that the dominant policy coalition viewed as relevant at that time. What that coalition views as pertinent and worthy of reform depends both on hard facts (e.g. whether the energy system is stable) but also on landscape factors (Geels, 2002), especially ideological factors exogenous to the energy system (e.g. fundamental views on market vs. state, economic efficiency vs. equity, etc.). Thus, decisions may be inconsistent, either over time (e.g. before and after a government shift) or across countries (e.g. France may decide to expand nuclear power whereas Germany abandons it).

Figure 1 highlights how each policy decision is a branching point that creates new potential pathways (Foxon *et al.*, 2013b; Hughes *et al.*, 2013). The future socio-technical transition unfolds as a function of the decisions taken at each point in time, and the socio-technical regime at each point in time is the sum of all policy decisions that preceded it. Because there are so many possible decisions, and as each decision leads to the possibility for further decisions, there are impractically many pathways from now (2018) to very different future regimes in, for example 2020, 2030, 2040, and 2050. A key part of this work thus aims to reduce the number of possible pathways to make meaningful analysis possible (see section 2.3).

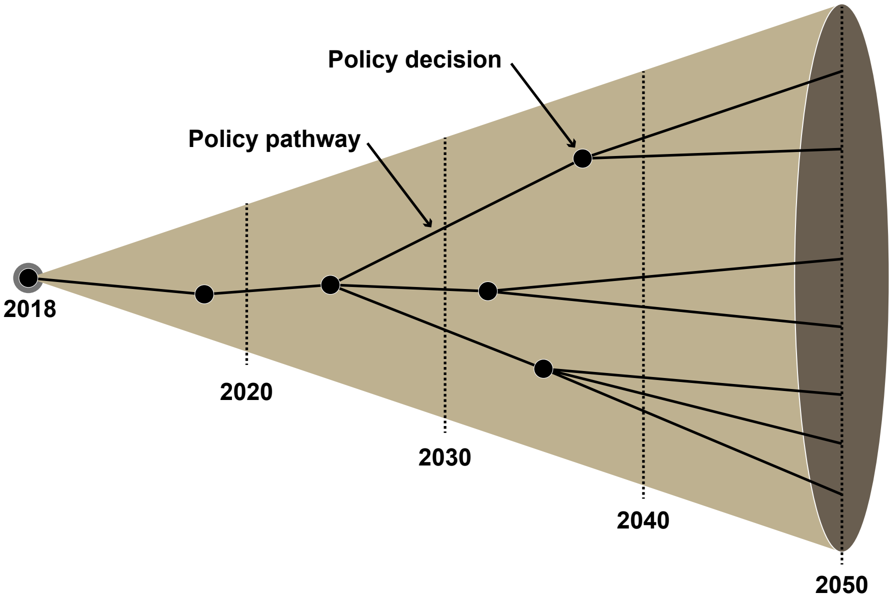

Figure 1: Policy pathways: the sum of policy decisions between today and the target year. Adapted from DENA (2017).

The energy transitions policy pathways require analysis of numerous decisions addressing a multitude of challenges, ranging from political and social to economical and technical ones. One particularly thorny challenge of the energy transition concerns the secure integration of large shares of fluctuating renewables (Grams *et al.*, 2017a; Pfenninger *et al.*, 2014a; Pfenninger *et al.*, 2014b), and this is the challenge we are investigating in this report.

These fluctuations appear on all time scales, from seconds/minutes (e.g. a dip in local PV generation as a cloud passes by) to hours (e.g. the wind dies down after the passing of a weather front), days/weeks (e.g. a lock-down of large-scale weather patterns) to seasonal (e.g. less solar power in winter than summer). There are many approaches to integrate fluctuating renewables, ranging from the addition of large amounts of electricity storage (Safaei & Keith, 2015a; Schmidt *et al.*, 2017) to demand-side management (Aryandoust & Lilliestam, 2017; Paulus & Borggrefe, 2011) and reinforcing the transmission system to effectively span continents or more (Rodríguez *et al.*, 2014; Zickfeld *et al.*, 2012). Another approach – the one in focus of the MUSTEC project – is to add further dispatchable renewable power, such as CSP with thermal storage or dam hydropower/pumped hydro, to fill in the gaps created by fluctuating sources.

Consequentially, we do not generate policy pathways to describe general possible power system futures: as we are interested in the effect of specific policy decisions on the future role of dispatchable CSP and hydropower, we focus only on decisions that have a direct effect on power system *flexibility*, which we define as the ability of a power system to maintain stability at all times when exposed to fluctuating supply and demand (ECF, 2010; Poncela *et al.*, 2018). Our pathways are thus made up of all policy decisions that affect the flexibility of the power system, either by increasing the need for flexibility (e.g. adding fluctuating generation) or providing flexibility (e.g. by adding dispatchable carbon-neutral generation) (see section 0). In this, we refer to especially technologies (e.g. CSP with thermal storage, dam hydropower, or batteries) or institutional changes (e.g. price-responsiveness of customers, enabled by new market designs).

In this, we turn the mainstream optimisation approach on its head and explore the implications for technology, in this case the need for flexibility to be supplied by dispatchable CSP or hydropower, of specific policy decisions. Further, by basing the policy pathways on concrete, near- or mid-term policy decisions, we will identify which specific decisions increase or decrease the possible role for dispatchable CSP and hydropower expansion in Europe, where there are trade-offs between particular decisions, and we will be able to describe *why* and *how* each policy pathway develops based on what policy-makers decide. By linking the pathways with subsequent modelling work, we can additionally show the techno-economic effects of single decisions. The answers to such issues will contribute to decision-making processes across, especially as they are closer to the decision-making process than the more common optimisation and depiction of cost-optimal futures.

2.3 Electricity policy rationales

The ultimate complication of the energy transition is that there is more than one possible (normative) aim, and there is more than one possible way to reach each vision. The preference of an actor, or a group of actors, is a matter of norms, interests, beliefs and worldviews. These factors all affect the problem definition, possible solutions and what is perceived as the most desirable end-state of the power system; what is "best" or "optimal" is thus a subjective matter (on the individual level) or a discursively shaped issue (on the group level) (Ellenbeck & Lilliestam, 2019). Very many – if not infinitely many – different futures can be envisioned, making it impractical to assess the effects on the need for dispatchable renewables of all of them. To make this task possible and meaningful, we draw on two theories describing multiple rationalities and their effect on policymaking.

2.3.1 Cultural theory

Cultural theory (CT) argues that every policy debate is characterised by four fundamentally different *rationalities*, or ways to view the world. This is based on differences in how humans perceive human-human and human-nature interaction and explain the differences in what different individuals see as a problem and what is the best way to solve it (Thompson *et al.*, 1990). CT arranges these worldviews along two dimensions: the *grid*, describing the degree to which rules and external authority determine actions, and the *group*, describing the *we*, or the degree to which commitment to a group decides actions, see Figure 2 (Scolobig & Lilliestam, 2016). Developed in anthropology, the classification of cultural theory has been tested and used also for climate policy (e.g. (Verweij & Thompson, 2006)) and energy policy (e.g. (Thompson, 1984; West *et al.*, 2010)).

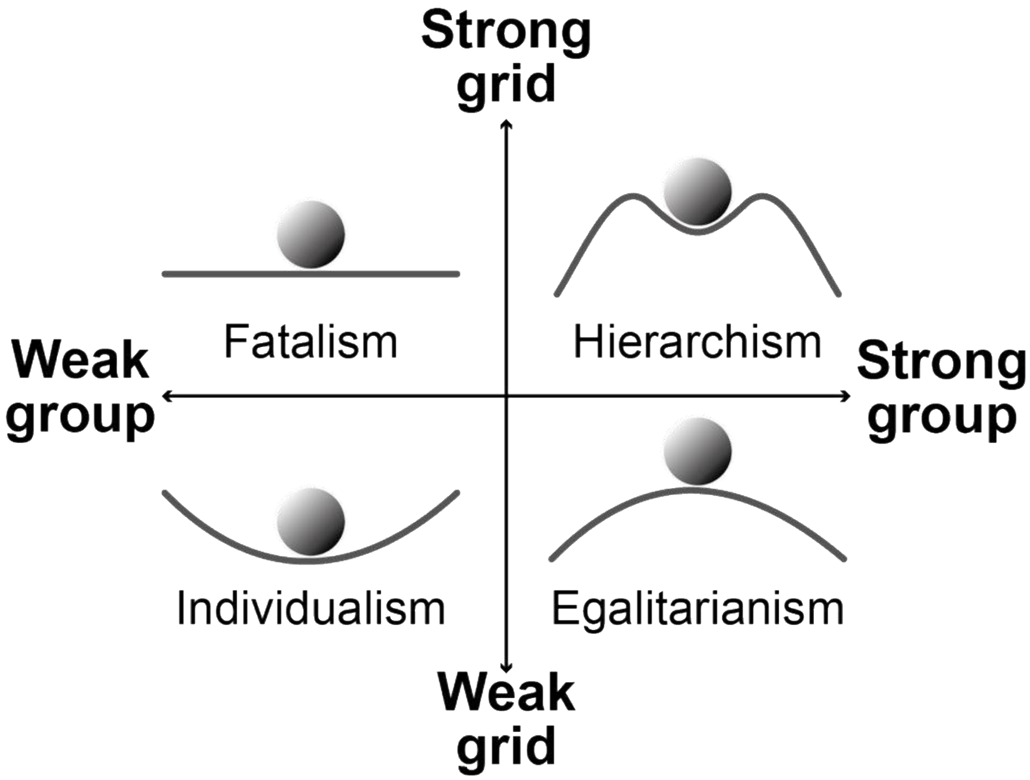

Figure 2: The four rationalities of Cultural theory and their views on nature based on (Thompson et al., 1990; Verweij et al., 2006). Figure adapted from Schmitt & Hartmann (2016).

Fatalists see the state of the environment as uncertain. For them each state of nature is equally precarious and (un)desirable and they have a strong feeling that "nothing I can do matters". Hence, they have no agency in solving environmental problems, because they feel that solving global problems like climate change is futile.

Hierarchists understand nature as tolerant to human interventions within the understanding of science. For them, nature is stable within (known, or at least knowable) boundaries, and will remain stable unless it is pushed too far from its equilibrium state. Hence, hierarchists perceive that nature can be controlled, so that they acknowledge planetary boundaries and become active to stop their violation. Decision makers with this logic aim to solve problems by command and control policies. They prefer technocratic decision-making that goes linearly from a problem to the implementation of a solution, relying on expert opinion and stringent regulation. To solve climate change they propose setting strict sector specific detailed prescriptions that are realistic improvements.

Individualists see the environment as the building blocks of human ingenuity. They emphasise that nature is highly resilient and always changing. As nature will adapt to new conditions, humans should create the conditions that best fit their needs. Often, individualists highlight the potential positive aspects of climate change and want to take the benefits from burning fossil fuels into account to come up with an optimal level of pollution (Nordhaus, 2013). Decision makers want to rely on emergent entrepreneurial solutions that humans were always been able to conceive when phased with problems. They argue that markets would be best suited to solve environmental problems.

Egalitarians seek to solve problems by fundamentally rethinking the relationship of humans with each other and nature. They perceive that nature is fragile and fundamentally unstable, and that humans could lose the natural support systems they rely on for their survival. They see climate change as the consequence of a fundamentally wrong way of treating nature and other humans: as all environmental problems are caused by our immoral and unsustainable way of life, it is the way of life that needs to be changed. Egalitarians rely on community solutions emphasising equality and drawing on the local assets and resources of each individual community.

Cultural theory states that there are two types of policy solutions: elegant ones, which are optimal from the perspective of one of the rationalities but ignores the needs and views of the others, and clumsy solutions, which are suboptimal to all rationalities but because of their compromise nature, they hold elements of all rationalities and are thus non-objectable to all (Lilliestam & Hanger, 2016; Verweij *et al.*, 2006). Whereas elegant solutions are the ones proponents of each rationality advocate and strive for, such solutions are unlikely to be implemented and, if they are, successfully sustained over time: the opposition will eventually be too strong. Only the clumsy solution, says Cultural Theory, will be feasible, as it serves the need of all groups, and not just of one.

Cultural theory is very helpful to understand the reasons for policy conflict, directing our attention away from the surface to the deeper disagreements on where to go and how to do it. It however gives less guidance as for how the socio-technical system needs to change, and how to achieve that; it also give little specific guidance for changes in particular policy subsystems – in our case, the electricity transition (Scrase *et al.*, 2010). Our aim is to identify concrete policy decisions following different ways to view the world, in the different European cases. Although CT tells us that also the energy policy debate will be based on three (active) different rationalities, it is too remote from the energy field to guide us to identify them. Further, CT is vague on just how a clumsy solution emerges – it seems to just happen, as the result of active deliberations among all involved actors (Scolobig & Lilliestam, 2016) This is problematic for our purposes, as it offers little help when observing actual policies: we cannot know who negotiated which solution in which context, to what end. Hence, we cannot know what a policy is a compromise for, and we cannot know what the original standpoints were – and finding out the maximally different feasible policy positions is our very aim. Hence, we will draw on CT in this work, as the theoretical (and empirically verified) basis for plural rationalities in policymaking, but we need another framework to support our energy policy analysis, and to identify feasible but maximally different policy options.

2.3.2 Energy transition logics framework

The concept of energy transition logics was developed in the *Realising Transition Pathways* project in the UK around 2010. This theory says that there is an energy transition policy space within which all policy decisions will be located. The space is spanned by three corner points, each marking the complete dominance of one logic and one set of actors for governing the energy transition: the market-centred, the government-centred, and the grassroots-centred logic.

The logics concept is based on the multilevel perspective on sociotechnical transitions (Geels, 2002; Geels *et al.*, 2017) and complements it by adding explicit normative governance choices, thus helping to close on of the MLP's open flanks (Geels *et al.*, 2018; Hughes, 2013; Smith *et al.*, 2005). It is also, although it is based on an entirely different theoretical setting, very similar to CT in that it finds multiple possible rationalities for governance – and, importantly, the logics it finds (see below) are very similar, but energy-specific, to the rationalities of CT (Lilliestam & Hanger, 2016;

Scrase & Ockwell, 2010). We thus base our study on both theories, where especially CT gives the theoretical foundation of multiple rationalities, whereas the energy transition logics are particularly useful for the operationalisation of our study.

For their energy policy pathways, Foxon and colleagues cluster possible transition paths according to their governance, asking

- Who should govern the transition?
- Based on what governance principle?
- Who should carry out the transition and decide what is the best options?
- Which key technological, infrastructural, and institutional changes are needed to realise each pathway? (list adapted from Foxon *et al.* (2010a); Foxon *et al.* (2013a)).

They find that this gives three ideal-typical but empirically defendable energy transition policy pathways, each based on a distinct governance logic (Foxon *et al.*, 2010a). The resulting three logics span a *policy space*, within which all energy transition decisions are located. We describe these below, based on Foxon (2013), Foxon *et al.* (2013a), Foxon *et al.* (2010a), and Foxon *et al.* (2010b).

The *market-centred logic* (corresponding to the individualist rationality of CT) envisions a future in which the market decides how to best achieve high-level policy targets, within a high-level policy framework. In a sense, policymakers are to define the goals – likely a climate target, and possibly a security/system stability target – and set a level playing field for all, and then get out of the way: the market actors will know how to achieve these in the most efficient way without further government interference. In this logic, it is not important who owns generators: there is competition between incumbents and new entrants, and the companies that offer the best and most efficient solutions will prevail. Yet, new entrants will only succeed if they are able to break into a market dominated by (usually) financially strong incumbent, for example with new business models or new, valuable technology. Transmission – which remains a natural monopoly and a part of the high-level policy frame – is a strong focus in this logic: as a market approach emphasises economic efficiency, trade between regions and countries is encouraged, leading to the expansion of the transmission system. For a decarbonised future in Europe, onshore and offshore wind are likely the cheapest technologies, further emphasising the need for a transmission system expansion to reach the best generation sites, which are often far away from demand centres.

The *state-centred logic* (hierarchical rationality) leads to a future in which a strong state dominates the energy transition, both by setting high-level, typically technology-specific targets and by directing energy sector actors on how they are to be achieved. Possibly, the state itself (or state-owned companies) is the main actor carrying out the transition. This favours large-scale generation, as it suits the centralised decision-making style, and as it favours short-term economic efficiency. Consequentially, new entrants have a hard time, as they are often not financially capable of large-scale, often gigawatt-scale, investments. New technologies, including currently immature ones, break through only to the extent that the state decides to expand them, either by building them itself, or by implementing targeted support for each desired technology, to the desired amount of capacity/generation. The emphasis on large-scale generation, such as wind power, leads to a strong expansion of the transmission system, including between countries, which may trade with each other and share capacities to make the system more stable and robust.

The *grassroots-centred logic* (egalitarian rationality), in contrast, emphasises equality and the role of citizens in a bottom-up transition: as the local citizens know best what their region and their community needs and can provide, they need to decide how they can reach the overarching policy goals, including climate targets. In this logic, the people will both govern the transition and be the main agent to carry it out, especially in small-scale generators close to the demand, or via bottom-up, citizen-driven investments in generators elsewhere in a larger market. This favours small-scale generation, geographically and politically close to the consumers, and a strong role for prosumers. Large-scale assets, such as centralised generation and transmission, will still exist, but is not encouraged; in more radical grassroots futures, equality is to be achieved through the replacement of the big actors of the existing energy system, and the removal of all centralised assets and structures is a key instrument to achieve this (Lilliestam & Hanger, 2016). New technologies appear if they are well suited for a particular (organisational and natural) environment. The emphasis on small-scale, distributed generation creates a need to overhaul the distribution grid, in particular by making it smart and capable of handling power flow in two directions, and across voltage levels.

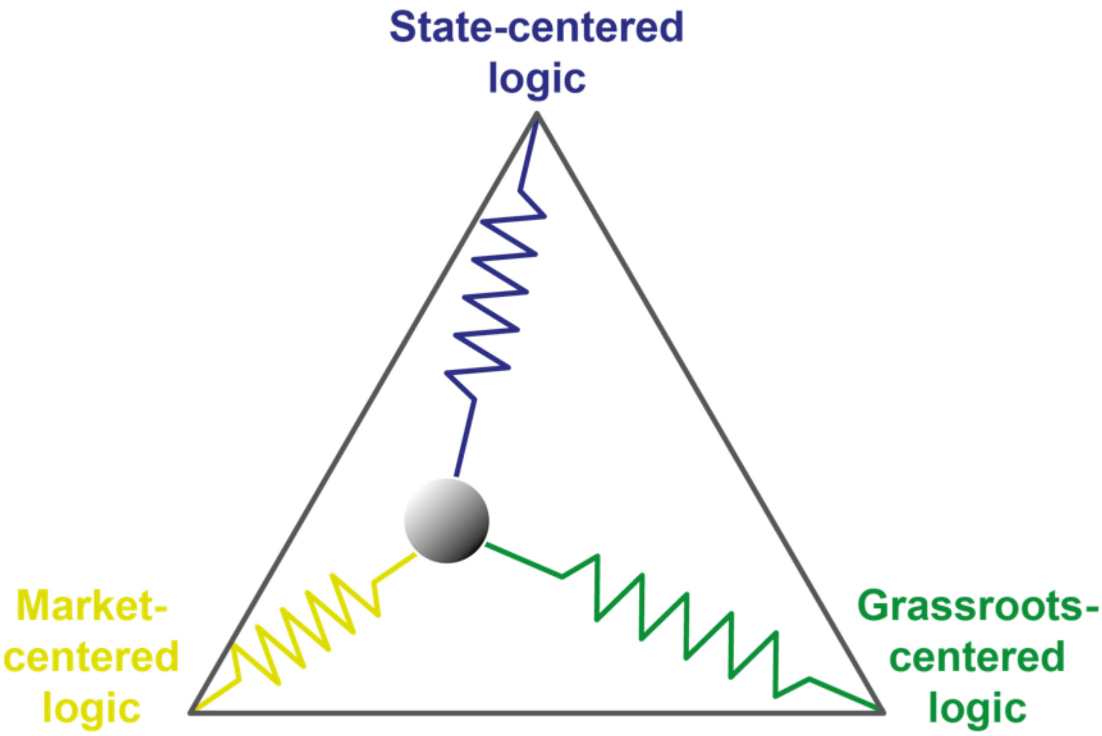

Figure 3: The policy space of the energy transition logics framework. Adapted from (Foxon, 2013).

Every policy or strategy holds elements of at least one of these fundamental logics; the policy, symbolised by the dot in Figure 3, is the result of a tug-of-war between proponents adhering to each of the three logics. Energy policy making is a continuous struggle between coalitions, which seek to change policies they perceive as insufficient or misdirected by pulling the centre of gravity of each policy decision towards their corner of the policy space ((Foxon, 2013), see also (Sabatier, 1988)). In that sense, each policy decision reflects the power balance between coalitions of actors adhering to the logics of each corner of the policy space. This means that if governments and political majorities change, the direction of a country's energy policy may also change, if the new and the old governments adhere to different energy transition logics. In such cases, the policy pathway of a country could suddenly bend and take an entirely new direction.

Further, and of key importance for this report, it means that if we can define a "pure" version of a pathway completely following each logic, we can also define a policy space, in which all possible policies can be found. We do this, for maximally different feasible pathways, as described in section 0.

Our work thus builds on the work of Foxon and the Realising Transitions Pathways project, and we follow a similar aim – to inform new thinking among policy-makers, industry and civil society about the *effects* of radically different energy policy approaches and decisions. We diverge from the Foxon's approach, as we do not define the policy pathways in interaction with stakeholders, but base the pathways on the actual or suggested policies of political parties: hence, we do not generate ideal-typical pathways, but empirically based ones, based on concrete and realistic policy decisions. Further, we do not create general power system pathways, but focus only on the flexibility of the system, and in particular on the need for dispatchable renewable generation as a function of all other directly relevant policy decisions. Our analysis is broader and looks at Europe as a whole as well as a set of European countries, and the interactions between policy pathways in different places.

Finally, this report is to be seen as the first part of two: the results described here will be used as input data for two energy system model frameworks, in which the system impacts – e.g. stability and cost – of the observed policy decisions are analysed.

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3 METHOD

In this report, we construct sets of policy pathways for the cases Spain, France, Germany, Italy, Switzerland, and the European Commission, based on the energy transition logics framework of Foxon (2013). We do this for decisions with a direct effect on the need for or provision of flexibility in the power system. For each of the cases, we create qualitative storyline and quantitative data tables for how the climate and energy policy target in each country and in the European Union as a whole was reached, by looking back and telling the story of how the vision materialized, in the past tense from a fictive future in 2050. We do this in three steps.

First, we select representative organisations for each of the ideal-typical logics of Foxon. These representatives are real-world actors, such as political parties or other influential organisations advocating an energy transition proposing a strategy following one of the logics. We do this to tie our analysis closely to actual discourses, thereby making the work empirical, describing issues that are or could be decided – thereby making the analysis more realistic than if we would simply use ideal-typical, theoretical considerations as base. We describe this in section 3.1.

Second, we select the variables of interest – metrics for the most relevant decisions affecting the flexibility of the future power systems in Europe. These metrics are described in section 3.2 and are the same for all cases. These metrics will be a main input for the energy system models in subsequent steps in the MUSTEC project.

Third, we construct policy pathways in both narrative and quantitative form based on what the entities representing each logic in each country state, in terms of quantitative aims and justifications – the story – of the aims and general rules of the transition. There will be three (if possible) pathways for each case: one dominant, currently valid policy pathway, and two minority ones, representing rejected policies or such currently not viable for a political majority; the minority pathways thus represent transition strategies that *could* be implemented as real policies if the political wind turns. This is described in section 3.3.

3.1 Representative organisations for each logic

We base our pathways on empirical observation of representative organisations' view of power decarbonisation strategies and other policies directly affecting the power system flexibility, so as to tie our analysis close to actual (possible) near- to mid-term policy decisions. Policy is done differently in Europe, but all countries have a government consisting of representatives from one or several parties, whereas the other political parties are in opposition. As most countries have a limited number of political parties, and as these parties have typically have divergent views on energy policy (as on policy in general), we base our analysis on their positions. In some cases, one logic is not represented by a political party: in these instances, we instead base the pathways on the position of an influential organisation (e.g. an NGO) with explicit (e.g. organisational) or implicit (e.g. ideological) ties to political parties.

We do the organisation selection in two steps. First, we identify the current government strategy: this is the **dominant pathway**. The parties in government are not eligible candidates for representing the minority pathways, unless the government recently changed, but the energy policy did not yet do so, although the new government intends to do so; in two cases (France and Italy), the dominant pathway is not defined by the current (August 2019) government, but the government positions are included as minority pathways. We identify to which of the three ideal-typical energy transition logics the dominant pathway belongs – or to which one it is closest – based on the governance style of the pathway, as identified by the answers to the four transition logics questions (see section 2.3.2).

Following this, we seek influential organisations that advocate solutions following two other ideal-typical logics or are as near as possible to ground the narratives (and subsequently the quantitative variables, see below) in actual, empirically observable policy positions. These will form the **minority pathways** of each case. Ideally, these organisations are political parties currently not in government; alternatively, a minority pathway can be described by a party that recently formed a government but has not yet implemented its energy policy strategy (France, Italy). A starting point for the search will among green parties for grassroots pathways, liberal parties for market-centred and social democrat and/or conservative parties for the state-centred pathway narratives. In case no such parties exist, if they are not a mentionable political force in a specific case, or if they have no clear energy policy position, we deviate from political parties to nationally influential NGOs and use their position as empirical base for narratives and variable quantification. In some cases (Switzerland, Italy and the European Union), we could not identify strong representative organisations following all logics, and omitted one pathway for each case (see *Representative organisations* subsections in section 0 for more details on the selection for each case).

We make base the pathways on actual, observable strategies in order to define the maximally different feasible – as opposed to maximally different ideal-typical – pathways: we describe the pathways as described by the logics but contextualised by the specificities of the energy policy debates of each single investigated case. This also has the effect that we do not describe the position of every relevant party of each country, and there may be other influential actors with similar positions. Thus, we do not claim to represent the entire energy debate of each country or Europe as a whole, but we do claim to cover the entire energy transition policy space by having one representative for each corner of Foxon's energy transition logics triangle.

In order to acknowledge the recent political shifts in some European countries and the rise of right-wing populists, we will – in the countries where such parties have a substantial share of seats in parliament as well as a clear energy strategy – include their views in a separate policy pathway. This will not be a transition pathway, but rather an update of the existing system: all right-wing populist parties in Europe rejects the goal of climate protection and of a wholesale transition of the energy system; typically, they also reject the idea of a European Union, rejecting policy imperatives and goals from Brussels.

3.2 Variables that affect system flexibility

In a power system largely or completely based on renewables, and especially fluctuating renewables, the system concept of *flexibility* is central. The system flexibility refers to its capability to react to fluctuations, for example due to variable demand, fluctuating supply (on all timescales, from seconds to seasons), or to system malfunctions. Hence, any power system needs to have a certain amount of flexibility to remain stable, but in a system with high shares of wind and solar PV power, also a large share of the supply will fluctuate, increasing the demand for further flexibility. Power system flexibility is provided by measures that increase the possibilities to control (manually or, more commonly, automatically) and adapt the demand to the current and near-term anticipated supply (e.g. demand response schemes), increase electricity storage options, or provide additional dispatchable supply. In the modelling work of MUSTEC, these flexibility-affecting measures – or more specifically, the policy decisions to provide them – are the independent variable, and the role for dispatchable CSP or hydropower and CSP/hydropower trade within Europe to either provide additional flexibility or to do so more efficiently is the dependent variable.

In this section, we define the policy variables that will form the base of the policy pathways, representing decisions to increase (or not) each potentially flexibility-providing or flexibility-demanding measure. The set of policy variables is based on expert opinion – from the modelling teams in MUSTEC and in the ETH Institute for Environmental Decisions (the SCCER JA IDEA modellers involved in the previous report MUSTEC 7.2) – and a literature review (e.g. (Bauknecht *et al.*, 2016; Cochran *et al.*, 2014; DENA, 2017; Huneke *et al.*, 2017; Jansen & Sager-Klauß, 2017)).

3.2.1 Overall targets

Every European country, as well as the European Union as a whole, have targets for decarbonisation, often for decarbonisation of the energy and/or electricity system, and they all have targets for renewable electricity expansion. These targets do not directly affect the flexibility of the system, but they are nevertheless very important for our analysis, for two reasons. First, the climate and renewables targets are key drivers for the changes in the power system, and the main reason why fluctuating renewables are expanded – and hence why the flexibility provision is a problem in the first place. Second, they put limitations on the flexibility options, by first limiting the possible use of fossil fuel as backup (as climate targets tighten), and eventually practically banning it (as climate targets approach 0 emissions, or renewables targets approach 100%).

3.2.2 Intermittent renewables

The key driver for the need for flexibility in future power systems is the expansion of fluctuating (i.e. weather-dependent) renewable power generation, primarily solar PV and wind power. The potential generation of these sources is determined by the current weather, and not by current demand: it is hence supply-controlled, unlike fossil fuel generators, which are demand-controlled.

Onshore wind power is the currently dominant renewable technology in Europe, providing 300 TWh per year , or 10% of the European electricity demand, from over 150 GW of wind turbines (Eurostat, 2017a; WindEurope, 2018). Some countries, notably Denmark (28%), Portugal and Ireland (24% each) rely strongly on onshore wind power (WindEurope, 2018). Wind power has seen a strong cost reduction over the last decades, especially in terms of levelised costs, and recent auction outcomes in Europe are below €0.05 per kWh (BNA, 2018a; IRENA, 2018). The construction of wind parks also faces increasing problems, including public opposition of citizens concerned about the appearance of wind turbines in the landscape. Investment in wind power has attracted both large utilities and small-scale investors and citizen energy cooperatives.

In the last decade there was a push for **offshore wind power**. In 2017, 16 GW offshore wind turbines generated 43 TWh of electricity, or 1.5% of the European power demand (WindEurope, 2018). Although offshore wind power is currently more expensive than onshore, its advantages are higher reliability as winds on sea are more constant and with more advanced technology large future wind resources; consequentially, the installation pace doubled in 2017 compared to 2016. However, building wind turbines at sea requires much more infrastructure and capital than doing so on land, and offshore wind farms are almost exclusively developed by large utilities, which often receive their finance from large institutional investors. Because of their remote location at sea, public opposition against offshore wind farms is often low, but the expansion is instead constrained by the construction of offshore transmission infrastructure (against which there is opposition, both against sea cables and land connections).

Solar **photovoltaic** power (PV) has also grown rapidly in the last decade, now covering about 4% of European power demand from 110 GW of generation assets (EurObserver, 2017a; RenewableEnergyWorld, 2018). Many house owners and farmers installed PV arrays on empty roof areas. As a result of policy reforms, the European PV additions have slowed down in recent years and shifted from decentralised towards centralised units. Accompanying the rapid global growth has been remarkable cost reductions, exceeding 75% over the last decade; the average auction strike price is today below €0.05 per kWh (IRENA, 2018). Photovoltaic does not suffer from the same acceptance problems as wind power, but it is highly fluctuating, with a capacity credit of zero, as PV cannot generate power at night. Other than wind power, solar PV offers many advantages for decentralised generation, including autarky at the building level if coupled with storage solutions.

3.2.3 Dispatchable renewables

The second large group of renewables are dispatchable renewables. There main advantage is that they can be regulated according to demand patterns (largely) independent of the weather, so that they can provide supply-side flexibility equal or similar to that of fossil fuel generators.

Hydropower installations have been used since industrial revolution. They are well understood and there are many hydroelectric dams along large streams, rivers, and creeks. We exclude pumped hydropowerstorage from this category and view that as storage (see below). Hydropower also depends on the weather, but on a much longer scale than wind and solar PV (i.e. days or weeks (run-of-river); seasonal (dam)); whereas run-of-river plants operate at maximum possible load and are an inflexible source of power, dam hydropower can regulate its output according to demand and is considered as dispatchable here. Today there are about 150 GW of hydroelectric generation plants operating in Europe (Eurostat, 2017a), and the potential to increase hydropower generation in Europe is small.

Biomass is the most used source of renewable energy in the EU28 (1306 TWh – 2015) (Calderón *et al.*, 2017). It is mostly used for heating, but also for transport (164 TWh), and to generate electricity (178 TWh) (Calderón *et al.*, 2017). Electricity is generated in two ways, either from cogeneration in CHP boilers (60%) or direct electricity conversion (40%). Both types are independent of the weather, but for CHP plants dispatchability is restricted by heat demand – and that is dependent on the weather, especially on the temperature – as their production is generally heat- and not electricity-driven. There is large variation in the share of CHP vs non-CHP biomass plants in the share among EU countries, mainly determined by the prevalence of district heating systems. In terms of fuel, 12% of biomass electricity is generated from highly dispatchable biogas, while 34% are from the biogenic part from incinerating municipal waste and 51% from solid biofuels (i.e. woodchips) that are used in the CHP plants. A large concern for the future of biomass lies with EU regulation to make sure the sustainability and carbon neutrality of biomass that is used (Bogaert *et* *al.*, 2017), and such considerations (and the related regulations) will have a large influence on the overall expansion trajectory of further biomass applications.

A third source of dispatchable renewable electricity is **concentrating solar power** (CSP). CSP plants use mirrors to concentrate sunlight to generate steam for a turbine (Pitz-Paal & Lüpfert, 2011) and can be equipped with thermal storage, making it dispatchable to the desired degree, practically without affecting the LCOE (Lilliestam *et al.*, 2018). In Europe, the installed capacity is 2.3 GW and has remained constant since 2013, when Spain – where most of these plants are located – ended its support scheme (EurObserver, 2017b). The main advantage of CSP is that it can theoretically generate as much dispatchable renewable electricity as needed, but it must be built in places with high direct normal irradiation – and such places are found in deserts and other arid areas. In Europe, the potential for CSP is large in southern Europe, especially in the Iberian Peninsula, but CSP does not work well (or economically) in other parts. For other parts of Europe, CSP electricity would need to be imported from southern European countries.

3.2.4 Physical and statistical renewables imports

The European Union Member States have the option of importing renewables as a way to meet their renewables targets. This can be done statistically, in which case the importing country buys certificates from the exporting country, and counts renewable power generated somewhere else towards its target. This may also include a joint support scheme, in which case the importing country pays the support to a project in the exporting country, and receives the certificates. So far, the use of these options have been very limited (Lilliestam *et al.*, 2016).

Another possibility is to physically import renewable power. This option has not been used to date, but could become important especially for dispatchable renewables, which have an additional power system value (further than their value for achieving the renewables target).

3.2.5 Conventional generation

Seventy percent of Europe's electricity generation are still based on fossil electricity sources (1440 TWh) (Agora Energiewende & Sandbag, 2018). Most of this generation will need to be replaced with low carbon alternatives to meet the goal of 80-95% decarbonisation by 2050 and all of it must be replaced if Europe is to meet its Paris Agreement obligation (IPCC, 2014, 2018a; Patt, 2015).

In 2017, **coal** was the most widely used fossil electricity source in the EU28 (Agora Energiewende, 2018), providing 21% of the electricity, in about equal shares of lignite and hard coal. The long-term trend of coal-based generation is declining since 2012. There is a divide between Western European countries that are committed to phase out coal and the Eastern European countries that seek to rely on it to a much larger degree. Older coal plants, especially lignite stations, are relatively inflexible electricity sources that cannot rapidly or frequently adapt output to demand; newer coal plants and hard coal-fuelled ones are more flexible.

Natural gas is the cleanest and most flexible fossil fuel source, but it is also the one with the fastest decrease in generation in Europe. In 2017, 639 TWh were provided to the European electricity grid from gas combustion. There is a trans-European gas pipeline infrastructure and caverns can store large amounts of gas, and there are expansion projects both for new pipelines and for new LNG terminals. Currently, natural gas is a main flexibility provider to the European power system; in the future, it is possible that the existing gas infrastructure and power stations will be used in combinations with power-to-gas technologies to feed the current gas power system with climate-neutral gasses.

There is some **oil-based** and **other non-renewable** electricity generation, such as waste incineration that together contributed about 132 TWh of electricity (4.1%) of the European gross generation (Agora Energiewende & Sandbag, 2018). However, the high oil price and significant emissions are reasons that there will likely no oil-based power plants added and waste burning has no large expansion potential.

Carbon capture and storage (CCS) is a group of technologies that could decrease the emissions of fossil power plants by removing a large fraction (about 90%, (Lilliestam *et al.*, 2012)) of the CO_2 from the exhaust and storing it in deep underground geological formations. In principle, CCS could be added to any exiting combustion plant (retro-fit) or integrated into the construction of new plants. Therefore, there was much hope attached to decarbonising the power system with CCS technologies. However, there was a complete halt in CCS demonstration projects in Europe (and worldwide) in the last years, following concerns about who should carry the risk (public or developer) and about the economics of these projects. The international energy agency acknowledges that CCS lags behind expectations – but still maintains that CCS could contribute up to 14% to CO_2 reduction targets by 2060 (IEA, 2017). It is not clear how CCS would affect the flexibility of gas power, but it appears to be a solution allowing Europe to keep gas power as a backup and balancing option also in highly, although not in completely, decarbonised electricity futures.

Nuclear power is the largest conventional source of electricity in the EU. In 2017, it contributed 830 TWh, with about half of that being generated in France (400 TWh). Nuclear generation has decreased by some 10% since 2010, mainly driven by the German nuclear phase-out. There are currently single new reactors under construction in France, Finland and the UK, but costs are high and increasing, and in many countries it faces difficulties with public acceptance. The largest advantage of nuclear power is that it can generate electricity without carbon emissions, but it is more inflexible than fossil fuelled power and current reactor types (including the European Pressurised Reactor) do not have the flexibility to match high shares of renewables (Morris, 2018). The future for nuclear power in Europe will likely be decided in the next decade, when many aging nuclear power stations need to be retired or replaced.

3.2.6 Storage

A way to provide short-term flexibility for high renewable electricity systems is to store excess production of electricity and to use it when demand exceeds the production. These technologies are interesting to shift solar generation to use it at night (Safaei & Keith, 2015b), but also required to store them for longer periods of little renewable resource. Worldwide there were 176 GW capacity of storage installed with the majority (96%) constituted of pumped-hydro, with a minority of 4.4 GW (1.9%) thermal storage mostly in CSP plants, 1.9 GW battery storage and 1.6 GW mechanical storage (IRENA, 2017). With increasing importance of fluctuating renewables, most analysts expects a need for much more storage balance supply on all timescales (IRENA, 2017; Safaei & Keith, 2015b).

Pumped hydropowerstorage has been used to utilise overcapacities of base load plants in the European electricity system, for example shifting baseload nuclear power from night to day. In the EU, there are about 160 pumped hydropowerstorage stations with a cumulative capacity of 47.44 GW (Kougias & Szabó, 2017). The largest installations exceed 1 GW, and some have a storage capacity exceeding 5 GWh (BNA, 2017b). Pumped hydropowerstorage is restricted by geography, as it needs suitable mountainous locations with (the possibility to create) an upper and a lower lake. Hence, the pumped hydropowercapacity is located only in mountainous and water-rich countries, such as Switzerland and Norway, but the potential for further expansion is limited also in these regions (Hohmeyer & Bohm, 2015; Kougias & Szabó, 2017).

Battery storage (BES) and mechanical storage will here be subsumed as **batteries.** They can be either installed at a household level as decentralised storage together with decentralised renewable production or, at a higher grid level as grid scale storage. Batteries provide several benefits to grid including ramp control and frequency regulation within minutes as well as load shift for several hours. In 2017, the largest operational Lithium-Ion grid-scale battery was completed by Tesla in Australia – at 100 MW / 129 MWh (Reilly, 2017), it can provide electricity for 30,000 households for one hour. This is a factor of 50 smaller than the large pumped hydropower storage stations, and even further from supplying a whole country for a day or even weeks: to play a meaningful role, myriads of batteries must be built. Yet, many expect that these types of storage will become essential to deal with increasing volatility and higher/faster supply gradients in a future renewable power system (Després *et al.*, 2017; Schmidt *et al.*, 2017).

Currently, many R&D activities are taking place to develop new long-term storage technologies. To contribute effectively to overcome longer *periods of* little renewable generation, they need to be able to store several TWh of electricity. Large potential is seen in **power-to-X** technologies, that convert the access electricity in times of high renewable resource into hydrogen, methane or other chemical compounds (Hirth & Ziegenhagen, 2015; Jentsch *et al.*, 2014). For example, the production of **wind gas**, where overshoot renewables generation is used for electrolysis to split water into oxygen and hydrogen, is widely discussed. This gas can than later be stored in caverns or further converted into methane, which can also be easily stored in the existing gas storage infrastructure, but the round-trip efficiency to electricity is low (Bailera *et al.*, 2017; Zhang *et al.*, 2017).

3.2.7 Grid expansion: interconnections

The base pillar of a single European electricity market is **interconnections** – transmission capacity between Member States. In addition to enabling the internal market, interconnections are also a key measure to integrate fluctuating renewables: whereas storage shifts electricity supply in time, interconnectors shifts it in space (Rodríguez *et al.*, 2014). To facilitate both functions, the European Commission has set an interconnection target, prescribing that every Member State must be able to transmit 10% of its maximum gross generation to neighbouring countries by 2020 and 15% by 2030 (EC, 2017e). Such interconnection expansions must be coordinated with national grid expansion, and both are coordinated in the European Ten-Year-Network-Development plan (TYNDP), developed every two years by the European Network of Transmission System Operators for Electricity (ENTSO-E, 2018).

Overall grid expansion and cross-border connection can help to mediate long term flexibility issues. With high shares of intermittent generation, it can help to mediate local undersupply, because weather dependent solar resources are independent in different regions, i.e. there is always wind or sun somewhere in Europe (Grams *et al.*, 2017b). Moreover, additional interconnections would allow access to dispatchable renewable electricity imports from other countries (Trieb, 2011). For countries like Germany that have many neighbouring countries, grid integration with neighbours already provides a lot of flexibility. Hirth & Ziegenhagen (2015) showed that the **TSO cooperation** that was introduced in 2008 has reduced the overall need for short term flexibility to be provided by 20 percent in 2015, even though the intermittent generation capacity tripled in the same time horizon. Consequently, projects of common European interest aim at improving the integration between neighbouring countries and are a key focus of the Energy Union (EC, 2017d).

3.2.8 Sector coupling: electrification of further sectors

Another core aim of European and national energy policy is to increase the energy efficiency (EC, 2017f), both by using less energy per generated Euro of GDP (end-use efficiency) and by switching fuel to more efficient ones – in particular, however, through electrification of currently fossil fuel-based sectors, like heating and mobility.

The **electrification of heating** to some extent is in conflict with other efficiency policies foreseeing improved insulation of buildings or the expansion of CHP, so that the degree to which heating is electrified depends on which pathway a government (or the European institutions) chooses. There are several ways in which heating can be electrified, including both direct electric heating (as has been historically common in, for example, France and Scandinavia), which is relatively inefficiency but has the advantage of low investment costs, or heat pumps (as is currently pushed in both Switzerland and Germany), which are much more efficient but also more expensive to build. As all thermal processes, electric heating offers a flexibility potential as they can work with the thermal inertia of buildings and heat (to some degree) depending on current power availability and price (Aryandoust & Lilliestam, 2017).

Another type of flexibility effect comes from strategies to expand **combined heat and power (CHP)**: this affects electricity flexibility both by reducing the amount of heat that can be provided with electric heating (see previous point) and by adding a relatively inflexible (heat-controlled) electricity source. Its expansion is contingent on the existence of local/district heating systems, but it offers the advantage of very high energy efficiency, sometimes exceeding 90% of the primary energy input (Poncela *et al.*, 2018). CHP stations can be operated with fossil fuels or with biomass, and especially in Scandinavia, biomass CHP has been a major contributor towards reaching the renewable energy targets.

Further, both as affluence grows and comfort demands increase, and as temperatures increase with climate change, the demand for **cooling** is likely to increase, and with current technology most cooling consumes large amounts of electricity. As with the electrification heating, this would increase electricity demand, and it would also add some demand flexibility: as the temperature of buildings changes slowly, it is possible to run cooling (in part) dependent on power availability and price.

Further, the electrification of the **transport sector** is high on the agenda, both in Europe and elsewhere (EC, 2017b). The largest share of emissions in transport is today caused by personal mobility with internal combustion engine (ICE) cars that run on gasoline or diesel. There were about 250 million cars registered in the EU in 2015 with an increasing tendency (Eurostat, 2017b).

The emissions for personal mobility have also been growing in the last decade, but policy hopes to reverse this trend and to reduce emissions in 2030 by 20% compared to 2008 and 60% compared to 1990s levels by 2050 (2011/144/EC). Electrification of vehicles is a promising solution incentivised by many member states. Some EU member states have already announced a phase-out date for sales of the ICE cars, for example France by 2040 (Chrisafis & Vaughan, 2017). However, in 2015 only 1.2% of new sold cars were electric and the overall share was 0.15% (EEA, 2016). New policies aimed at increasing this share are enacted (2016/501/EC, 2016). A large share of battery electric vehicles or low emitting plug-in hybrid (PHEV) or hybrid electric vehicles will have a strong impact on the electricity system. Additional electric vehicles (EV) will certainly increase the demand for electricity and will also be able to provide grid services such as flexibility with vehicle-to-grid (v2g) approaches (Kempton & Tomić, 2005).

3.2.9 Electricity demand

The European climate policy follows a strategy of "energy efficiency first" (EC, 2017f) leading to the targets of decreasing energy demand compared to baseline projections by 20% by 2020 and 30% by 2030 (2016/0860/EC). There are no targets for electricity demand, but there are projections underlying the supply scenarios, strategies and policies of both the Commission and the Member States (BFEE, 2017). Since 2010, the European gross electricity consumption has remained relatively stable at around 3250 TWh per year with a slight decrease after the 2011 financial crises and a slight increase since the economy has stated growing again after 2015 (2012/27/EU; Agora Energiewende & Sandbag, 2018). However, a relative decoupling can be observed with a stronger increase in GDP to about 110% compared to 2010, which shows that the economy is indeed using electricity more efficiently, but without the total demand decreasing.

The interaction of efficiency goals on flexibility needs are two-fold. First, if less electricity is used over all, the need for new capacity will be reduced, meaning that less carbon-neutral generation is needed to meet the targets, and the peak demand that will need to be met will also be lower. Second, the demand will not decrease uniformly – specific process will decrease – and the easiest to save are thermal processes (room heating, air conditioning, and hot water), but these are at the same time the by far largest group of shiftable processes. Saving these will thus reduce the demand-side management (DSM) potential, possibly increasing the need for other flexibility measures.

3.3 Quantifying the policy pathways

We quantify the variables described above supported these data by qualitative narratives, resulting in one pathway per logic and case. We take the data from written texts from the relevant organisations, and rely on different types of documents in a certain order. Only if the a step yields no information do we go on to the next. If we find conflicting information, we rely on the information from the "highest" step: first I, then II, etc. If there is no statement for a data point, we leave the table cell empty and let the models decide how that technology develops. We use the following data sources and rely on them in the following order:

1. Currently valid laws or other specific decisions (e.g. an expansion target or strategy). Specific numbers follow from decisions. (marked with I in the table)
2. Published and adopted government strategy (marked with II in the table)

3. Published and adopted official party strategy (III)
4. (government or party) policy statement, policy brief reacting to a specific event (IV)
5. Nothing (V).

For some variables, there will be no information at all (stage V, "nothing"). This could be because that decision does not exist in the logic of that government/party; for example, a market-centred pathway will leave most supply options open, as it allows the market to find the most cost-efficient solution, without the government prescribing an energy mix. In this case, an empty table cell is a result: the market will decide which technology is used to what amount, not the government/party.

Further, data may be lacking because the government/party has simply not formulated a specific position, although it in principle has one. This would be an indication that the particular topic is not highly relevant to that government/party, and that letting the models quantify that data point is acceptable. Often, however, the government/party will have a policy and an intended direction regarding most variables, either explicitly or implicitly evident in the policy documents. For example, they may react to the current situation, suggesting that policies to increase or decrease something compared to "today" would be beneficial, or vague statements of policy continuation (e.g. "we should continue expanding PV also beyond 2020"). They may also publish vague statements that something needs to be ultimately phased out or become dominant in future (e.g. "the future of mobility is electric" suggests that there will be few gasoline cars and many electric cars by 2050). They may also suggest a policy to support a particular technology, but without stating how far. In all such cases, the government/party documents hold some information of value for the policy pathway quantification, and for the subsequent system modelling of the pathways: something will increase, decrease, disappear, etc., allowing us to enter relative quantitative data in our data tables.

If the European Union has decided upon a specific target for a specific year, and the sources for a pathway do not say anything, we will use the European Union-defined target, *unless* the narrative of the pathway explicitly rejects EU climate and energy policies.

We expect that the dominant pathway will be supported with a relatively large amount of concrete policy targets: each policy measure will be accompanied by at least one (quantitative or semi-quantitative) aim, and most countries have a comprehensive energy strategy. We also know that most variables in our table except the phase-out schedule for fossil fuels will be included in the National Energy and Climate Plans that each Member State must submit to the European Commission by end of 2018 – and the template for that includes quantified aims for every variable up to 2030 and "as far as possible" to 2050 (EC, 2017a, c). Hence, expecting that the National Energy and Climate Plans are submitted on time, most data uncertainty will affect the minority pathways, whereas the dominant pathways will be more specific.

We seek to quantify the data points as far as possible, with absolute quantitative statements (e.g. 15 GW, 50% by 2030; 0 or 100% by 2050, etc.). If no such statements are available, but information can still be deduced from the policy documents we analyse, we will also include relative quantifications, such as ≤; <; >; ≥; =. Relative statements are always followed by a reference year and, if the unit is different than described in the left column, we also include a reference unit, referring either to capacity (“GW”), energy (“TWh”), greenhouse gas emissions (“GHG”), final energy consumption (“FE”) or primary energy consumption (“PE”)[1].

Throughout, we focus on the electricity sector only, except where indicated otherwise. Especially for heat and mobility, sector-coupling blurs the boundaries between electricity and other energy sectors, and for such sectors are targets not always expressed as electricity (-consumption) targets. Here, we thus use the specifications RES-C, RES-H, and RES-T for cooling/heating/transport with renewables: this is not explicitly renewable electricity, but it sets upper boundaries for the renewable electricity demand of each demand type.

In all cases, we assume that aims will be realised the way they are stated and that the enacting actors behave as they are “supposed to”: if, for example, a party wants 25 GW wind power by 2030, then we assume that they will realise 25 GW wind power by 2030. This is, of course, a somewhat naïve approach – rarely or never do policy aims result in exactly the envisioned result. On the other hand, it is neither possible nor meaningful to model the impact of decisions that are not successfully implemented: if we did this, we would end up with a meaningless jumble of arbitrary numbers (see Hughes *et al.* (2013)).

The data tables are presented in a simplified format with only the quantitative data in section 0, whereas tables with all data, source types and full references are found in the Appendix section 0.

[1] For example, the entry ”-75% (GHG-1990)” should be read as ”75% less greenhouse gas emissions than in 1990”; the entry ”> 2016 (GW)” means ”more capacity than in 2016”, etc.

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4 RESULTS

In all cases, all or almost all sources are in a national language; for the European-level pathways, we relied on English texts. All translations are done by the authors.

4.1 European Union

4.1.1 Representative organisations

The European political process is shaped by three institutions: the European Commission, the European Council and the European parliament. However, only the European Commission has the right to introduce legislative proposals. Contrary to the Member State parliaments, the European Parliament does not have power to propose legislation. Consequently, its groups do not publish legislative proposals of their own, but rather react to the agenda set by the Commission. Diverging views are taken up in consultations in the *trilogue*, the negotiation process between the European institutions.

The current European climate and energy policy has been mostly proposed and shaped by the Juncker Commission between 2014 and 2019. It emphasises a common European approach to the energy transition, within an internal electricity market, to share resources and improve cost-efficiency for Europe as a whole. This economic rationale is a core rationality of the EU, and is reflected in the market-centric policy approach of the European Energy Union process. Consequently, dominant pathway for the European Union is a market-centred pathway. We use adopted directives as the status quo, and where necessary expand to proposals by the Commission.

Due to the limited role of parliamentary opposition we had to look elsewhere for the grassroots pathway. Although the European Greens support ambitious climate policies they do not have published legislative proposals of their own, and their statements are usually in direct connection to the ongoing parliamentary process, and generally state that ambition should be increased compared to what the Commission proposes. Instead, we use the policy briefs of the Climate Action Network Europe (CAN), which is a major European NGO working for an ambitious climate and energy policy. The European Greens often explicitly supports the positions of CAN, and we expect that a Green position would be quite similar, emphasising the need for very ambitious climate and energy polices through citizen engagement and empowerment within the internal electricity market (The Greens / EFA, 2019).

EU-level competencies in the field of energy policy remain limited under the Lisbon Treaty and the Treaty on the Functioning of the European Union (TFEU). In particular, the EU cannot decide the energy or power mix of the Union or of Member States, making, for example, a central decision in Brussels for or against a nuclear phase-out impossible. Despite the Commission's continuous europeanisation efforts, energy policy remains an area of shared responsibility between the Member States and the EU, and the energy mix is an exclusive Member State competency. This is in conflict to the top-down decision making of government-centred decision making. As a policy pathway based on direct Commission control of investments would not be possible under the Lisbon Treaty, we do not produce a government-centred pathway for the EU.

*4.1.2 Dominant pathway: market-centred (*European Commission*)*

In 2050, the European Union had largely decarbonised its economy, in line with the Paris agreement (EC, 2018a; UN, 2015). The decarbonisation of the electricity sector was practically complete, with over 99% less emissions than in 1990. A plethora of different European actors, especially incumbents but also a range of new entrants to the electricity market have realised a dynamic and cost-optimal transition. The common internal European electricity market has been completed, allowing free and unconstrained electricity trade among all EU Member States, facilitated by a common governance framework setting a level playing field for all actors and technologies, that had enabled the climate and renewables targets to having been achieved in a cost-optimal manner (2016/864/COM). Instrumental to reach the targets in a cost-efficient manner was the EU emission trading scheme, which through increasing carbon prices and a tightening cap had cost-efficiently pushed out the most carbon-intensive electricity generation first. Similarly, the climate action of the EU was based on the principle of energy efficiency first, viewing the not consumed energy as the most efficient and most climate-friendly.

The common internal electricity market and increasingly harmonised support schemes has facilitated the cost-efficient expansion of **renewable electricity sources** in a European, and not national, context. The main electricity supply technologies in Europe are **intermittent renewables** – the low costs and abundant resources of which enabled them to dominate the power system. In the 2030s and 2040s there was more emphasis on the addition of **dispatchable renewables**, triggered by a reformed market framework, allowing them to be financed through their increasingly high value compared to additional intermittent renewables, despite their higher LCOE. Whereas the Member States expanded renewables at different pace in the 2010s and early 2020s, with some being front-runners and others lagging behind, the opening of support schemes to bidders in other Member States, further market integration, new interconnections and the target gap filling mechanisms, allowed and forced all Member States to pursue ambitious renewables expansion strategies. However, the role of common European goals gained importance over national goals over time.

Over time, Member State borders and national support policies played less and less of a role. **Electricity trade** expanded in line with the common electricity market vision. This addition allowed cooperation, such as joint projects, between Member States, so as to lower the electricity bill for all Europeans. Electricity imports from non-EU countries (Switzerland, Norway, etc.) were facilitated through integrating them in the electricity market through cooperation agreements.

Nuclear energy generation decreased in the 2020s, as the German phase-out decision was implemented, and as reactors across Europe reached the end of their economic life. The economics of new reactors was insufficient to trigger a nuclear renaissance, especially as no support for new reactors was given in the free and common European market. Some old reactors remained operational after safety updates (2014/87/Euratom; EURATOM, 2012, Art 24, 30). During the 2030s and 2040s the amount of nuclear power was determined by the Member States, which were free to build new nuclear power plants. However, the large volumes of fluctuating renewables in the European system and the technical inflexibility of new reactor generations constrained the nuclear expansion (2017/237/EC).

The 2020s saw a continuous phase out of **fossil electricity sources** driven by the price of carbon emissions as implemented in the emission trading scheme. Consequently, the most polluting plants were shut down first, as they became increasingly unprofitable with increasing carbon prices. In the

Eastern European states, money from the ETS modernisation fund was used to increase efficiency of some old fossil plants, slowing but not reversing the cost-driven trend of diminishing coal power (2003/87/EC, Art 10 & Annex IIb). **Carbon capture and storage** did not play a big role in decarbonising the European electricity system, because the technology remained immature, following the scale-back of state support schemes in the 2020s, and later the contribution to decarbonisation remained low because of bad economic performance compared to renewables, including dispatchable renewables. This happened despite the fact that EU regulation allowing for CCS R&D, and market push policies for demonstration plans had been in place for a long time (2009/31/EC; 2017/37/EC).

In 2050 the EU has used technology push policies to contribute to the development and deployment of the needed **storage** technologies to balance the grid and guarantee security of supply. They were expanded mainly to balance intermittent renewables, triggered by an adequate payment mechanism in the common market. This ensured a cost-optimal, technology neutral expansion of the right amounts of storage technologies needed, especially in the 2030s and 40s when balancing function could increasingly not be fulfilled by fossil plants.

To complete the internal electricity market **expansion of cross border grid connections** was implemented as an important cornerstone of the EU energy strategy, and allowed all Member States to share resources and meet the climate targets in a cost-efficient way. Member State TSOs cooperated in planning and creating a common European interconnected grid infrastructure (ENTSO-E, 2016, 2018). The EU interconnection targets required 10% interconnection of each Member States peak load by 2020 and 15% by 2030 and it was further increased in the 2030s and 2040s in line with the common electricity market vision.

Energy demand reduction was a key area of action in the EU and the Member States, following the main decarbonisation principle of "energy efficiency first": the not consumed kilowatthour is both the cheapest and the one with the smallest environmental impact. Policies implemented in the 2020s enabled a reduction of the energy intensity by 32.5% in 2030 compared to 2005, both through end-use efficiency and electrification; this trend was continued in the two following decades. Together with the renewable electricity deployment, efficiency increases greatly reduced the European energy import dependency.

However, the **electrification** of additional sectors – mainly transport and, in part, heating – driven by EU standards for new vehicle emissions and emissions from heating, despite improved insulation of buildings (including a mandate for only near-zero energy buildings in new construction from 2021), led to additional electricity demand from these sectors especially in the 2030s and 2040s. Moreover, demand was increasingly flexible driven by the expansion of smart meters and suitable market mechanisms rewarding flexibility (2014/188/SWD).

This pathway followed the EU's dominant market-centred logic. The centrepiece for enabling the energy transition in Europe was the ***common internal electricity market*** with a governance framework that set an ***undistorted market*** for all investors and consumers. This enabled the increased deployment and usage of technologies with desired properties (e.g. no greenhouse gas emissions, by a cost-optimal expansion of both fluctuating and flexible renewable generation, especially in cooperation among the Member States, and a flexibilisation of demand). It also triggered a gradual and cost-efficient phase-out of technologies with undesired properties (high emissions, expensive, inflexible generation). The resulting European power system in 2050 is high in renewables and transmission (see Table 1). New technologies were developed through a mix of technology push (i.e. NER300, SET plan) and market pull policies (i.e. EU ETS), without policy interference in the market itself.

Table 1: Quantification of the European market-centred dominant policy pathway as described by currently valid policies of the European Commission.

EU: Dominant	**2016**	**2020**	**2030**	**2040**	**2050**
GHG reduction targets (economy-wide)	3989 Mt CO_{2eq}	> 20% (GHG-1990)	> 40% (GHG-1990)		100%
ETS sector reduction targets		21% (GHG-2005) 1.74% per year	43% (GHG-2005) 2.2% per year		100%
Non-ETS sectors emission reduction targets		10% (GHG-2005)	30% (GHG-2005)		100%
GHG reduction targets (electricity sector)			57-65% (GHG-1990)		>96-99% (GHG-1990)
Renewables targets (energy; % of final energy consumption)		20%	> 32%	> 2030	> 2040
Renewables targets (electricity; % of final energy consumption)	30%; 981 TWh; 421 GW				
Intermittent renewables	408 TWh; 255 GW				
Wind onshore	303 TWh; 154 GW				
Wind offshore	included above				
Solar PV	105 TWh; 101 GW				
Dispatchable renewables	573 TWh; 166 GW				
Biomass	159 TWh; 29 GW				
Hydro	380 TWh; 106 GW				
CSP	6 TWh;2 GW				
Other renewables	28 TWh				

EU: Dominant	2016	2020	2030	2040	2050
Traded renewables		≥ 5% all support schemes (2023-2026)	≥ 10% from (2027 2030).		
Physical import of renewables (cooperation)					
Statistical transfer of renewables (cooperation)					
Explicit trade of CSP or hydropower					
Nuclear	840 TWh; 122GW				
Fossil fuels	1433 TWh; 456GW				
CCS	0				
Lignite	300 TWh				
Hard coal	386 TWh				
Gas	642 TWh				
Petroleum	61 TWh				
Other non-renewables	43 TWh				
Storage					
Battery					
Pumped Hydropower					
Other storage					
Cross-border interconnection NTC		≥10% of yearly power production	≥15% of yearly power production		
Electrification of additional sectors					
Total heating demand incl. non-electric heating		< 2016	< 2020	< 2030	-90% (GHG-1990)
Heating with electricity		Each MS: +1.3% (RES-H-2020)	> 2020	> 2030	> 2040
Total cooling demand incl. non-electric cooling		< 2016	< 2020	< 2030	< 2040

EU: Dominant	**2016**	**2020**	**2030**	**2040**	**2050**
Cooling with electricity		Each MS: +1.3% (RES-C-2020)			
Electric mobility		10% (RES-T)	> 14% (RES-T)		-60% (GHG-1990) 65% (RES-E)
EV chargers		1 public charger for every 10 cars Readiness for new buildings	> 2020	> 2030	> 2040
Smart meters		200 million (72% of households)	> 2020		
Gross electricity consumption	3254 TWh				
Final energy consumption		-20% (baseline projection)	-26% (PE-2005); -20% (FE-2005); -0.8% FE per year) -32.5% (compared to baseline projection); upward revision 2023	-0.8% FE per year	-0.8% FE per year

*4.1.3 Minority pathway: grassroots-centred (*CAN Europe*)*

The European Union achieved full decarbonisation of the entire economy by 2040, thereby fulfilling the Paris Agreements 1.5 degree goal (IPCC, 2018b; UN, 2015). In the electricity sector, this was done by enacting strict phase-out policies for fossil fuel power, and by emphasising the role of citizens in the energy system. The keys to the successful transition was putting the needs of the citizens at the core of the climate and energy policies. On the one hand, this meant empowering citizens to act themselves through policies supporting the decentralisation of the energy system. On the other hand, larger actors also efficiently carried out a part of the transition within the context of the internal market. In a sense, the maxim of this pathway was *"local renewables first, European renewables second"*. Mainstreaming climate action criteria into all areas of European policy making and budgeting ensured the decarbonisation of all sectors and economic activities, while empowering local communities to achieve the targets in the way best suited for them (CAN Europe, 2018a). The energy transition was enacted by market actors, but also and in particular by European citizens that took decisions based on what they and their communities can contribute to the overall on specific design elements of the decarbonised power system and many became prosumers or were organised in energy communities. This active participation enabled the bottom-up growth of a democratically legitimised electricity system that fit the specific needs of each European region (CAN Europe, 2017).

Overall, citizen empowerment has had a strongly encouraging influence on the expansion of small-scale **intermittent renewables**, i.e. rooftop PV and on-shore wind. Local citizen-led renewable energy projects across Europe profited from improved transparency and an EU enshrined right to self-consumption. The EU governance framework encouraged this through optimal conditions for market access of renewables and by prioritising their dispatch over fossil generation. Additionally, off-grid and decentralised renewables were encouraged by removing grid connection requirements (CAN Europe, 2015a). Only where citizen engagement remained too low, renewable power expansion was driven by reintroducing binding Member State renewables targets and support policies in the 2020s to allow renewables to compete in each Member State (CAN Europe, 2017).

In many communities **dispatchable renewables** expansion faced more difficulties, due to natural constraints, and the reluctance of small-scale actors to engage in building large-scale assets. Hence, dispatchable renewables were one of the key areas for cooperation and larger-scale expansion within the internal market. Biomass usage had to comply with strict sustainability requirements to minimise impact on land-use and food security so it only expanded where local conditions were favourable and excess resources were readily available. The EU reduced its imports of biomass for energy generation to a minimum (CAN Europe, 2016e). Also, hydropower expansion was restricted by strict environmental legislation and depleted potentials.

Physical **trade** of power was restricted to renewables, as fossil fuelled power became less prevalent during the 2020s. The European Commission encouraged Member States to cooperate in balancing their renewables through cooperation mechanisms in to achieve their national renewables targets (CAN Europe, 2015a), as well as through expanding the European Energy Community in line with the strict EU's climate and energy policy proposals (CAN Europe, 2015e), encouraged especially imports of dispatchable renewables from those countries.

Nuclear power was stripped of all R&D funds for new generation technology and further discouraged through high and increasing security requirements, as key tools to get rid of this centralised and risky technology. Effectively, this amounted to a de-facto ban on new nuclear construction, because new nuclear power plants became too expensive, and the renewable expansion in the 2020s to fast and effective to leave room for new nuclear power plants in the 2030s or 2040s.

A phase out of the largest and most polluting **fossil fuel** plants was accelerated starting in 2020 by increasingly tightening emission standards, starting with 350 gCO_2/kWh. This forced both **lignite** and most **hard coal** generators off the grid, rapidly reducing electricity system emissions and also making room in the grid for more renewables (CAN Europe, 2017). Another measure was the phase-out of all subsidies for fossil fuels, including an exclusion of fossil fuelled generators from capacity payments within the internal market. Further, the tightening cap of the EU ETS linearly drove down electricity sector emission allowances to 0% by 2030 (CAN Europe, 2015d). CCS was not supported by any additional European technology push funding, so the progress of this technology was constrained by EU external and Member State R&D (CAN Europe, 2006) and application remained limited.

Technologies that increased the power systems flexibility were encouraged through R&D funding and favourable regulations (EU, 2017). Innovative **storage** technologies were incentivised by capacity mechanisms (CAN Europe, 2018c) and creating a market design allowing for flexibility payments, making flexibility a good traded across the European market. Consumers were empowered and rewarded to participate in flexibility markets through **smart meters** that allowed them to play a more active role, especially through demand-side management but also through self-consumption of their own power, especially small-scale PV (CAN Europe, 2015a). On the infrastructure level, the Connecting Europe Facility was redesigned to have additional funding available toward electricity **grid infrastructure and especially "smart"** distribution grids that were especially emphasised, while the union discontinued all investment into new large-scale gas infrastructure, especially LNG terminals and pipelines ceased already in the 2020s.

Heating and cooling as well as **transport** were 100% renewable by 2040, especially through electrification (both sectors) and efficiency measures (heating/cooling) (CAN Europe, 2015b). Overall heating and cooling demand strongly decreased, driven by efficiency gains through stronger building standards both for existing and new buildings. This emphasis of the efficiency first principal allowed for an over-all strong reduction of demand of primary energy by 1.5% per year (CAN Europe, 2016c). Member state specific targets were used to ensure the needed activity in all member states. Funding for this came in part from the innovation fund of the EU-ETS. For transport, a more equal system with a higher share of public transport was prioritised over individual mobility. Moreover, the electrification of transport was prioritised over biofuels or other alternative fuels through strict emission standards, making the car sector fully electrified by 2050 (CAN Europe, 2016b).

In this pathway, customers were the central transition actors according to the grassroots-centred logic. The centrepiece for enabling the energy transition in Europe was the emphasis on empowering citizens as the enactors of the transition strategy, complementing the larger-scale investments in the common internal electricity market. A set of strong incentives for decarbonisation through decentralisation opened opportunities for action, but the design choices of the future system encouraged local communities to get involved in line with the subsidiarity principle. The resulting European power system is high in decentralised small-scale renewable and "smart" local power grids (see Table 2). New technologies were developed through a mix of technology push (i.e. NER300, SET plan) and market pull policies (i.e. EU ETS), without state interference in the market itself.

Table 2: Quantification of the European grassroot-centred minority policy pathway as described by CAN Europe.

EU: Grassroots	**2016**	**2020**	**2030**	**2040**	**2050**
GHG reduction targets (economy-wide)	3989 Mt CO_{2eq}	30% (GHG-1990)	>65% (GHG-1990)	100%	100%
ETS sector reduction targets				100%	
Non-ETS sectors emission reduction targets			45% (GHG-2005)	100%	
GHG reduction targets (electricity sector)			100% (GHG-1990)		
Renewables targets (energy; % of final energy consumption)			>45% (GHG-1990)		100%
Renewables targets (electricity; % of final energy consumption)	30%; 981 TWh; 421 GW				
Intermittent renewables	408 TWh; 255 GW	> 2016	> 2020		
Wind onshore	303 TWh; 154 GW				
Wind offshore	included above				
Solar PV	105 TWh; 101 GW	(decentral)	(decentral)	(decentral)	(decentral)
Dispatchable renewables	573 TWh; 166 GW				
Biomass	159 TWh; 29 GW	(sustainable)	(sustainable)	(sustainable)	(sustainable)
Hydro	380 TWh; 106 GW				
CSP	6 TWh; 2 GW				
Other renewables	28 TWh				
Traded renewables					
Physical import of renewables (cooperation)					
Statistical transfer of renewables (cooperation)					

EU: Grassroots	2016	2020	2030	2040	2050
Explicit trade of CSP or hydropower					
Nuclear	840 TWh; 122 GW				0
Fossil fuels	1433 TWh; 456 GW	< 2016	0	0	0
CCS	0				
Lignite	300 TWh	< 2016 (GHG-1990)	0	0	0
Hard coal	386 TWh	< 2016 (GHG-1990)	0	0	0
Gas	642 TWh	< 2016 (GHG-1990)	0	0	0
Petroleum	61 TWh	< 2016 (GHG-1990)	0	0	0
Other non-renewables	43 TWh	< 2016 (GHG-1990)	0	0	0
Storage					
Battery					
Pumped Hydropower					
Other storage					
Cross-border interconnection NTC					
Electrification of additional sectors					
Total heating demand incl. non-electric heating		< 2016	< 2020	< 2030	< 2040
Heating with electricity		> 2016	> 2020	100% (RES-H)	
Total cooling demand incl. non-electric cooling		< 2016	< 2020	< 2030	< 2040
Cooling with electricity		> 2016	> 2020	100% (RES-C)	
Electric mobility		> 2016	> 2020	> 2030	100% (RES-T)
EV chargers					
Gross electricity consumption	3254 TWh				
Final energy consumption		< 2016	-1.5% FE per year	-1.5% FE per year	-1.5% FE per year

4.2 Spain

4.2.1 Representative organisations

Traditionally, Spanish governments have been formed either by a socialist or a centre-right parliamentary majority. When the socialists or the centre-right party did not get an absolute majority, they tended to get support from centre-right regional/nationalist parties in Catalonia and the Basque Country instead of looking for national allies. The traditional differences in energy policy are consistent with the government-centred/market logic divide, with the socialists pushing for more public intervention while the centre-right advocated for privatisation and liberalisation. However, after the financial crisis, a new political party (Podemos) emerged representing the populist left. The results of the 2015 elections were so fragmented that elections were repeated in 2016. The centre-right obtained a relative majority in Parliament, but was expelled from the government in 2018 by an ensemble of opposition parties forged among the left and nationalist parties. More recently, the Andalucía regional elections saw the rise of the populist right represented by VOX. This has changed the Spanish political system from bipolarity to fragmentation. Furthermore, the Catalan crisis has made it more difficult for separatist parties to support any national party, making parliamentary alliances more and more complex, with several parties involved in the bargaining process. General elections were held in April 2019, and sitting Prime Minister Sanchez was called by the King to form a government, but so far (August 2019), no new government coalition has been formed and the prospects are uncertain.

Table 3: Parties currently (April 2019) represented in the Spanish national parliament.

Party	Spanish general election 2019	Seats
Partido Socialista Obrero Español	28.7%	123
PP	16.7%	66
C's	15.9%	57
Unidas Podemos	11.1%	33
VOX	10.3%	24
ERC-SOBIRANISTES	3.9%	15
eN Comú Podem	2.4%	7
JxCAT	1.9%	7
PNV	1.5%	6
EH Bildu	1.0%	4
En Comun	0.9%	2
Compromis	0.7%	1
CC-PNC	0.5%	2
Navarra Suma	0.4%	2
PRC	0.2%	1

This section describes and quantifies three different energy policy pathways for the Spanish energy transition: the dominant government-centred pathway represented by *PSOE* as expressed in government strategies and the draft NECP, a market-centred minority pathway represented by the *PP*, and a grassroots minority pathway represented by *Unidas Podemos*. Although these parties are not the only ones with explicit energy visions, these three span the entire energy transition policy space – and are the currently largest ones, with the highest probability of government power in the near term. Further, PP, PSOE and Unidas Podemos have prepared law proposals allowing for better specification and quantification of their pathways (Ministerio para la Transición Ecológica, 2018; Partido Popular, 2018; Unidas Podemos, 2018).

Each of the three decarbonisation pathways can include elements that would theoretically fall within other two decarbonisation pathways. For instance, the new socialist government's Climate Change and Energy Transition Law proposal includes bidding and other market mechanisms, but on the whole, it tends to assume energy transition requires tough, mandatory measures, like phase-outs, deadlines, bans and ambitious targets. In a similar manner, Unidas Podemos sets the most ambitious decarbonisation targets, argues for state (and local) intervention, but its key differentiating factor lies in the grassroots-centred logic, focused on the small-scale and local action, seeking decarbonisation through decentralisation of the energy system. Finally, the Popular Party self-stated market-centred logic is based on carbon pricing and letting the market identify the most cost-efficient way to meet energy and climate targets.

4.2.2 Dominant pathway: state-centred (Partido Socialista Obrero Español)

By 2050, Spain had achieved near-zero net emissions, both economy-wide and, in particular, in the electricity sector, which was fully renewable. The NECP (NECP Spain, 2019) operationalized the long-awaited *Climate Change and Energy Transition Law* (Ministerio para la Transición Ecológica, 2018) that was finally passed in 2020, along with the development of a *Long-Term Strategy* and a *Just Transition Strategy* (Ministerio para la Transición Ecológica, 2019). Several factors drove Spain's shift to a lower carbon development model. These included: first, the adoption of increasingly stringent targets for renewables and energy efficiency in the EU set up in the NECP. Second, the implementation of the EU's Long Term Strategy that enshrined the net zero goal by 2050 (2018/773/COM, 2018). Third, the banning (in sales and registration) by 2040 of internal combustion engine vehicles in Spain and the banning of these vehicles' circulation in 2050. And fourth, the increasing concern regarding climate change impacts by Spanish citizens, who ranked climate change as the top policy priority concern from 2016 onwards (European Commission, 2017; Centro de Investigaciones Sociológicas, 2018; Real Instituto Elcano, 2018; Wouter *et al.*, 2018).

A set of laws and policy measures guided the radical decarbonisation of the electricity sector, and of society as a whole, under tight government control. For the power system, this included decisions such as an orderly phase-out of nuclear power between 2025 and 2035, phase out of coal by 2030[2], a ban on new fossil fuel subsidies from 2020, centrally planned phase-out of existing fossil fuel subsidies, banning internal combustion engines in cars, mandatory low-emission zones in municipalities and mandatory renovations and building retrofitting.

[2] The government did not decide a phase-out schedule, but relied on EU legislations and market forces to shut down the coal power fleet, explicitly keeping the option of a mandated phase-out, by "the actions it considers necessary" (NECP Spain, 2019).

By 2030 Spain's economy had reduced its GHG emissions by 21% compared to 1990, thus achieving the government target. By 2050, Spain's GHG emissions were 90% lower than in 1990, with the remaining 10% being offset by various carbon sinks, making the Spanish economy carbon neutral by mid-century, in alignment with the NECP and with the Spanish Climate Change and Energy Transition Law.

By 2030, the NECP's 42% **renewable energy target** was achieved in Spain's final energy consumption, supported by an electricity system that was almost ¾ renewable. Among other measures, this objective was met through a steady stream of auctions, leading to 57 GW of new renewable capacity – half of which was PV – during the 2020s (NECP Spain, 2019). During this decade, 5 GW of concentrated solar power (CSP) was auctioned and constructed, restarting a expansion of this technology in Europe. By 2050, the Spanish power sector was fully (100%) renewable.

In order to achieve integration, demand-side management measures were fostered to change consumption patterns. Additionally, storage capacity was increased.

New **fossil fuel subsidies** were banned by the government in Spain as of 2020 (Ministerio para la Transición Ecológica, 2018), and the old phased out. New exploration and extraction of hydrocarbons by conventional and new techniques such as hydraulic fracturing were also banned in Spain as of 2020. Existing permits for exploration and extraction of hydrocarbons were not extended. The Spanish government furthermore divested its fossil fuel extraction and processing assets from 2021 onwards, offering incentives for other actors and companies to do the same (Ministerio para la Transición Ecológica, 2018).

Half of the Spanish coal power was closed in 2020, with the rest having been phased out by 2030. Nine of Spain's fifteen coal power plants were closed in 2021 as the necessary adaptions to limit atmospheric emissions to comply with the Industrial Emissions Directive (2010/75/EU Directive, 2010) were not carried out. The remaining coal power stations were shut down as they became unprofitable, following decreasing costs for renewables and rising carbon prices (€35 in 2030 in the ETS) (NECP Spain, 2019). The Spanish nuclear fleet was phased out by 2035, following an agreement between the government and the utilities to shut down reactors after 46 years of operation (Cinco Días El País, 2019).

Spain's **interconnections** with France, Morocco and Portugal remained very limited until 2020 amounting to <5% of Spain's generation capacity in 2019, half of which were interconnections to France. This made Spain the only European country that failed the EU target of 10% interconnection capacity in 2020. Hence, Spain developed new interconnections with Portugal (reaching 3,000 MW in 2030) and with France (reaching 8,000 MW in 2030, up from 2,800 MW in 2019), following a new government initiative for more interconnections as a part of Spain's Stocktake for the Paris Agreement in 2023. Hence, Spain met the target of 15% interconnection in 2030. This helped balance the Spanish power system as fluctuating renewables increased, together with the introduction of large-scale battery storage and a doubling of pumped hydro capacity. Over the 2020s, as the interconnection capacity grew, Spain became a net exporter of electricity. In 2019, Morocco was a net electricity exporter to Spain (Ramón Roca, 2019), but this stopped in the early 2020s as new rules were introduced to prevent coal and gas-generated electricity being exported to the EU, and as growing demand in Morocco reduced its export potential. Over time, the electricity flow acorss Gibraltar became more balanced, with no strong net import or export sums (Montel, 2019).

As regards the **transport sector and electric mobility,** Spain banned the registration and sales of internal combustion engine vehicles in 2040 (Ministerio para la Transición Ecológica, 2018) By 2050, only zero-emission privately owned vehicles were allowed to circulate. By 2030, 5 million EVs were in use in Spain, with a significant impact on electricity demand. Charging infrastructure for EVs was small in 2018, but from 2019 onwards the Spanish Climate Change and Energy Transition Law required petrol stations across the country selling more than 5 million litres of fuel annually to first present a project to install charging stations of ≥22 kW, immediately reaching 9% of petrol stations.. For smaller petrol stations the deadlines for projects and operation of charging points was more flexible, with a slower expansion in pace with the deployment of electric vehicles. Additionally, municipalities of ≥50,000 inhabitants established by law low emission zones by 2023 (at the latest), which further fostered the deployment of both electric cars and installation of public and private EV charging points.

Spain achieved its **energy efficiency** goal of 39.6% primary energy intensity improvement in 2030, which was achieved, among others, through electrification of transport and heating. Hence, the electricity demand increased by almost 10% to 2030, and continued increasing. This increase was counteracted by the implementation of EU rules for building insulation (2018/844/EU, 2018), water heating and air conditioning, through a programme to renovate 300,000 buildings and, in addition, 3% of publicly owned buildings per year (NECP Spain, 2019). The government also promoted an increase of renewable energy sources in retrofitted and new buildings, in accordance with the European Buildings Directive (2018/844/EU, 2018). Subsidies were also given to low income families to allow for retrofitting investments, based on energy savings audits and performance. Public-private partnerships were established to reach retrofit goals.

Demand-response measures were introduced during the 2020s, to make demand more flexible and nudge consumers into lower carbon consumption patterns, for example through smart metering – which both raised awareness of energy consumption and enabled demand shifts especially for heating, cooling and hot water. Financing mechanisms were fostered by the government to ensure retrofitting and nearly-zero energy buildings.

The dominant Spanish pathway followed a state-centred pathway. The government was active in all sectors, implementing and enforcing measures for the economy-wide decarbonisation by 2050. The government tightly controlled the development, in particular through the scheduled phase-out of nuclear, the phase-out of coal power, and the introduction of electric cars through the ban on fossil fuelled ones. Throughout the decades, the transition happened in close collaboration between governments nd incumbent power companies, who were main developers of the auction-triggered renewables (Table 4).

Table 4: Quantification of the Spanish state-centred dominant policy pathway as described by currently valid policies of the Partido Socialista Obrero Español and its government.

ES: Dominant	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	283 Mt CO_{2eq}	327 $MtCO_{2eq}$	227 Mt CO_{2eq} 21%		≥90% (GHG-1990
ETS sector reduction targets	229 Mt CO_{2eq} (European annual emission allocation)	219 Mt CO_{2eq} (European annual emission allocation)	60% (GHG-2005)		
Non-ETS sectors emission reduction targets		10% (GHG-2005)	38% (GHG-2005)		
GHG reduction targets (electricity sector)		63.5 Mt CO_{2eq} 4% (GHG 1990)	19.7 Mt CO_{2eq}; 70% (GHG 1990)		
Renewables targets (energy; % of final energy consumption)		20%	42%		100%
Renewables targets (electricity; % of final energy consumption)	39% 108 TWh 49 GW	40%	>74%		100%
Intermittent renewables	57 TWh; 28 GW	36.4 GW; 75.7 TWh	87.1 GW; 182.5 TWh	≥ 2030	≥ 2040
Wind onshore	49 TWh; 23	60.5 TWh; 28.0 GW	116.1 TWh; 50.3 GW		
Wind offshore	included above	included above	included above		
Solar PV	8 TWh; 5 GW	15.1 TWh; 8.4 GW	66.4 TWh; 36.9 GW	> 2030	> 2030
Dispatchable renewables	51 TWh; 21 GW	24.0 GW; 42.8 TWh (incl. pumped hydro)	33.8 GW; 72.3 TWh (incl. pumped hydro)	≥ 2030	≥ 2040
Biomass	5 TWh; 1 GW	5.3 TWh;1.6 GW	13.2 TWh;2.4 GW		
Hydro (without pumping)	40 TWh; 14 GW	28.3 TWh; 14.1 GW	29 TWh;14.6 GW4		
CSP	6 TWh; 2 GW	5 TWh, 2.3 GW	22.6 TWh,7.3 GW	≥ 2030	≥ 2040
Other renewables	1 TWh	0	0.3 TWh, 0.1 GW		
Traded renewables					
Physical import of renewables (cooperation)					
Statistical transfer of renewables (cooperation)					

ES: Dominant	2016	2020	2030	2040	2050
Explicit trade of CSP or hydropower					
Nuclear	59 TWh; 7 GW	57.7 TWh; 7.4 GW	24.8 TWh; 3.2 GW	0	0
Fossil fuels	108 TWh; 48 GW	112 TWh; 45.1 GW	55 TWh;32.5 GW		0
CCS	0	0	0		
Lignite	0 TWh	0	0	0	0
Hard coal	36 TWh	47.2 TWh; 10.5 GW	0 TWh; 0-1.3 GW		0
Gas	54 TWh	56.8 TWh; 31.2 GW	50.5 TWh 30.2 GW		0
Petroleum	16 TWh	7.4 TWh; 3.4 GW	4.7 TWh;2.3 GW		0
Other non-renewables	1 TWh	0.7 TWh	1.5 TWh		0
Storage	(V)	(V)	(V)	(V)	(V)
Battery	(V)	(V)	2.5 GW	(V)	(V)
Pumped Hydropower	3.3 GW (2015)	3.3 GW	6.8 GW	(V)	(V)
Other storage	(V)	(V)	(V)	(V)	(V)
Cross-border interconnection NTC	2750 MW (France) 2800 MW (Portugal) 800 MW (Morocco)	2900 MW (France) 3500 MW (Portugal) 800 MW (Morocco)	8000 MW (France) 4300 MW (Portugal) 1200 MW (Morocco)	=2030	=2040
Electrification of additional sectors					
Total heating demand incl. non-electric heating					
Heating with electricity (energy supplied by heat pumps) COP>3	4.1 TWh	7.6 TWh	47.4 TWh		
Total cooling demand incl. non-electric cooling			< 2018		
Cooling with electricity			< 2018		
Electric mobility	6.6 TWh	4.9 TWh	20.7 TWh; 5 million EV	>> 2030 Ban on ICE sales	>> 2030 Ban on ICE circulation
EV chargers	4974 (2017)	> 2017	>>2020	>> 2030	>> 2040
Gross electricity consumption	275 TWh	267 TWh	284 TWh		
Final energy consumption	983 TWh (2015)	1035 TWh	922TWh		

4.2.3 *Minority pathway: grassroots-centred (Unidas Podemos)*

Spain achieved almost full decarbonisation of the entire economy by 2050 (Unidas Podemos, 2018, 2019). In the electricity sector, this was achieved by strict phase-out policies for fossil fuel power and emphasising the role of citizens and communities in building up a new, renewable power system. The needs of the citizens were at the core of all climate and energy policies, supported by institutions such as the State Climate Change Agency and the Citizen Climate Change Commission. Through active policy, citizens were empowered to have a more pro-active role by supporting the decentralisation of the energy system and encouraged to become prosumers. The re-communalisation of electricity provision was approved in subsequent local referenda following the example of Barcelona Energy in 2018 (Ayuntamiento de Barcelona, 2019), when a public metropolitan electricity operator started supplying renewable electricity to the city, so that over time, control over the entire system became communal.

Regarding interconnections and EU cooperation mechanisms, the emphasis is on decentralisation and re-communalisation instead of cross-border mega-projects and further market integration. As a consequence, by 2050 interconnections stay at the 2030 15% goal while virtual and physical cooperation mechanisms remain marginal: the maxim was and remains "*Spanish renewables for and by Spanish citizens*". Another key aspect of the Unidas Podemos strategy was an emphasis on energy efficiency: the targets of 40% less primary energy demand by 2030 and 50% less by 2050 (compared to the reference scenario) were achieved in part with efficiency measures and in part through electrification of additional sectors, primarily transport (Unidas Podemos, 2018).

The Spanish **greenhouse emissions** continuously decreased, and hit -95% compared to 1990, in 2050 (Unidas Podemos, 2018). This was achieved as a result of the combination of primary energy consumption decline (by 2030 and 2040 there was a 40% and 45% decline compared to the reference scenario) as well as a strong deployment of renewables to fill the gap of the phased-out fossil and nuclear generators. This transition was facilitated by two broad energy programmes: (i) the Energy Efficiency National plan that targeted the housing, transport and industrial sectors and (ii) the Renewable Energies National plan that focused on deployment of renewable power generation (solar, wind, geothermal, small hydropower and low emitting biomass) (Unidas Podemos, 2018).

To implement these plans, 2.5% of GDP (Unidas Podemos, 2019) was mobilised annually over 20 years, comprising both public and private resources, to stem the necessary investments in generation and infrastructure. For example, a Green finance fund for mitigation and adaptation was created and the law for energy transition also provided for the special funds for a fair transition, in part raised through new environmental taxes and the abolishment of tax exemptions for fossil fuel industry and consumption. New measures to prevent oligopolistic practices (including vertical integration) in the electricity market were implemented to avoid large energy corporations concentrate too much power and support the small-scale actors entering the system. Finally, measures were put in place to decouple the ownership and management of the distribution system.

Aligned with a grassroots political party ideal, both plans were implemented in a way that most electricity generation and distribution phases remained in the hands of public entities (esp. municipalities), consumers or small enterprises and not large corporations. A public electricity company was created during the 2020s. This company, together with the Vice President of Ecological Transition and New Industrial Model and the Investment Bank for Technological and Economic Transition (BITTE), was an essential agent when undertaking the energy transition. This company played an active role in the installation of renewable energies, pushing the transformation of the electricity system and ensuring that no one suffered energy poverty. At the same time, it worked in coordination with the municipal public companies that were created for the commercialisation and management of their own energy (Unidas Podemos, 2019).

With respect to **renewable power**, the power system has been 100% renewable since 2045, following the achievement of the interim renewable power target of 80% in 2030. Besides targeted support measures for small renewable power plants, the municipalities granted soft loans through the Green Fund ("Fondo de Financiación Verde"). Furthermore, there was a green procurement strategy by which all public administrations were obliged to consume 100% renewables in all their premises, so as to reduce the life cycle environmental impacts of its energy use. Finally, the government divested funds from fossil fuel related companies to incentivise private consumers to invest in renewable energy through subsidies.

Intermittent renewables, especially PV, experienced a great expansion as a result of the support measures included in the Renewable National Plan, including dedicated support for onshore wind power (>6 MW). A special emphasis was put on special support mechanisms for investments in renewable generators smaller than 1 MW (Unidas Podemos, 2018). Furthermore, a new regulatory framework was implemented in 2018, and maintained since, to support self-consumption which included the following features: (i) self-consumption was not taxed, (ii) electricity fed into to the electricity system was remunerated in a fair manner by the distributor company and (iii) quick and simple administrative procedures were established. Consequentially, all renewables grew continuously from 2018 onwards, but decentralised PV grew particularly fast.

When it comes to **dispatchable renewables**, research, development and innovation plans were specifically designed for the development of new dispatchable technologies, including measures to improve the flexibility of controllable renewables, such as CSP. As these technologies improved, their deployment grew from 2020 on, seeing the development of a diverse fleet of dispatchable renewables over time, including both CSP, hydropower and biomass. When large hydropower plants private ownership reached an end, they became state-owned. In this, the role of large hydropower plants changed from providing bulk power to being providers of back-up capacity to complement solar PV and wind power generation; the growing biomass power fleet was also used mainly to balance the system, and not merely to generate bulk energy.

Accompanying the rise of renewables was the decline of nuclear and fossil power. Following the phase-out decisions in 2018, all **nuclear and coal power** was shut down progressively, until the last power plants were closed in 2025. The existing gas power stations were allowed to continue operating beyond 2025 insofar as they provided back-up capacity to the system and contributed to guarantee the supply. In the whole period, fracking was forbidden, practically banning natural gas production in Spain; further, as CCS was not supported, there was no expansion of CCS stations at any time. In all these phase-out cases (esp. nuclear and coal plants), the abandonment of the plants followed a fair transition for the industrial workers so that they have found new employment opportunities.

Given its focus on small-scale, local and distributed electricity, Unidas Podemos limited the development of new **interconnection** capacity to the minimum necessary to support the further deployment of renewables in Spain (in accordance to EU targets). Instead of developing new transmission infrastructures, Unidas Podemos supported the development of micro- and other local networks, minimising the need for transmission. Consequently, there was no explicit trade with renewables, dispatchable or fluctuating, and Spain has not made use of the cooperation mechanisms.

In order to support the balancing of fluctuating renewables, and to minimise the need for further electricity grids, the government early on supported the development and deployment of new **storage technologies**. This included both batteries and hydrogen, initially through R&D support and later on through deployment support, so as to keep the power system stable and minimise the need for new national and cross-border grid infrastructure.

The law for the energy transition and climate change introduced various measures were put in place to support the **electrification of certain consumptions such as industrial, heating and transport**. Giving priority to the most vulnerable homes and neighbourhoods, 500,000 homes were refurbished annually, reducing their energy consumption – and energy bill – by 50%.

As to the decarbonisation of the transport sector, Unidas Podemos (i) promoted the use of bicycles in many ways (for example, by facilitating bicycles access to other public transportation modes), (ii) revised the public transport services provision contracts and (iii) promoted **electric vehicles** and vehicles running on alternative fuels. Thanks to the various support measures in place, Spain achieved a 25% electric share of new cars by 2025; by 2030 70% of new cars were EV; and by 2040, all new vehicles were EVs. Furthermore, a program was developed to promote the use of **electric vehicles chargers** so to have enough points to supply all the demand.

Summarising, aligned with grassroots logics, the key for enabling the energy transition in Spain was empowering citizens and local communities as the main actors of the transition strategy, while progressively abandoning the fossil and nuclear technologies. As a result, a highly decentralised small-scale and smart local community-owned power system was achieved. New technologies were developed as a result of R&D programs (technology push) as well as market pull policies (support policies in the form of subsidies and other incentives). Regarding interconnections and cooperation mechanisms, the local and community logic has limit interconnections to compulsory EU targets and intra-EU renewable exchange remains small (see Table 5).

Table 5: Quantification of the Spanish grassroots-centred minority policy pathway as described by Podemos.

ES: Grassroots	**2016**	**2020**	**2030**	**2040**	**2050**
GHG reduction targets (economy-wide)	283 Mt CO_{2eq}		35% (1990)	70% (1990)	95% (1990)
ETS sector reduction targets	229 Mt CO_{2eq} (European emission allocation)	219 Mt CO_{2eq} (European emission allocation)			
Non-ETS sectors emission reduction targets		10% (GHG-2005)	26% (GHG-2005)		
GHG reduction targets (electricity sector)					
Renewables targets (energy; % of final energy consumption)		20%	45%	60%	100%

ES: Grassroots	2016	2020	2030	2040	2050
Renewables targets (electricity; % of final energy consumption)	39%; 108 TWh; 49 GW	> 2016	80%		(By 2045 100%
Intermittent renewables	57 TWh; 28 GW	> 2016	> 2020	> 2030	> 2040
Wind onshore	49 TWh; 23 GW	> 2016	> 2020	> 2030	> 2040
Wind offshore	included above	= 2016	= 2016	= 2016	= 2016
Solar PV	8 TWh; 5 GW	>> 2016 (mainly decentralised)	>> 2020 (mainly decentralised)	>> 2030 (mainly decentralised)	>> 2040 (mainly decentralised)
Dispatchable renewables	51 TWh; 21 GW	> 2016	> 2020	> 2030	> 2040
Biomass	5 TWh; 1 GW	> 2016	> 2020	> 2030	> 2040
Hydro	40 TWh; 14 GW	> 2016	> 2020	> 2030	> 2040
CSP	6 TWh; 2.3 GW	> 2016	> 2020	> 2030	> 2040
Other renewables	1 TWh				
Traded renewables	As little as possible	As little as possible	As little as possible	As little as possible	As little as possible
Physical import of renewables (cooperation)					
Statistical transfer of renewables (cooperation)					
Explicit trade of CSP or hydropower					
Nuclear	59 TWh; 7 GW	Phase-out as licences expire: Almaraz I, II, Vandellós II (2020); Ascó I, II, Cofrentes (2021); Trillo (2024)	0 (by 2025)	0	0
Fossil fuels	108 TWh; 48 GW				
CCS	0				

ES: Grassroots	2016	2020	2030	2040	2050
Lignite	0 TWh	<< 2016	0 (by 2025)	0	0
Hard coal	36 TWh	<< 2016	0 (by 2025)	0	0
Gas	54 TWh	< 2016	< 2020	< 2030	< 2040
Petroleum	16 TWh	< 2016	< 2020	< 2030	0
Other non-renewables	1 TWh	≥ 2016	≥ 2020		
Storage					
Battery		> 2016	> 2020	> 2030	> 2040
Pumped Hydropower					
Other storage		> 2016	> 2020	> 2030	> 2040
Cross-border interconnection NTC		≥10% of installed cap.	≥15% of installed cap.	= 2030	= 2040
Electrification of additional sectors					
Total heating demand incl. non-electric heating					
Heating with electricity		Same as dominant	Same as dominant		
Total cooling demand incl. non-electric cooling					
Cooling with electricity		Same as dominant	Same as dominant		
Electric mobility		4.9 TWh; 3% of new sales are EV by 2020, 25% by 2025	70% of new sales; 16.8 TWh* (20% less than dominant)	100% of new sales (same as dominant)	
EV chargers		>> 2016	> 2020	> 2030	≥ 2040
Gross electricity consumption	275 TWh	267 TWh (same as dominant)	280 TWh**		
Final energy consumption	983 TWh	1035 TWh (same as dominant)	927 TWh***	***	

* 3% of new vehicles as electric vehicles in 2020, 25% in 2025 and 70% in 2030 lead to a cumulative EV fleet of around 4.2 million vehicles, 19% less than in the dominant pathway.

** Same as dominant, but slightly lower electrification of transport leads to slightly lower electricity demand.

*** 40% reduction in primary energy demand vs 39.6% in dominant and 3% more of renewables in final energy (2030); 45% primary energy demand reduction compared to reference scenario (2040).

4.2.4 Minority pathway: market-centred (Partido Popular)

By 2050, Spain had achieved an 80% decarbonisation of its economy in a manner that was economically efficient and hence not only meeting international commitments, but also in a way that was "beneficial for our families and companies" (Partido Popular, 2018). To achieve this, the government to the extent possible abstained from active interference in the market, except where necessary to correct market failures associated to environmental externalities and where international climate commitments threatened to not be met. Hence, among the few measures taken were market-based ones, in particular a carbon tax (for the non-trading sector), the EU emission trading scheme, and auctions for renewable power, leading to efficient levels of decarbonisation.

While all types of actors were enabled to carry out the transition, the private sector and particularly large corporations remained important drivers over the entire period, given their ability for large and cost-efficient investments. Besides renewable generators, especially utility-scale plants with lower specific generation cost, nuclear and fossil fuels with CCS played an important role in the energy transition towards a decarbonised economy. Increasing the interconnection capacity always ranked high in the government agenda as a pre-requisite for and cost-optimal exchange of electricity and balancing in the internal European electricity market.

Spain has always followed the trajectory prescribed by the EU, neither lagging behind nor rushing ahead, in order to achieve a coordinated, cost-efficient decarbonisation of Europe, together with the other EU Member States. Hence, the Spanish economy is 80% decarbonised by 2050 (compared to 1990), following the accomplishment of 26% reduction of emissions in the non-trading sector by 2030. The key to this was the implementation of the National Strategy for a Low-Emission Economy by 2050 guided the transition to a low carbon economy. Among other measures, this strategy was based on cost-efficient measures to increase energy efficiency and to deploy a mix of low-carbon technologies, leading to a cost-optimal mix of renewables, nuclear power and fossil fuels with CCS.

In order to make use of the most cost-efficient decarbonisation measures, the Spanish government did not define specific renewable energy or electricity targets beyond the 2030 renewable energy target (32% renewable energy). Instead, decarbonisation of all economic sectors counted equally; in the electricity sector, this led to the deployment of the renewables with the lowest system cost, in Spain and to the extent allowed by the interconnectors, abroad. As already in the period before 2018, renewable electricity deployment was promoted through technology-neutral auctions and a relative increase in competitiveness through carbon pricing.

While there was no specific target for **intermittent renewables**, given the lower cost of utility-scale PV and onshore wind power compared to other renewables and the technology-neutral design of the auctions (Popular, 2016), these two technologies became the main pillar of the Spanish system. Similarly, **dispatchable renewables,** including biomass (with and without CCS) hydropower and CSP, never had explicit targets, but were supported and their expansion happened at the time and place where they cost-efficient from a system perspective, in particular to balance PV and wind power.

Similarly, both **physical import and statistical transfer of renewables (through cooperation),** were important measures both for balancing the Spanish power system and to meet the EU-mandated renewables targets in a cost-optimal manner. This was further supported by the expansion of **new interconnectors**. This was one of the key priorities of the government, both to facilitate the completion of the internal electricity market and to allow increased trade, including trade with renewables to meet the targets (Partido Popular, 2018). To this end, the government both met and exceeded the EU-mandated interconnector targets.

Nuclear power continued to play a non-trivial role in the Spanish power system, as the old reactors were replaced at the end of their economic lifetimes. Yet, fossil-fuelled CCS and renewables were expanded to become the main pillars of the decarbonising Spanish power system; (Sociedad Nuclear Española, 2015; Partido Popular, 2018; Público, 2018). Consistent with the focus on cost-efficiency, there was no mandated closure of any power station, including coal power (Público, 2018); however, the increasing carbon price (within the EU ETS) started to force older coal/lignite power stations off the market from the 2020s onwards. The government also promoted gas interconnections in order to strengthen the European internal gas market through the gas coming from Africa (Popular, 2016).

Several measures were aimed at promoting the deployment of distributed generation and electric self-consumption and therefore an increased use of **decentralised batteries** followed (Partido Popular, 2018). The increased penetration of renewable energies made it necessary to increase the use of electricity storage technologies in the form of **grid-scale batteries and pumped hydropower** installations.

In the residential, institutional and commercial sector, various measures were put in place to improve and promote energy efficiency, zero emission buildings, distributed generation, electricity self-consumption, low emission heating and cooling systems and smart metering (Partido Popular, 2018). A sustainable transport sector was promoted with a special boost to the transport of goods by rail and the expansion of the *Cercanias* rail commuter network in big cities. Sustainable mobility in cities was supported creating point-to-point multi-modal mobility (Partido Popular, 2019). The promotion of the use of **electric vehicles** was limited to the expansion of a **network of charging points**, enabling but not directly supporting an expansion of the EV fleet (Partido Popular, 2018).

When it comes to public procurement, public tenders for new vehicles only allowed for alternative vehicle fuels, except for those vehicles that could not perform public duty or for unjustified economic costs. **Electrification of other sectors** was pursued to the extent that it supported a cost-optimal decarbonisation of society as a whole, and no specific targets or support measures for heating were introduced.

Summarising, the energy transition under this market-centred logic was mostly driven by private actors under an economy-wide decarbonisation target. The government took a few high-level, strategic decisions to ensure the alignment with EU energy and climate objectives and ambition and, whenever needed, the government used market-based instruments (carbon tax, technology neutral auctions for renewables, etc) to correct market failures and get the transition going. The government also put a special emphasis in increasing interconnections as a way to transition to an integrated and cost-efficient EU electricity market (see Table 6).

Table 6: Quantification of the Spanish market-centred minority policy pathway as described by Partido Popular.

ES: Market	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	283 Mt CO2eq	10% (GHG-2005)	Non-ETS 26%	> 2030	80%
ETS sector reduction targets	229 Mt Mt CO_{2eq} (European annual emission allocation)	219 Mt Mt CO_{2eq} (European annual emission allocation)			
Non-ETS sectors emission reduction targets		10% (GHG-2005	26% (GHG-2005)		
GHG reduction targets (electricity sector)					
Renewables targets (energy; % of final energy consumption)		20%	> 2020		
Renewables targets (electricity; % of final energy consumption)	39%; 108 TWh; 49 GW	> 2016	> 2020	> 2030	> 2040
Intermittent renewables	57 TWh; 28 GW				
Wind onshore	49 TWh; 23 GW	> 2016	> 2020	> 2030	> 2040
Wind offshore	included above	> 2016	> 2020	> 2030	> 2040
Solar PV	8 TWh; 5 GW	> 2016	> 2020	> 2030	> 2040
Dispatchable renewables	51 TWh; 21 GW	> 2016	> 2020	> 2030	> 2040
Biomass	5 TWh; 1 GW				
Hydro	40 TWh; 14 GW				
CSP	6 TWh; 2.3 GW				
Other renewables	1 TWh				
Traded renewables					
Physical import of renewables (cooperation)		> 2016	> 2020	> 2030	> 2040
Statistical transfer of renewables (cooperation)		≥ 2016	≥ 2016	≥ 2016	≥ 2016

ES: Market	2016	2020	2030	2040	2050
Explicit trade of CSP or hydropower					
Nuclear	59 TWh; 7 GW	= 2016	= 2016	= 2016	=2016
Fossil fuels	108 TWh; 48 GW				
CCS	0	> 2016	> 2020	> 2030	> 2040
Lignite	0 TWh	≤ 2016	≤ 2016		
Hard coal	36 TWh	≤ 2016	≤ 2016		
Gas	54 TWh	≥ 2016	≥ 2016	≥ 2016	≥ 2016
Petroleum	16 TWh				
Other non-renewables	1 TWh				
Storage					
Battery		> 2016	> 2020	> 2030	> 2040
Pumped Hydropower		> 2016	> 2020	> 2030	> 2040
Other storage					
Cross-border interconnection NTC		≥ 10% of installed capacity	≥ 15% of installed capacity	≥ 2030	≥ 2030
Electrification of additional sectors					
Total heating demand incl. non-electric heating					
Heating with electricity		Same as dominant	Less than dominant*		
Total cooling demand incl. non-electric cooling					
Cooling with electricity		Same as dominant	Less than dominant*		
Electric mobility		Same as dominant	Less than dominant*		
EV chargers		> 2016	> 2020	> 2030	> 2040
Gross electricity consumption	275 TWh	270 TWh; Same as dominant	279 TWh** Lower than dominant		
Final energy consumption	983 TWh	1035 TWh Same as dominant	987 TWh***		

* No specific policies addressing the electrification of other sectors. No specific EV promotion policies.
** Lower than the dominant due to lower electrification of end use sectors. Taken as the trend scenario of the NECP.
*** calculated using a 32.5% reduction of primary energy from the reference scenario and a factor to convert PE to FE higher than in the dominant due to the reduced penetration of renewable energies (32% vs 42% in the dominant).

4.3 France

4.3.1 Representative organisations

French policy has traditionally been defined by two large parties, the Socialists and the conservative UMP (and its predecessor parties). The last years have been marked by large political shifts, which have greatly diminished the old parties, and in particular the Socialist party, and given rise to two new strong parties in parliament, the liberal *En Marche* of President Macron, and the right-wing *Rassemblement National*.

France is governed by the National Assembly (Parliament), the Senate (Representation of the Territorial Collectivities) and the President. The President is elected directly and powerful, and can, for example, appoint the Prime minister or dissolve the government.

A dominant issue in French energy policy has been and remains nuclear power, which supplies about ¾ of the French electricity. Most French political parties are more or less pro-nuclear power, and although some seek to reduce its role and diversify the power supply, few parties want to abandon it completely.

In general, France is seeking a leadership role in the fight against climate change and energy transition. As such, it has been active in promoting renewable electricity and energy policies, especially internationally. Nationally, the role of renewable energies is highlighted, yet given the large share of CO_2-neutral nuclear energy, this is not an extremely urgent topic.

Currently, 8 parties are represented in the national assembly (see Table 7). The current President Emmanuel Macron is supported by the liberal parties *La République En Marche* and the *Mouvement democrate*. Measured in number of seats, they have a majority in the National Assembly.

Table 7: Parties currently (November 2018) represented in the French national parliament.

Party	National Assembly election 2017
La République En Marche	28.2%
Les Republicains	15.8%
La France Insoumise	11.0%
Parti Socialiste	7.4%
Mouvement democrate	4.1%
Union des democrats et independants	3.0%

As President Macron and the new government have not yet implemented any significant changes to the French energy policy, the dominant pathway here is the one decided and implanted by the previous President, the socialist Hollande. This is a state-centred pathway, focused on diversifying the French power supply by reducing the dominance of nuclear and scaling up renewables in a controlled manner through strong state policies. The 2019 French draft NECP strongly builds on this dominant pathway and the Macron government introduces only minor amendments: the French energy policy as described in that dominant pathway has its origin with the Hollande government and is executed without major changes by the Macron government.

For the minority pathways, we identified two parties with energy strategies representative for the remaining two corners of Foxon's triangle. We base the grassroots-centred minority pathway of the energy policy position of the Green party *Europe Écologie – Les Verts* (EELV). This strategy foresees the phase-out of nuclear power by 2030 and the expansion of mainly decentralised renewables to compensate the lost capacity, triggered by carbon prices and feed-in tariffs. We base the market-centred pathway on the position of the liberal party *En Marche,* which foresees a moderately fast transition of the energy system triggered by carbon taxes and a ban on internal combustion engine cars.

In addition, we also include the strategy of the right-wing *Rassemblement National* (previously Front National), which rejects climate change mitigation as a valid policy aim and instead puts French energy autonomy at the top of its energy agenda, to be achieved by strong centralised policies (making it in essence a state-centred pathway, but without the perceived need for an energy transition to a carbon-neutral future). The consequence is an isolated French electricity system strongly dominated by nuclear power, but also with renewables, as the only large domestic French energy resource.

4.3.2 Dominant pathway: state-centred (Hollande and Macron governments)

In 2050, France has arrived at the decarbonisation envisaged in the Energy Transition Law (ETL, 2015). The motivation for the design and passing of the ETL was clear: to make France – in the run-up to the Paris Climate Summit – an exemplary nation in terms of reducing its greenhouse gas emissions, diversifying its energy supply and increasing the deployment of renewable energy sources, as made a key national goal by president Hollande personally (Ministry of the Environment Energy and the Sea, 2016b). The pathway taken by France was strongly controlled by the state, which directly mandated both the shut-down of a range of nuclear reactors and coal power in the 2020s and the replacement of the remaining ones thereafter (Barroux, 2016b), and directed the rapid scale-up of renewables in a tightly controlled 4:1 ratio of wind and solar power to replace the phased-out generators in a secure and stable manner; it also conducted shifts in other sectors, including a roll-out of new infrastructure for electric cars.

The overarching goal of the implemented strategy had been to make a more effective contribution to tackling climate change and reinforce the French energy independence, while also diversifying its energy mix and creating jobs and growth. Further, it was also shaped by a strong intention to show international climate leadership, especially ahead of the UNFCCC conference in Paris 2016 (Ministry of the Environment Energy and the Sea, 2016a), under a green growth paradigm, opening up new opportunities for innovative companies (Hollande, 2016). The French greenhouse gas emissions were reduced by 40% between 1990 and 2030 and by 75% by 2050 (with respect to 1990). The underlying target of a "factor 4" carbon-efficiency target was proposed already in 2005 (EPL, 2005), and confirmed in the Grenelle Laws (Grenelle I Law, 2009; Grenelle II Law, 2010). Even at that time, this objective had permeated all French institutions and society at large for over a decade (IDDRI, 2018).

The electricity sector was a primary field of action in order to comply with the target of a 75% reduction of greenhouse gas emissions until 2050 established in the Energy Policy Law from 2005. The power sector was highly decarbonised already in 2016, given the ¾ share nuclear power. In order to comply with other targets than climate, including reducing dependency on a single electricity source, the share of **nuclear** power was reduced to 50% in 2025 (ETL) by the mandated shut-down of 24 reactors by 2025 (IDDRI, 2018). The remaining capacity was replaced: the nuclear capacity remained constant between 2025 and 2050.

During the 2020s, France accelerated **wind and solar PV** power deployment to achieve its 40% renewables target in power production in 2030. This was done through a premium (*complément de rémunération*) paid to renewable power producers in addition to the price received on the regular power market. This strategy was continued until the share of renewable power hit 50% in 2050.

In combination, the reduction of firm nuclear capacity and an increasing penetration of wind and solar PV as intermittent renewable power sources created new electricity grid challenges, requiring a substantial refurbishment of the power system and network (Ministry of Ecological and Solidary Transition, 2016c). To increase the manageability and control of the power system, France acted on several fronts.

It maintained the controllability and stability of the power system through four separate policy approaches. First, it increased the amounts of **dispatchable renewables**, especially biomass, while also increasing the energy output of hydropower without expanding the capacity (ADEME, 2016b, c; Ministry of Ecological and Solidary Transition, 2016c). Further, France built up a small fleet of CSP (0.4 GW). Second, intermittency was addressed by tying the solar and wind power expansion rates to each other, to minimise the seasonal variability: solar and wind are anticorrelated in France on a seasonal scale (ADEME, 2016c). Third, geographical diversification of electricity generators increased the resilience of the system. By spreading generation across the country, both for intermittent renewables and dispatchable nuclear and renewables across the country helped stabilise all parts of the grid, especially as the different regions were tied tighter together through improvements in the domestic transmission grid (ADEME, 2016c). Fourth, France introduced **direct electricity storage** (batteries), mainly to deal with intra-day and -week supply fluctuations. Fifth, France from the 2030s on increased sector coupling between electricity and gas through a large-scale expansion of **power-to-gas** (methane) and gas-to-power, capable of “storing” up to almost 50 TWh electricity to balance the power system (ADEME, 2018).

Another pillar of the French energy transition was **energy efficiency,** especially by insulating buildings and reducing the heating need, but also through electrification. Although final energy consumption had decreased significantly (by 20% in 2030 and by 50% in 2050), electricity consumption remained constant over time, and is still 420 TWh in 2050 (ADEME, 2016a).

Regarding European cooperation and electrical **interconnections** with neighbouring countries, France already had a high number of already existing physical cross-border electricity connections in 2018, and did not expand them beyond the European interconnection requirements. France was and is an important net exporter of electricity of around 50 TWh yearly (more than 10% of total production) to all of its neighbouring countries except Germany (Ministry of Ecological and Solidary Transition, 2016a; Pelé, 2018). Further, France was reluctant to increase its electricity interconnections with Spain, which remained low.

To sum up, the government-led strategy included in the Energy Transition Law, which had been approved with a wide political consensus, significantly reduced greenhouse gas emissions by encouraging renewables and energy efficiency through several policies and measures, while also addressing the challenges of intermittency and manageability of an increasing renewable generation which replaced nuclear (see Table 8).

Table 8: Quantification of the French state-centred dominant policy pathway as described by currently valid policies of the Parti Socialiste and its government.

FR: Dominant	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	421 Mt CO_{2eq}	-20% (GHG-1990)	-40% (GHG-1990)		-75% (GHG-1990) / Max. 140 Mt CO_{2eq}
ETS sector reduction targets	393 Mt Mt CO_{2eq} (European emission allocation)	355 Mt Mt CO_{2eq} (European emission allocation)			
Non-ETS sectors emission reduction targets		14% (GHG-2005	37% (GHG-2005)		
GHG reduction targets (electricity sector)					
Renewables targets (energy; % of final energy consumption)		23% 71-78 GW (By: 2023); 150-167 TWh by 2023 23%	34%		
Renewables targets (electricity; % of final energy consumption)	18%; 102 TWh; 40 GW		40%	Close to but below 50%	50%
Intermittent renewables	30 TWh; 19 GW				
Wind onshore	21 TWh; 11 GW		4-to-1 ratio (wind onshore to PV)	4-to-1 ratio (wind onshore to PV)	4-to-1 ratio (wind onshore to PV)
Wind offshore	included above				
Solar PV	8 TWh; 7 GW		4-to-1 ratio (wind onshore to PV)	4-to-1 ratio (wind onshore to PV)	4-to-1 ratio (wind onshore to PV)
Dispatchable renewables	73 TWh; 21 GW	≥ 2020 (by 2023)	≥ 2023	≥ 2030	≥ 2040
Biomass	5 TWh; 1 GW	≥ 2020 (by 2023)	≥ 2023	≥ 2030	≥ 2040
Hydro	65 TWh; 18 GW	≥ 2016 (by 2023) (TWh); =2016 (by 2023) (GW)	≥ 2016 (by 2023) (TWh); =2016 (by 2023) (GW)	≥ 2016 (by 2023) (TWh); =2016 (by 2023) (GW)	≥ 2016 (by 2023) (TWh); =2016 (by 2023) (GW)
CSP	0 TWh; 0 GW				0.4 GW
Other renewables	3 TWh				
Traded renewables					

FR: Dominant	2016	2020	2030	2040	2050
Physical import of renewables (cooperation)					
Statistical transfer of renewables (cooperation)					
Explicit trade of CSP or hydropower					
Nuclear	403 TWh 63GW		By 2025: 50% of mix	= 2030	= 2030
Fossil fuels	51 TWh; 23GW		-30% (GW-2012)		
CCS	0				
Lignite	0 TWh				
Hard coal	8 TWh	By 2023: -37% (GW-2012)			
Gas	37 TWh	By 2023 -15.8% (GW-2012)			
Petroleum	2 TWh	By 2023: -22.4% (GW-2012)			
Other non-renewables	3 TWh				
Storage					
Battery					Technologically unspecified direct storage interweekly and interdaily >> 2016
Pumped Hydropower		= 2016	= 2016	= 2016	= 2016
Other storage					200 TWh (Power-to-gas) 10-46 TWh (Gas-to-power)
Cross-border interconnection NTC		≥ 2016	≥ 15% of yearly power production	= 2030	= 2030
Electrification of additional sectors					
Total heating demand incl. non-electric heating		By 2023: +50% (TWh-2014)	Growth rate of heating and cooling by RETs: +1%/year between 2020 and 2030		
Heating with electricity			38% (RES-E)		

FR: Dominant	2016	2020	2030	2040	2050
Total cooling demand incl. non-electric cooling					
Cooling with electricity					
Electric mobility		By 2023: 2.4 million EV	4 million EV	Ban on new ICE	
EV chargers			7 million chargers		
Gross electricity consumption	556 TWh	< 556 TWh	-20% (2012) << 556 TWh	< 2030	420 TWh
Final energy consumption		1528 TWh	1368 TWh	<1368 TWh	<<1368 TWh

4.3.3 Minority pathway: outside the energy transition logics framework (Rassemblent National)

In 2050 France has a largely decarbonised electricity sector, but only marginally more decarbonised than in 2017. This is so because the share of nuclear in electricity generation, which already represented ¾ of its power mix in 2017, has remained at the same level, but the share of fossil fuels has been halved and renewables (solar, biomass and hydro) have filled the resulting gap (Barroux, 2016a). The government has had a strong role in leading these trends, given its "energy independence" goal, guided by a philosophy of an autarkic France and a rejection of multilateralism (including a rejection of "Europe"), and of international energy or electricity exchange. In this context, the government has not been committed to comply with the Paris Agreement, but in the French context, electricity decarbonisation happened as a side-effect of the energy independence ideal (Barroux, 2016a; Laconde, 2017). Climate, as all other (potential) policy areas was believed to be a "national issue", if at all relevant. A main objective has been to nationalise ("keep control") EDF as the central actor in the electricity sector, and a way for the state to keep direct control of the electricity system (Laramée, 2017; Pié, 2017; article 134 of the programme of the Rassemblement National, 2017). The party has been against any market-based instruments and, particularly, fiscal instruments or emissions trading, relying rather on command and control regulation and using EDF to this purpose (Astier, 2017; Brezet, 2017b; Pié, 2017). Thus, the state has strongly controlled the energy pathway leading to this future, using EDF as the central instrument to achieve the government's goals and interests.

The centrepiece of the electricity strategy was and remains **nuclear power**, which maintains its 75% share of the power mix. To achieve this, existing laws were revoked around the turn to the 2020s, as the old energy transition law was amended to allow the "maintenance of the nuclear industry", to keep the economic benefits of depreciated, existing reactors (Gobert, 2017; Murer, 2014) and to ensure that nuclear power remains a key contribution to French energy independence (Astier, 2017). The party has aimed to maintain and modernise the safe operation of the French nuclear sector. It has extended the lifetime of the EDF reactors (by an additional 20-30 years beyond their 40 years lifetime, called the "Grand carénage") (Brezet, 2017b; Cherki, 2017; Dupin, 2017b). In order to maintain France's nuclear industry, the state has kept control of EDF and given it "a true mission of public service" (Electoral Programme of the Rassemblement National, 2017).

The government has defended the deployment of **renewables** in electricity generation, following its goal of a "massive development of renewable energy sectors" and guided by its own principles of "intelligent protectionism" and "economic patriotism" (Astier, 2017; Institut Montaigne, 2018; Les Echos, 2017; Pié, 2017). This deployment of renewables, both for self-consumption and feed-in to the central grid, has been based on hydro, biomass and biogas, and from 2040 onwards also PV, leading to the development of a "renewable energy mix" to complement the nuclear fleet (Joffre, 2017).

A **moratorium on new wind power** (both on-shore or off-shore) was passed in 2018. This was based on the idea that wind energy was polluting (visual impacts), expensive, it needed back-up when the wind is not blowing, and that its impacts on health had not been well assessed (Astier, 2017; Challenges, 2012; Durox, 2018; Le Pen, 2015; Odoul, 2018). Thus, the installed wind capacity has remained constant between 2017 and 2050. Similarly, hydropower remained constant across the decades until 2050, despite it being seen as a highly reliable domestic resource, not subject to the weather variability problems of solar and wind power, as the potential for further expansion was limited (Aliot, 2018; Astier, 2017; Coativy, 2018; Laramée, 2017).

Within solar, **PV** was given pre-eminence, but reluctantly: because PV was seen to be "made of rare earth elements which led to the discharge of very toxic elements in the Chinese mines" (Lechevalier, 2018), its expansion was stopped in 2018. This disqualified PV, until innovation allowed the emergence of a second generation of PV which was 100% clean (Lechevalier, 2018). However, when this second generation became available in 2040, the French PV expansion re-started, as a step towards more energy independence. CSP was not explicitly supported, but was rather seen as more adapted to the "Southern European countries and the South of France; its share of French power remains zero also in 2050 (Joffre, 2017).

In 2035, the share of **fossil fuel energy sources** in electricity generation has been halved compared to 2017 (Barroux, 2016a). In 2050, no fossil fuels are used in electricity generation (Astier, 2017; Joffre, 2017). The government has forbidden the exploration of possible wells for shale gas and, thus, based on its policy goal of "energy independence", by 2050, there are no fossil fuels in the power mix anymore (Astier, 2017; Cherki, 2017). The reduction of fossil fuels in electricity generation in 2035 has been filled by nuclear power (including reduced electricity exports) and in 2050 also by renewables (Joffre, 2017; Laconde, 2017).

The role of **hydrogen** as an energy carrier was expanded from the 2020s on, borne by the rise of a national hydrogen industry supported through public R&D funds. On the one hand, this allowed the emergence of long-term and large storage coupled with dispatchable generation of electricity as a central system balancing measure (Astier, 2017; Joffre, 2017; Murer, 2014): the hydrogen is produced through power-to-gas technology by using excess nuclear power at night (Joffre, 2017), and used during day or whenever needed to balance the power system. Further, domestically produced hydrogen has been used to drive the French fleet of hydrogen cars, as a step towards eliminating the French dependency on imported oil. Electromobility has not been a focus of the government, and its role remains small also in 2050 (Brezet, 2017b).

Interconnections with neighbouring countries played a minor role in French energy policy, which was thought of as a purely national topic. An energy-autarkic France was considered one that manages demand and production effectively, without having to recur to exports or imports with neighbouring countries in order to counteract surpluses or shortages in the system. Instead, France cooperated in a series of specific renewable power projects with its neighbouring countries. Yet these projects had very little impact on both French and foreign energy mixes and the interconnection capacities existing in 2017 were more than sufficient to deal with the electricity exchange needs (Martin, 2016).

Energy efficiency has been, in principle, a goal of the government insofar as it supports the independence goal. In practical terms, policy measures were restricted to ensure that demand did not soar, whereas the level of consumption per se was never of interest to the government (Brezet, 2017b).

To sum up, the main logic of this pathway has been to comply with the energy independence goal, in a context of "unilateralism" and strong government role, with a central role of EDF as an instrument of the government to achieve its goals. The result was a still large role of nuclear power and a new significant amount of renewable power, leading – as a side-effect – to a fully decarbonised power system by 2050 (see Table 9). A state control of EDF was adopted. Civil society and the market do not play a relevant role in this pathway.

Table 9: Quantification of the French minority policy pathway (outside the energy transition logics framework) as described by Rassemblement National.

FR: Outside logic	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	421 Mt CO_{2eq}				
ETS sector reduction targets	393 Mt CO_{2eq} (European annual emission allocation)				
Non-ETS sectors emission reduction targets		14% (GHG-2005)	37% (GHG-2005)		
GHG reduction targets (electricity sector)					
Renewables targets (energy; % of final energy consumption)					
Renewables targets (electricity; % of final energy consumption)	18%; 102 TWh; 40 GW				All that is not covered by nuclear power. Applies to solar and biomass
Intermittent renewables	30 TWh; 19 GW				
Wind onshore	21 TWh; 11 GW	= 2018	= 2018	= 2018	= 2018
Wind offshore	included above	= 2018	= 2018	= 2018	= 2018
Solar PV	8 TWh; 7 GW	= 2018	= 2018	> 2030	> 2040
Dispatchable renewables	73 TWh; 21 GW				

FR: Outside logic	2016	2020	2030	2040	2050
Biomass	5 TWh; 1 GW		= 2018	> 2030	> 2040
Hydro	65 TWh; 18 GW	= 2018	= 2018	= 2018	= 2018
CSP	0 TWh; 0 GW	0	0	0	0
Other renewables	3 TWh	0	0	0	0
Traded renewables					
Physical import of renewables (cooperation)		0	0	0	0
Statistical transfer of renewables (cooperation)		0	0	0	0
Explicit trade of CSP or hydropower		0	0	0	0
Nuclear	403 TWh; 63 GW	75% of mix	75% of mix	75% of mix	75% of mix
Fossil fuels	51 TWh; 23 GW			By 2035: -50% (FE-2016)	0
CCS	0				
Lignite	0 TWh				0
Hard coal	8 TWh				0
Gas	37 TWh			-50% (2018)	0
Petroleum	2 TWh				0
Other non-renewables	3 TWh				
Storage					
Battery					
Pumped Hydropower					
Other storage				>2016 (hydrogen)	> 2040 (hydrogen)
Cross-border interconnection NTC			=	=	=
Electrification of additional sectors					
Total heating demand incl. non-electric heating					
Heating with electricity					
Total cooling demand incl. non-electric cooling					
Cooling with electricity					
Electric mobility		0 EV	0 EV	0 EV	0 EV
EV chargers					
Gross electricity consumption	556 TWh				
Final energy consumption					

4.3.4 Minority pathway: grassroots-centred (Europe Écologie – Les Verts)

Inspired by political ecology thinking, EELV advocated a new relationship with nature based on the respect of species and protection of nature and biodiversity. Hence, the EELV-led government achieved a fully renewable power system by 2050, having phased out nuclear, gas and coal power to this date. The shortfall was compensated by mainly decentralised renewables, and by efficiency measures to control and reduce demand. In order to adopt environmentally-friendly consumption and production models, EELV supported a wide array of policies, all referring to the idea of "energy sobriety", such as a focus on local resources and policy-making, the construction of local and small resilient systems, energy autonomy, and communal solutions (AFP & Sciences et Avenir, 2018; EELV, 2018a, d). These solutions foreshadowed a new society model based on confidence, the "humankind commune" and the "socialist commune" (AFP & Sciences et Avenir, 2018). A long-term energy transition strategy to a renewables-based energy system was implemented, to get rid of polluting fossil fuel energy sources (EELV, 2018d). Furthermore, deployment of renewables was regarded as a way to decentralise energy decisions and achieve a more "democratic" energy system, which involved participation of civil society (EELV, 2018d; RSE, 2015). The aim was to redirect the economy and empower civil society actors and citizens to play an active role in the transition (Dupin, 2017a), for example by prioritising distributed energy production and self-consumption (EELV, 2018d), within a collaborative international and European policy context (AFP & Sciences et Avenir, 2018). The power decarbonisation required both European cooperation and a massive decentralisation of energy services (EELV, 2018d). The environmentally-friendly fiscal system was a powerful driver of the modification of individual and collective behaviour (AFP & Sciences et Avenir, 2018), such as a CO_2 tax starting at €36 and increasing over time (RSE, 2015).

A key energy principle of EELV has been to **consume less, but to consume better** ("*Consommer moins, consommer mieux*"). An energy policy based on sobriety and energy efficiency has been implemented in all sectors of activity in order to reduce energy consumption while ensuring the best services for the population (AFP & Sciences et Avenir, 2018; EELV, 2018d). The EELV quickly reduced the share of nuclear and fossil fuels in electricity generation and increased the share of renewables correspondingly.

Renewable electricity (PV, wind, hydro, biomass and biogas) was rapidly increased, and accounted for 40% of electricity generation in 2020 (Dupin, 2017a; EELV, 2018b). The country reached the European-set 32% target for renewables in total energy consumption by 2030 (AFP & Sciences et Avenir, 2018). France achieved its target of 100% renewables in electricity generation in 2050, with a particular focus on decentralised generation (EELV, 2018b, d; RSE, 2015; Théobald, 2016). This has been achieved by an ensemble of stable and predictable policy measures giving priority to local renewable energy and electricity production and self-consumption and support for energy saving projects, including support for industry and businesses to build their own renewable energy generators (support for business start-ups, research efforts, etc.), the adoption of feed-in tariffs for renewable electricity, heat and gas and for renewable cogeneration to achieve the objectives set and by consultation between stakeholders (EELV, 2018b).

The **intermittency problem** has been handled through an overall lower electricity consumption and increased flexibility allowed by smart grids, greater storage capacity ("close to the point of electricity production") and a balanced power mix making use of the geographical and time-of-day complementarity between wind power and solar PV (EELV, 2018b). CSP was never expanded in

France, and hence its share in the power mix remained zero. Because of its low potential for expansion, hydropower remains constant throughout the period 2009-2050.

Nuclear power had no role to play in the decentralised, local energy system. Hence, nuclear power experienced a sharp reduction between 2017 and 2032, reaching 40% in 2020 and 0% in 2032 (EELV, 2018b; Théobald, 2016). The nuclear plants were closed at the end of the 40 years of lifetime initially foreseen by EDF (EELV, 2018d; RSE, 2015).

Similarly, **coal power** was abandoned in electricity generation by 2030, to allow for further decentralisation and to reach the climate target (EELV, 2018b, d). **Natural gas power** was gradually reduced and disappeared completely as the last station was closed in 2030 (CCGT and cogeneration) (RSE, 2015).

Regarding **heat production**, the objective has been to ensure that 40% of heat consumption was met with renewables (biomass and geothermal) (EELV, 2018b). Local district-and building integrated production was prioritised over centralized production (EELV, 2018b).

An energy policy based on sobriety and **energy efficiency** in all sectors has been key in reducing greenhouse gas emissions (together with the removal of coal power) and to fill the electricity gap following the nuclear phase-out. Final energy consumption has been reduced by 15% in 2020 and 50% in 2050 (compared to 2009 levels) (RSE, 2015). The energy efficiency policy has mostly been based on the energy renovation of buildings (EELV, 2018d).

To sum up, a main feature of this pathway is not only what the policy goals have been and what decisions have been taken but how they have been taken and who is the main actor in such decisions. Although a key role of the government exists, this pathway and party (EELV) is the one giving a more prominent role in energy consumption and production to the citizens (EELV, 2018d). In sum, the policies of EELV led to a fully decarbonised, largely decentralised power system based on the resources available for electricity generation in the different regions of France (see Table 10).

Table 10: Quantification of the French grassroot-centred minority policy pathway as described by Europe Europe Écologie – Les Verts.

FR: Grassroots	**2016**	**2020**	**2030**	**2040**	**2050**
GHG reduction targets (economy-wide)	421 Mt CO_{2eq}	-30% (GHG-1990)	-40% (GHG-1990)		-85% (GHG-1990)
ETS sector reduction targets	393 Mt CO_{2eq} (European emission allocation)	355 Mt CO_{2eq} (European emission allocation)			
Non-ETS sectors emission reduction targets		14% (GHG-2005)	37% (GHG-2005)		
GHG reduction targets (electricity sector)					
Renewables targets (energy; % of final energy consumption)					

FR: Grassroots	2016	2020	2030	2040	2050
Renewables targets (electricity; % of final energy consumption)	18%; 102 TWh; 40 GW	40%; 175 TWh			100%
Intermittent renewables	30 TWh; 19 GW				
Wind onshore	21 TWh; 11 GW	10-60 TWh (incl. offshore) / 14%	≥ 2020	≥ 2030	≥ 2040
Wind offshore	included above	≥ ()	≥ 2020	≥ 2030	≥ 2040
Solar PV	8 TWh; 7 GW	25 TWh (6%) (mainly decentral)	≥ 2020 (mainly decentral)	≥ 2030 (mainly decentral)	≥ 2040 (mainly decentral)
Dispatchable renewables	73 TWh; 21 GW				
Biomass	5 TWh; 1 GW	4.5%	≥ 2020	≥ 2020	≥ 2020
Hydro	65 TWh; 18 GW	70 TWh (16% of mix)	= 2020	= 2020	= 2020
CSP	0	0	0	0	0
Other renewables	3 TWh				
Traded renewables					
Physical import of renewables (cooperation)					
Statistical transfer of renewables (cooperation)					
Explicit trade of CSP or hydropower					
Nuclear	403 TWh; 63 GW	40% (2012)	0 by 2032	0	0
Fossil fuels	51 TWh; 23 GW				
CCS	0	0	0	0	0
Lignite	0 TWh	0	0	0	0
Hard coal	8 TWh	0	0	0	0
Gas	37 TWh	20% of mix (combined cycle)	0	0	0
Petroleum	2 TWh	0	0	0	0
Other non-renewables	3 TWh				
Storage					
Battery		> 2016 (decentralised)	> 2020 (decentralised)	> 2030 (decentralised)	> 2040 (decentralised)
Pumped Hydropower		≥ 2016	≥ 2020	≥ 2030	≥2040
Other storage		> 2016	> 2020	> 2030	> 2040
Cross-border interconnection NTC		≥ 2016	≥ 2020	≥ 2030	≥ 2040

FR: Grassroots	2016	2020	2030	2040	2050
Electrification of additional sectors					
Total heating demand incl. non-electric heating					
Heating with electricity		40% RES-H	≥ 2020	≥ 2030	≥ 2040
Total cooling demand incl. non-electric cooling					
Cooling with electricity					
Electric mobility		By 2025: -20% (GHG-1990) (mainly e-mobility and reduced demand)	-45% (GHG-1990) (mainly e-mobility and reduced demand)		
EV chargers					
Gross electricity consumption	556 TWh	< 556 TWh << dominant	<< 556 TWh << dominant	<< 556 TWh << dominant	360 TWh << dominant
Final energy consumption		<< dominant	<< dominant	<< dominant	<< dominant

4.3.5 *Minority pathway: market-centred (La République en Marche)*

In 2050, the French economy achieved a 75% decarbonisation compared to 2005, through effective and efficient involvement of the entire society in the energy transition, including businesses and citizens. The key paradigm of *En Marche*'s policy was to set an overarching framework for meeting climate and energy targets but to leave it to the various actors to decide exactly how the targets were to be achieved. In particular, this meant the continuation of the EU ETS and the additional implementation of a carbon tax for the non-trading sector, as the two central energy and climate policy instruments between 2017 and 2050. These instruments led to very large investments from the private sector, triggered both by the carbon prices themselves and by government support using funds raised by the tax and auctions of emission allowances (Energie Plus, 2017; Qualit-EnR, 2017). The carbon tax, applicable for the non-trading sector, has increased substantially during these years, from €56 per ton in 2020 to €100 per ton in 2030, following the trajectory of the Energy Transition Law (En Marche, 2017b; Qualit-EnR, 2017). International cooperation, both within Europe (especially within the European common energy and electricity markets) and globally, including within UNFCCC, have been central elements to achieve cost-efficient decarbonisation of the French energy sector, which was 75% decarbonised by 2050 compared to 2005 (En Marche, 2017b).

The carbon price policies accelerated the rate of growth of **renewables**, which represented 40% of electricity generation in 2030, replacing all fossil power, as it had become unprofitable by this date. Both wind and PV capacity doubled during the five-year period 2018-2022 and continued to grow thereafter (Clavel, 2018; De Ravignan, 2018; En Marche, 2017a, b, 2018). The government relied on regular auctions to let the renewable grow in a cost-efficient manner, close to the market (Brezet, 2017a; Roux-Goeken, 2017). No targets or signals on the decentralisation of energy production/consumption activities (self-consumption) were set, and renewables grew in the most cost-effective way, unconstrained by unnecessary government interference (Brezet, 2017a; Roux-

Goeken, 2017). Energy R&D focused on storage and smart grids, has been a main government priority of the Macron government, enabling the efficient deployment of electricity storage to the amount needed to balance the growing fleet of intermittent renewables (Brezet, 2017a). This made storage and the efficient (both for France and Europe as a whole) use of **interconnectors** to neighbouring countries the key balancing measures for the French power system.

The share of **nuclear** in electricity generation has been reduced to 50% by 2025 (En Marche, 2017b; Qualit-EnR, 2017) due to the closing of old reactors (Brezet, 2017a; Ryon, 2017). Over the decades, after 2025, the share of nuclear power remained by 50%, as reactors were replaced by new ones. The last **coal-based** electricity generation plants were closed in 2023, in order to support the climate targets (En Marche, 2017b; Energie Plus, 2017; Feuilleux, 2017). For environmental reasons, the exploration of **shale gas** was forbidden and new permits for hydrocarbon explorations were not issued (En Marche, 2017b; Energie Plus, 2017).

The deployment of **electric cars** was accelerated rapidly from 2018 onwards, making France a central market for electric vehicles. Key measures for this was economic incentives such as the introduction of a bonus-malus scheme for the purchase of vehicles, and the acceleration in the electricity recharging points (En Marche, 2017b; Energie Plus, 2017; Hulot, 2017). Since 2040, following the entry-into-force of the ban of new internal combustion engines, no internal combustion vehicle, including both cars, buses and trucks, has been sold in France (Brezet, 2017a): all new vehicles from 2040 were electric.

Energy efficiency has been a priority of the government in the past, mostly related to the refurbishment and insulation of private and public buildings (Brezet, 2017a; En Marche, 2017b). Four billion Euros were dedicated to refurbishments of public buildings (En Marche, 2017b). The insulation of 1 million buildings was improved between 2018 and 2022.

To sum up, the actions of the government have been in line with the energy transition law, relying on the role of private actors to drive the energy transition encouraged by the (few) strategic decisions of the government, government support leveraging private investments and market-based instruments such as carbon taxes and auctions for renewables (see Table 11).

Table 11: Quantification of the French market-centred minority policy pathway as described by La République en Marche, in government since 2017.

FR: Market-centred	**2016**	**2020**	**2030**	**2040**	**2050**
GHG reduction targets (economy-wide)	421 Mt CO_{2eq}		-40% (GHG-1990)		-75% (GHG-1990) Max. 140 million tons CO_{2eq}
ETS sector reduction targets	393 Mt CO_{2eq} (European annual emission allocation)	355 Mt CO_{2eq} (European annual emission allocation)			
Non-ETS sectors emission reduction targets		14% (GHG-2005)	37% (GHG-2005)		

MUSTEC
Market Uptake of Solar Thermal Electricity

FR: Market-centred	2016	2020	2030	2040	2050
GHG reduction targets (electricity sector)					
Renewables targets (energy; % of final energy consumption)			32%		
Renewables targets (electricity; % of final energy consumption)	18%; 102 TWh; 40 GW		40%		
Intermittent renewables	30 TWh; 19 GW	By 2022: +26 GW; +32 TWh	≥ 2020	≥ 2030	≥ 2040
Wind onshore	21 TWh; 11 GW	By 2022: +100% (2018)	≥ 2020	≥ 2030	≥ 2040
Wind offshore	included above				
Solar PV	8 TWh; 7 GW	By 2022: +100% (2018)	≥ 2020	≥ 2030	≥ 2040
Dispatchable renewables	73 TWh; 21 GW	> 2016	> 2020	> 2030	> 2040
Biomass	5 TWh; 1 GW				
Hydro	65 TWh; 18 GW				
CSP	0				
Other renewables	3 TWh				
Traded renewables					
Physical import of renewables (cooperation)					
Statistical transfer of renewables (cooperation)					
Explicit trade of CSP or hydropower					
Nuclear	403 TWh; 63 GW		By 2025: 50% of electricity mix	= 2025	= 2025
Fossil fuels	51 TWh; 23 GW		Min. -30% (2012)		
CCS	0	By 2023: 0	0	0	0
Lignite	0 TWh	By 2023: 0	0	0	0
Hard coal	8 TWh	By 2023: 0	0	0	0
Gas	37 TWh				
Petroleum	2 TWh	By 2023: 0	0	0	0
Other non-renewables	3 TWh				
Storage		≥ 2016	≥ 2020	≥ 2030	≥ 2040
Battery					
Pumped Hydropower					

FR: Market-centred	2016	2020	2030	2040	2050
Other storage					
Cross-border interconnection NTC		≥ 2016	≥ 2020	≥ 2030	≥ 2040
Electrification of additional sectors					
Total heating demand incl. non-electric heating		By 2022: 1 million buildings insulated			
Heating with electricity					
Total cooling demand incl. non-electric cooling					
Cooling with electricity					
Electric mobility		By 2023: 2.4 million EVs	4 million EVs	Ban on sale of any ICE vehicle	
EV chargers			7 million chargers		
Gross electricity consumption	556 TWh	< dominant	< dominant	< dominant	< dominant
Final energy consumption		< dominant	< dominant	< dominant	< dominant

4.4 Germany

4.4.1 Representative organisations

Traditionally, German Politics have been shaped by shifting majorities of its two major parties, the conservative *Christian Democratic Party of Germany* (CDU and CSU) and the *Social Democratic Party of Germany* (SPD). Either party formed coalitions with the German liberal party the *Free Democratic Party* (FDP). Together CDU/CSU, SPD, FDP have shaped the German electricity system that was highly centralised and divided between four large utilities and built on large scale fossil fuel and nuclear power stations. This stable regime was interrupted when the first coalition between SPD and the Greens (Bündnis 90/Die Grünen) came into power in 1998. With its origins in the anti-nuclear movement, the Greens pushed for a nuclear phase-out and to replace the declining nuclear capacity with renewables, a policy program that later became known as *Energiewende*. In the 2000s, the parliamentary landscape has evolved so that today six parties are represented in the *Bundestag*. This diversity has, however, failed to produce larger diversity in government coalitions, but instead lead to a higher incidence of *grand coalitions* of CDU/CSU and SPD.

Since 2013, Germany has been governed by a coalition of the two largest parties of CDU/CSU and SPD, both of which are invested in the status-quo of the German energy system. These parties have a majority in the parliament (see Table 12) and form the current government (together with CSU). Consequently, we use the currently valid policies of their ministries, party programs of SPD and CDU/CSU, and the government coalition agreements to inform the dominant pathway. This continuity is also reflected in the German draft NECP, which is a continuation of past plans, but also includes references to ongoing – nut not yet finished – legislative and stakeholder processes to phase out coal power and change the mobility sector to a carbon-neutral one.

Table 12: Result of the 2017 German federal elections (Bundeswahlleiter, 2017).

Party	**German federal elections 2017**
Christlich Demokratische Union Deutschlands (CDU)	26.8 %
Sozialdemokratische Partei Deutschlands (SPD)	20.5 %
Alternative für Deutschland (AfD)	12.6 %
Freie Demokratische Partei (FDP)	10.7 %
Die Linke	9.2 %
Bündnis 90/GRÜNE	8.9 %
Christlich-Soziale Union in Bayern (CSU)	6.2 %
Others	5.0 %

We base the market-centred minority pathway on the position of the liberal party, FDP. The main reason is that the party is strongly advocating for market-based mechanisms and aims to dismantle all technology-specific support, and subsidies in general. It expresses its position in policy proposals and has a well-developed energy policy position from the time when it was in government from 2009-2013. The FDP's policy aims fits well with the logic of a market-centred europeanisation of German energy policy.

The Green party developed out of the peace movement and a civil-society movement against nuclear power. Empowerment and democratic participation are still at the heart of the Green position, although the party also support higher carbon prices and other market-based mechanisms and favours strong government involvement in reducing fossil and nuclear power generation. This focus on empowering citizens and cooperatives to consume their own energy and to make their own energy decisions is at the core of the grassroots logic, and is strong in the Green party position as well. Moreover, the party has precise and elaborate positions on most of the variables that we investigate, resulting in an ambitious vision for complete decarbonisation to achieve Germanys full contribution towards the Paris agreements 1.5-degree goal.

The decision to leave out the other two parties in the German Bundestag has several reasons. The Left party (*Die Linke*) does not have an elaborate energy policy strategy, but mainly aims to ensure distributional fairness of existing policies, i.e. that people with low income are not excluded from energy consumption through decarbonisation policies. The Alternative for Germany (*AfD*) on the other hand does not support the goal of decarbonisation at all and often question the existence of anthropogenic climate change in general. They also argue for cheap electricity prices, through continued use of fossil fuels and giving up decarbonisation policies all together, but do not have a detailed vision expressed in written documents. Hence, we do not include any of these parties in our analysis.

*4.4.2 Dominant pathway: state-centred (*Christlich Demokratische Union Deutschlands, Christlich-Soziale Union in Bayern *and* Sozialdemokratische Partei Deutschlands*)*

In 2050, the German electricity sector has been fully decarbonised as a key part of the economy-wide almost complete decarbonisation. The government had successfully planned and executed a fair and effective transition of the electricity sector. The linear emission trajectories as laid out in the climate action plan (BMUB, 2016) to achieve its commitments under the Paris Agreement were successfully implemented all the way from 2017 to 2050 (EC, 2015; NECP DE, 2018; UN, 2015), through strong central control and technology-specific auctions of additional renewable energy projects (EEG, 2017). Sector-specific targets set by the government guaranteed long planning horizons for all companies and stakeholders (BMUB, 2016). Central planning and attractive returns benefitted large investors, so that fewer but larger projects were realised, while citizen energy groups did not receive strong support. Germany has achieved a balance between being a frontrunner in establishing an innovative renewable industry, securing cheap industrial electricity prices, and ensuring an equitable transition for incumbent companies and workers, and citizens alike, while also complying with and participating in the common European electricity market (EnWG, 2016).

Continuous addition of **intermittent renewables** realised the goal of creating an electricity system able to supply cheap, secure and carbon-neutral electricity (CDU/CSU/SPD, 2018; NECP DE, 2018). The government held technology-specific auctions guaranteeing low prices and linear expansion corridors for on-shore wind and PV through the 2020s, 2030s, and 2040s, as prescribed in the Renewable Energies Act (EEG, 2017), reaching 65 % renewable electricity in 2030 and full power sector decarbonisation in 2050 (NECP DE, 2018). The auctions resulted in an effective steering of the transition trajectory and a desired technology mix and locations. The reconfigurations enacted by the third Merkel government has had lasting effect. Whereas in 2017 most renewable assets were owned by citizens, local utilities and other non-incumbent actors (trend:research, 2018), the ownership structure changed towards the incumbent actors and new utility entrants, both from Germany and other EU countries, during the 2020s. The opening of renewable auctions to renewables installations in other countries starting from 5% of auctioned volumes in 2018, increased the share of imports of renewable electricity in the 2020s (EEG, 2017, §5). Trade was useful to balance the grid as the volume of domestic **dispatchable renewables** only increased only slowly. This was restricted by a lack of resources in Germany for dispatchable renewables, and neither CSP nor geothermal power played any significant role in the domestic supply. Only a few biomass power generators were added, while hydropower remainded constant (EEG, 2017, §4.4a).

In the decade between 2020 and 2030, most of the existing large-scale dispatchable and baseload generation assets were phased out. The first important milestone was the **nuclear phase-out**, with the last reactor being closed at the end of 2022 (AtG, 2017), that was a direct political consequence of the disaster in Fukushima. To reach the binding 2030 target of 61-62% emissions reduction in the electricity sector compared to 1990 (BMUB, 2016), strong domestic policy measures were implemented, in addition to the European carbon market EU ETS (CDU & CSU, 2017). An expert commission planned and executed the phase-out of coal and lignite power generation in Germany by 2038 (KWSB, 2019). Germany did not realise any **CCS** projects**,** as permitting procedures and legal issues could not be solved, and as the techno-economic outlook of the CCS remained unfavourable (KSpG, 2012, §2). Consequently, electricity generation from imported **gas** were increasingly concentrated to hours of high electricity prices and was eventually pushed out by high emission prices in the runup to 2050.

While Germany was a net electricity exporter in the 2010s, the shift towards less fossil and nuclear generation led to a more balanced **trade** balance starting at the middle of the 2020s. In times of high renewable generation there were exports, while in time of little renewable generation Germany relied on imports. These benefits to flexibility provision were aided by continuous **grid expansion** in the 2020s and 2030s carried out by the TSOs to alleviate grid congestion (BNA, 2018b; NABEG, 2011; Rippel *et al.*, 2017), as well as increased interconnector capacities with neighbouring countries. The grid was also used for the joint implementation of renewable power projects with neighbouring countries.

Starting in 2019, many newly installed small-scale PV arrays were equipped with a **decentralised battery**, a number that increased further because self-consumption was encouraged for home owners allowing them to access cheap electricity (Figgener *et al.*, 2018). This allowed for solar peaks to be shifted from day to night and ensured increasing levels of self-supply for home owners.

Emission reduction policies in other sectors strongly influenced electricity demand and supply. In the **heating sector,** demand reduction policies in line with the efficiency first principle were implemented that spread efficient house insulation at a rate of 2% of the building stock per year and renewable heating including millions of heat pumps for new buildings and renovations (EEWärmeG, 2008). Overall, this resulted in a virtually climate-neutral building stock by 2050 (BMWi, 2015) needing only 20% of the heat energy compared too 2008, that also increased the flexibility of electricity demand for heating. In the **mobility sector,** the government supported the expansion of electric vehicle charging infrastructure with 100,000 charging points by 2020 (CDU/CSU/SPD, 2018), and this contiuous effort, including with support for e-cars, led to a large market of several million BEV in the 2030s (BNA, 2018b). Additionally, the number of train passengers was doubled by 2030 (CDU/CSU/SPD, 2018), increasing the demand for electricity as well. Both trends continued through the 2030s and 2040s resulting in a high electrification share in the transport sector. **Demand-side measures**, including the mandatory deployment of Smart meters, ensured that the additional electricity demand from heating and the mobility was highly flexible and shiftable over the day allowing for a decreasing peak electricity demand after 2020 (BFEE, 2017). Overall power demand decreased in the 2020s (NECP DE, 2018); the demand in sectors already electrified in 2018 continued to decrease, but the total power demand grew from 2030 on, driven by sector coupling, especially increased e-mobility.

The dominant German energy policy pathway followed a state-centred trajectory. Both in the domain of phase-out of incumbent technologies and the addition of new technologies, the government took a central position by determining the pace of capacity deployment for each renewable technology through auctions, and by setting strict phase-out dates for the unwanted coal and nuclear power fleets (see Table 13) (NECP DE, 2018). The role of the market was emphasised in keeping the costs of specific projects low through auctions, but the government kept tight control of tenders and project implementation. The government role was especially strong in the managed phase-out of nuclear and coal power (BNA, 2018b; NECP DE, 2018), and most projects realised by large incumbent companies. The role of grassroots initiatives was kept to the minimum necessary involvement and decreased over time when government success increased the trust in their energy and climate framework.

Table 13: Quantification of the German state-centred dominant policy pathway as described by currently valid policies of the government of Christlich Demokratische Union Deutschlands, Christlich-Soziale Union in Bayern *and* Sozialdemokratische Partei Deutschlands *and by the draft NECP.*

DE: Dominant	**2016**	**2020**	**2030**	**2040**	**2050**
GHG reduction targets (economy-wide)	894 Mt CO_{2eq}	40% (GHG-1990)	55-56% (GHG-1990); <562 Mt CO_{2eq}	> 70% (GHG-1990); <375 Mt CO_{2eq}	80-95% (GHG-1990); 263-62.5 Mt CO_{2eq}
ETS sector reduction targets	474 Mt CO_{2eq} (European emission allocation)	431 Mt CO_{2eq} (European emission allocation)	EU: 43 % (2005)		
Non-ETS sectors emission reduction targets		14% (GHG-2005)	38% (GHG-2005)		
GHG reduction targets (electricity sector)			61-62% (GHG-1990)		100%
Renewables targets (energy; % of final energy consumption)		18%	30%	45%	60%
Renewables targets (electricity; % of final energy consumption)	30%; 194 TWh; 108 GW	By 2025: 40-45%	65%	>65%	>80%
Intermittent renewables	117 TWh; 90 GW		180-220 (including Dispatchable)		

DE: Dominant	2016	2020	2030	2040	2050
Wind onshore	79 TWh; 50 GW	+2.8 GW per year (2017-19); +2.9 GW per year	+2.9 GW per year 74-85.5 GW	≥74-85.5 GW	≥74-85.5 GW
Wind offshore	included above	6.5 GW	15 GW	≥17-20 GW	≥17-20 GW
Solar PV	38 TWh; 41 GW	+2.8 GW per year	72.9 GW-104.5 GW	≥72.9 GW-104.5 GW	≥72.9 GW-104.5 GW
Dispatchable renewables	77 TWh; 18 GW		14.9 GW	=14.9 GW	=14.9 GW
Biomass	45 TWh; 7 GW	+150 MW per year (2017-19); +200 MW per year (2020-2022)	6.0 GW	=6.0 GW	=6.0 GW
Hydro	26 TWh; 5 GW		5.6 GW	=5.6 GW	=5.6 GW
CSP	0 TWh; 0 GW	=0	=0	=0	=0
Other renewables	6 TWh		1.3 GW	=1.3 GW	=1.3 GW
Traded renewables					
Physical import of renewables (cooperation)		Up to 5% of auction volume available to foreign bidders	≥2020	≥2020	≥2020
Statistical transfer of renewables (cooperation)					
Explicit trade of CSP or hydropower					
Nuclear	85 TWh; 11 GW	< 2016	By 2023: 0	0	0
Fossil fuels	371 TWh; 96 GW				
CCS	0	0	0	0	0
Lignite	150 TWh		9.0-9.4 GW.	By 2038: 0	0
Hard coal	112 TWh		8.1-13.5 GW	By 2038: 0	0
Gas	94 TWh		32.8-35.2GW		
Petroleum	5 TWh		0.9-1.3 GW		
Other non-renewables	10 TWh		4.1 GW		
Storage					
Battery			8-12.5 GW		
Pumped Hydropower			11.6 GW		
Other storage			1-3 GW (Power-to-Gas)		

DE: Dominant	2016	2020	2030	2040	2050
Cross-border interconnection NTC		≥ 10% of yearly power production	≥ 15% of yearly power production		
Electrification of additional sectors					
Total heating demand incl. non-electric heating		-20% (TWh-2008) 2% renovation rate	681-766 TWh -67-66% (GHG-1990)	546 -685 TWh	444-623 TWh -80% (TWh-2008)
Heating with electricity		14% RES-H	1.1 -4.1 mio heat pumps 27% RES-H		-100% (GHG-1990)
Total cooling demand incl. non-electric cooling					
Cooling with electricity			27% RES-C		
Electric mobility	11.8 TWh	All transport: -10% (PE-2005)	-42-40% (GHG-1990) ; 1-10 million EV; Double number of train passengers (2018) 14% RES-T		All transport: -40% (PE-2005) 0 GHG
EV chargers		+100,000 Charging points	≥2020	≥2030	≥2040
Gross electricity consumption	597 TWh	557 TWh (equals -10% (2008)) + new demand from sector coupl.	554-615 TWh	<2030	464 TWh (equals -25% (2008)) + new demand from sector coupl.
Final energy consumption					

4.4.3 Minority pathway: grassroots-centred (Bündnis 90/Die Grünen*)*

Following the grassroots logic, the German electricity system became **100% renewable by 2030** (Bündnis 90/Die Grünen, 2016). Without a short-term focus on costs, but with genuine engagement by citizens to avoid the climate crisis, Germany carried out a renewable generation revolution, reconfiguring the electricity system from the bottom up between 2020 and 2030. The transformation was driven by an ambitious expansion of small-scale decentralised intermittent renewables and doubled efforts on energy efficiency. The main balancing mechanism for the grid was repurposing gas infrastructure for renewable gas from utilising intermittent supply peaks for power to gas, as well as decentralised batteries for short-term storage. The German government enacted robust phase-out policies including a national floor price on carbon emissions (starting at €40 per ton CO_2 (Bündnis 90/Die Grünen, 2019c)) and bans on the sales of polluting technologies, including internal combustion engine cars from 2030 and new oil boilers from 2021 (Bündnis 90/Die Grünen, 2018) to create space for the emerging system. Regional capacity markets ensured a decentralised character of the generation system fitting for each region, with minimum necessary grid expansion.

A new subsidy scheme that was based on a feed-in tariff and the absolute priority of renewables in the grid had led to fast expansion of intermittent renewables, namely solar PV and on-shore wind, to a large extent owned by citizen energy cooperatives and communal utilities (Bündnis 90/Die Grünen, 2016). As a result, individual house owners, farmers and small businesses created and owned a highly decentralised electricity system that emphasised small-scale renewables, such as roof-top PV, and self-consumption (supported by small-scale batteries). However, there was little expansion of **dispatchable renewables,** especially biomass and hydropower, because Germany lacked the sustainable resource potential for both of these technologies. Consequently, there was need for inter-regional trade especially within the **grid** infrastructure that was modestly expanded along the lines of TSO planning to ensure security of supply with renewables sources from elsewhere when local generation was insufficient. **Trade** with neighbouring countries was minimised to the level required by the European Union and restricted to renewable electricity only (Bündnis 90/Die Grünen, 2013).

The **nuclear phase-out** by the end of 2022 was a land-mark success of grassroots energy policy making (AtG, 2017). For many citizens, this provided proof that change induced by the people was indeed possible and that the power of incumbent energy utilities could be and had been broken. Although nuclear power generation is carbon neutral, it was a long-standing goal of grassroots initiatives in Germany to phase out nuclear power because of the perceived dangers posed by radiation and nuclear accidents; this goal is a main reason for the foundation of the Green party. This success in creating the future against the establishment gave legitimacy to other policy measures suggested by the Greens and other grassroots organisations to create the future themselves.

All **fossil fuel** electricity generation was phased out between 2020 and 2030 – first lignite, then hard coal and gas. The end of both lignite and hard coal was achieved by a phase-out trajectory that had a fixed emission budget similar to the successful nuclear phase-out, including a rapid closure of 20 old coal power blocks to meet the 2020 -40% reduction target and cumulative phase out of 7 GW of coal and lignite between 2019 and 2022 (Bündnis 90/Die Grünen, 2019a). For other fossil fuels phase-out policies in addition to the EU ETS price signal included a national floor prices and a fixed end date for carbon emissions from electricity generation in 2030 (Bündnis 90/Die Grünen, 2016). Some of the existing fossil fuels infrastructure especially **pipelines and gas turbines** were reconfigured to serve as flexible renewable generation capacity based on power to gas in the 2020s. Additionally, micro-CHP plants were repurposed to only use renewable gas, from biogas or from power-to-gas converters.

To contribute to local independence there was an ambitious program to expand decentralised home **batteries** (Bündnis 90/Die Grünen, 2016) to increase regional sufficiency and shifting solar power availability to the night. However, the key to enable the renewable revolution in Germany was a revolution of **long-term storage**. Driven by subsidies, **power-to-gas** generation facilities that could use up to 50 GW of excess load were added between 2020 and 2030 (Sterner *et al.*, 2015). These plants made use of intermittent electricity supply peaks and created hydrogen and methane that were used both for seasonal storage in the existing gas infrastructure and for local renewable electricity generation, available on days with little intermittent generation.

Flexibilisation of the heating sector was encouraged through a stricter regulation on renewable **heating** in the 2020s. Because of the requirement for completely renewable heat in all buildings, first new and then existing, and the ban on both oil and natural gas heating and direct electric heating, many home owners opted for heat pumps or micro co-generation based on renewable gas that created additional decentral electricity demand and supply. This shift was strengthened by an outlook of very low heating costs, especially because of power-to-heat tariffs that made use of peaks in fluctuating generation. However, because of strict building standards, following by the EU Buildings Directives, the overall demand for heating energy strongly decreased, as it practically vanished over the 2020s for new buildings. The requirement of zero energy buildings for new constructions from 2030 onward led to an overall shrinking demand for power to be provided through the grid for heating and made additional renewable electricity available for the decarbonisation of the industrial and mobility sectors as well, to allow Germany to be fully decarbonised by 2050. In sum, the integration of wind gas in CHP, an expansion of heatpumps, and much stricter insulation enabled a highly efficient carbon neutral heating sector by 2040.

Strengthened by the successes in electricity and heating sectors, citizens demanded and created a **mobility sector** with less personal mobility and a strong emphasis on public transport including high-speed trains and bicycles. This was encouraged through lower taxation of public transport tickets and a ban of inland flights and enforcing high emission standards within urbanized areas (Bündnis 90/Die Grünen, 2019b). The electricication of the remaining fossile transport was in 2020s pushed by infratrucutre investments into charging infrastructure in public places, a shift in subsidies from diesel to electric vehicles, easy permitting prossedures,the requirement for new buildings to have EV-chargers available, and strengthening the right for tenants to install EV chargers in rented residential housing (Bündnis 90/Die Grünen, 2019c). This trend was intensified in the 2030s by banning the sales of new ICE cars effective from 2030 onwards (Bündnis 90/Die Grünen, 2017b). As a result, the German automobile industry fully embraced electric mobility and came up with innovative solutions. Consequently, the entire **mobility** sector was decarbonised, by far most of this through electrification and modal shift away from personal cars, by 2040 (Bündnis 90/Die Grünen, 2017b).

The Greens fully embraced the **efficiency first** principle of the EU. Electrification, expansion of renewable power, and modal shift in the transport sector and a tendering scheme for efficiency improvements cut the primary energy demand of Germany in half by 2050 (Bündnis 90/Die Grünen, 2017a). This scheme was run by local Efficiency Offices that ran the tenders and subsidies for local businesses and home-owners to become more involved. One co-benefit was that overall less infrastructure in the forms of wind turbines and grid expansion was needed, contributing to better acceptance of the *Energiewende* and less land use.

The grassroots pathway re-established Germany as an ambitious leader of the citizen-driven energy transition. The new, carbon-neutral and decentralised power system was built bottom-up by individual persons, groups and companies. The amount of additional grid infrastructure was minimised through legislation encouraging decentralised self-consumption and energy efficiency. Markets played only a small role in the systems design. Although the strict phase-out policies followed a strong top-down government logic, these measures were needed to create gaps for the bottom-up system creation. Balancing of generation was provided as locally as possibly, with local measures and infrastructures, but also relied strongly on the national action, providing large amounts of largely centralised power-to-gas converters and gas storage (see Table 14). The properties of the emerging system were mainly shaped by citizen groups empowered by government policies.

Table 14: Quantification of the German grassroot-centred minority policy pathway as described by Bündnis 90/Die Grünen.

DE: Grassroot	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	894 Mt CO_{2eq}		>55%		> 95%
ETS sector reduction targets	474 Mt CO_{2eq} (European emission allocation)	431 Mt CO_{2eq} (European emission allocation)			
Non-ETS sectors emission reduction targets		14% (GHG-2005)	38% (GHG-2005)		
GHG reduction targets (electricity sector)			100%	100%	100%
Renewables targets (energy; % of final energy consumption)					
Renewables targets (electricity; % of final energy consumption)	30%; 194 TWh; 108 GW		100%	100%	100%
Intermittent renewables	117 TWh; 90 GW				
Wind onshore	79 TWh; 50 GW	≥ +5 GW per year	≥ +5 GW per year		
Wind offshore	included above	6-8 GW	20 GW in 2030 and 30 GW in 2035		
Solar PV	38 TWh; 41 GW	≥ +5 GW per year (mainly decentral)	≥ +5 GW per year (mainly decentral)		
Dispatchable renewables	77 TWh; 18 GW				
Biomass	45 TWh; 7 GW	≥ 2016 (sustainable) 25% (Biomass with mini-CHP)	≥ 2020 (sustainable); ≥2020 (Biomass with mini-CHP)	≥ 2030 (sustainable); ≥2030 (Biomass with mini-CHP)	≥ 2040 (sustainable); ≥ 2040 (Biomass with mini-CHP)
Hydro	26 TWh; 5 GW				
CSP	0				
Other renewables	6 TWh				
Traded renewables					

DE: Grassroot	2016	2020	2030	2040	2050
Physical import of renewables (cooperation)		≥ 2016 As little as possible	≥ 2016 As little as possible	≥ 2016 As little as possible	≥ 2016 As little as possible
Statistical transfer of renewables (cooperation)					
Explicit trade of CSP or hydropower		Trade hydropower from Scandinavia and the Alps	Trade hydropower from Scandinavia and the Alps	Trade hydropower from Scandinavia and the Alps	Trade hydropower from Scandinavia and the Alps
Nuclear	85 TWh; 11 GW		By 2023: 0	0	0
Fossil fuels	371 TWh; 96 GW		0	0	0
CCS	0	0	0	0	0
Lignite	150 TWh	By 2022: at least 3 GW closed	0	0	0
Hard coal	112 TWh	By 2022: at least 4 GW closed	0	0	0
Gas	94 TWh	25% (Decentral mini-CHP with gas)	0; Micro-CHP only with renewable gas	0	0
Petroleum	5 TWh		0	0	0
Other non-renewables	10 TWh		0	0	0
Storage					
Battery		100,000 batteries (decentral)			
Pumped Hydropower					
Other storage		Emphasis on Power to gas (Wind gas) Power to Heat			
Cross-border interconnection NTC		Less additions than dominant pathway	Sustainable cross-border connection (no nuclear import)		
Electrification of additional sectors					
Total heating demand incl. non-electric heating		<< 2016	<< 2020	<< 2030	<< 2040
Heating with electricity				All heating: 100% carbon-free	

DE: Grassroot	2016	2020	2030	2040	2050
Total cooling demand incl. non-electric cooling		<< 2016	<< 2020	<< 2030	<<2040
Cooling with electricity		< 2016	< 2020	< 2030	< 2040
Electric mobility		>> 2016	>> 2020 Ban on new ICE vehicles 95-98 Mt CO_{2eq}	>> 2030	
EV chargers		>> 2016	>> 2020	> 2030	> 2040
Gross electricity consumption					
Final energy consumption					50% (PE-2017)

4.4.4 *Minority pathway: market-centred (***Freie Demokratische Partei***)*

The europeanisation of German energy and climate policy was at the core of the market-driven decarbonisation of the German energy system (FDP, 2016). Germany realigned its national policies to reflect the common European Energy Union decarbonisation framework and its policy goal of at least 80% decarbonisation by 2050. With arguments of economic efficiency, Germany moved from its role as a frontrunner of renewable expansion and technology development to a hub of electricity and flexibility trade in the common European electricity market. This reflected the belief that a shared goal and shared expansion policies, as well as a shared emission trading on the European Union level would facilitate the most cost-efficient transition. The main driver of equal opportunities in a pan-European energy transition was a reformed European carbon market with a stringent cap reduction, which resulted in an increasingly strong price signal that induced the retirement of uncompetitive fossil fuel plants, less fossile fuel use in cars with internal combustion engines, and reduced oil and gas heating.

The increase in carbon prices together with sticking to the energy-only market (FDP, 2016) resulted in a fast decline of the **fossil fuel** based generation. In the 2020s and 2030s, all high-emitting fossil generation, i.e. coal and lignite, were retired from the market, as the high carbon price made them unprofitable. The relative importance of less carbon-emitting natural gas plants increased, especially to produce power in times of high prices, including scarcity price times. In 2050, the most flexible fossil fuel plants were still operated profitably when power prices were high, despite the carbon price (FDP, 2017a). Moreover, CCS projects were permitted and used, to the extent that they were economically profitable, for emissions reduction driven by the carbon price (FDP, 2019) – allowing German companies to develop this technology for export. In the market logic, shutting down depreciated nuclear power plants providing cheap low-carbon energy, was counter-logical, but since the legislation to phase them out was already in place and the public opinion demanded it, the German **nuclear** exit strategy was successfully concluded by the end of 2022. No new nuclear capacities were added, as they were not competitive without state support – and support was not acceptable in the market-driven power sector transformation.

The expansion of **fluctuating renewables** was slow in the first half of the 2020s, because German technology-specific support schemes that were considered economically inefficiency were abandoned by the government, so as to not interfere with the workings of the market. The high and increasing carbon price, together with increasing electricity prices as conventional generators left the system, made renewables increasingly competitive and resulted in a boom of fluctuating renewables starting in the second half of the 2020 all the way through the 2030s and 2040s. Since regulation for onshore wind was complicated with distance requirements to ensure public acceptance (ban on new wind turbines near buildings closer that 10x the height) there was a slower expansion of this technology than of PV (FDP, 2017a). As costs became competitive, there was a boom in off-shore wind in the 2020s, aided by the new national North-South grid connections. The incumbent big four and other large European utilities secured the largest share of the market and the new renewable assets (FDP, 2015) and made use of the possibilities of the internal electricity market to balance the grid with imports of cheap fluctuating renewables from other Member States. Regarding domestic **dispatchable renewables**, there were only capacity additions where they were competitive with traded intermittent renewables. The existing biomass and hydropower generators were optimised to provide flexibility and make use of the high prices during scarcity events (FDP, 2017a).

As cost efficiency and competition were increasingly important, electricity utilities were **trading** flexible power with other Member States. While at first, much conventional electricity was imported, renewable projects in other Member States for import to Germany became increasingly lucrative towards the end of the 2030s, especially to cover times of low domestic generation. Market actors did not only consider the good wind resources in the North and Baltic sea countries, but were also considering cheap PV and dispatchable CSP imports from Southern EU countries; this was especially attractive due to its low correlation with generation in Germany itself (FDP, 2013). To realise these international projects and enable power flows to Germany, additional **grid infrastructure and interconnectors** continued to be expanded in the 2030s and 2040s (FDP, 2019).

The main driver of **sector coupling** was a dramatic decrease in the relative cost of using electricity for heating and driving, as well as cost reductions in the world market prices of hydrogen and other e-fuels compared to increasingly expensive fossil fuels (FDP, 2019). This competitiveness was enabled by a cut in electricity taxes, as well as an expansion of the carbon market into both transport and heating in 2020. Private companies developed business opportunities to create and bring the required infrastructure and technologies to market. The energy efficiency legislation for buildings and other prescriptive policies were revised to allow for technology-neutral competition with a main focus on carbon emission abatement. However, compliance with EU regulation required strict insulation standards for all new buildings. Still, this resulted in less ambition in insulation of the existing building stock and, as a result, higher demand for heat than in the dominant German pathway. Because of their economic attractiveness, the number of heat pumps and the amount of renewable heat they produced increased, which in turn increased the electricity system short-term flexibility, leveraged by **demand-side management**. Consequently, the contribution of the heating sector to smooth electricity supply peaks is large, enabled through smart-metering technology. Also in other sectors, market-based mechanisms (including the carbon price) ensured that only cost-efficient **efficiency** investments were made (FDP, 2019). The government deregulated by cancelling the national energy conservation legislation and relying solely on price signals of the common European Market and the ETS, so as to increase productivity (FDP, 2014).

The **electrification of the mobility sector** was never a specific goal of the liberal German governments. As a result, there was little electrification dynamic in the mobility sector in the 2020s. Given the EU legislation on vehicle fleet average emissions, there was a switch to hybrid electric vehicles (EC, 2018b), and later to carbon-neutral vehicles based on combustion engines but driven with carbon-neutral fuels, including e-fuels imported from countries with abundant renewable resources (FDP, 2019). The share of battery-electric vehicles increased slightly in the 2020s and 2030s, reflecting the cost reduction dynamics of induced by electric mobility development in other countries, as well as the availability of charging infrastructure expanded by innovative business practises, financed by abundant venture capital (FDP, 2019).

The market-centred pathway emphasised technology-neutrality in decarbonisation efforts and a level playing field for all market actors on the one side, and the green growth and export opportunities for German businesses on the other (FDP, 2019). Common European decisions, shared rules, and international goals played a crucial role for enabling the energy transition – not only in Germany, but in a European context, within the Internal Market. Because the government did not act to push out the incumbent fossil generation system in this pathway, incumbent utilities and other market participants were the principal actors in shaping the new power system. As barriers to citizen engagement were not resolved, their contribution to the creation of the renewable power system remained small. Consequently, there was much more centralised large-scale infrastructure than in the other German pathways. To balance the grid, the electricity trade between Euroepan countries increased strongly, enabled by a strongly increased transmission and interconnector capacity (see Table 15).

Table 15: Quantification of the German market-centred minority policy pathway as described by the Free Democratic Party.

DE: Market	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	894 Mt CO_{2eq}		40% (GHG-1990)		80% (GHG-1990) (or EU-Goals if higher)
ETS sector reduction targets	474 Mt CO_{2eq} (European emission allocation)	431 Mt CO_{2eq} (European emission allocation)	-3% per year reduction instead of 2.2% (FDP, 2019)		
Non-ETS sectors emission reduction targets		14% (GHG-2005) Expand ETS to all sectors (FDP, 2019)	38% (GHG-2005) Expand ETS to all sectors (FDP, 2019)	Expand ETS to all sectors (FDP, 2019)	Expand ETS to all sectors (FDP, 2019)
GHG reduction targets (electricity sector)					
Renewables targets (energy; % of final energy consumption)					
Renewables targets (electricity; % of final energy consumption)	30%; 194 TWh; 108 GW				
Intermittent renewables	117 TWh; 90 GW				
Wind onshore	79 TWh; 50 GW	< less than Dominant: regulation to reduce available areas (10x height rule)	No technology-specific goals		
Wind offshore	included above				
Solar PV	38 TWh; 41 GW				
Dispatchable renewables	77 TWh; 18 GW				
Biomass	45 TWh; 7 GW				

DE: Market	2016	2020	2030	2040	2050
Hydro	26 TWh; 5 GW				
CSP	0				
Other renewables	6 TWh				
Traded renewables					
Physical import of renewables (cooperation)		> 2016	> 2020	> 2030	> 2040
Statistical transfer of renewables (cooperation)					
Explicit trade of CSP or hydropower		in favour of *DESERTEC*			
Nuclear	85 TWh; 11 GW		By 2023: 0	0	0
Fossil fuels	371 TWh; 96 GW				>0
CCS	0	≥0	≥0	≥0	≥0
Lignite	150 TWh				
Hard coal	112 TWh				
Gas	94 TWh				
Petroleum	5 TWh				
Other non-renewables	10 TWh				
Storage					
Battery					
Pumped Hydropower					
Other storage					
Cross-border interconnection NTC		> 2016	> 2020	> 2030	> 2040
Electrification of additional sectors					
Total heating demand incl. non-electric heating					
Heating with electricity					
Total cooling demand incl. non-electric cooling					
Cooling with electricity					
Electric mobility					
EV chargers					
Gross electricity consumption					
Final energy consumption					

4.5 Italy

4.5.1 Representative organisations

Italy has a broad spectrum of parties with different perspectives on energy policy. In the parliament and the senate, majorities usually follow a pattern centre-right or centre-left. After five years with a centre-left parliament and senate, the general elections of 2018 saw the emergence of the catch-all and protest-party *Movimento Cinque Stelle* (M5S). This disrupted the usual change pattern between left and right governments with a new governing alliance between the M5S and the right-wing party *Lega*.

Table 16: Main parties (>3%) currently represented in the Italian parliament (2018; Source: Italian Ministry of the Interior).

Party	Senate election 2018
Movimento Cinque Stelle	32.2%
Partito Democratico	19.1%
Lega	17.6%
Forza Italia	14.4%
Fratelli D'Italia	4.3%
Liberi e Uguali	3.3%

In this deliverable, we describe the pathways for the parties with an explicit energy and climate strategy following one of the ideal-typical logics described above. The dominant pathway is based on the Italian draft NECP (NECP IT, 2018), which is very similar to the Democratic Party's Energy Strategy 2017 (SEN, 2017), with a few elements of bottom-up development, such as decentralised PV and self-consumtion added (inserted by the sitting M5S-led government); hence, we attribute the dominant pathway to the previous government (until 2018), led by PD. The M5S, which is currently (August 2019) the strongest party in the parliament and leading the government (see Table 16), has a very explicit energy vision, based on decentralisation and citizen control. As M5S has not yet been able to implement this vision in actual energy policies, we position this pathway as a grassroot minority pathway. The government coalition partner of M5S, *Lega*, has a similar but less explicit energy position, and is not included here. *Forza Italia* may (and have been in the past) be part of a future government coalition, but it has no distinct, well-described energy policy position, and we do not include its strategy here.

*4.5.2 Dominant pathway: market-centred (*Partito Democratico*)*

By 2050, the Italian government had fully decarbonised its economy. The aim of the government was to reach the goals of the Energy Roadmap set out by the European Union (2011/885/EC), through a set of policies that were least intrusive for its economy and industry while still making sure the targets were met (NECP IT, 2018). While Italy did not pursue a leading role in the energy transition of the European Union, it managed to achieve all intermediate goals set by the different Directives**.** This policy pathway was largely market-centred and relied on market mechanisms, in particular carbon pricing, but also held clear state-centred elements, including the ban on nuclear power. The market-oriented vision of this dominant pathway was an implementation of policies to penalise fossil energy sources and to promote renewable energy capacity development in a way that did not harm the overall economy and industry.

Italy reached a renewable electricity share of 55 % in 2030 (NECP IT, 2018) and further increased that share close to 100% until 2050. A series of auctions led to a doubling of the annual **intermittent renewable power** production for wind and solar electricity between 2020 and 2030 (SEN, 2017) reflecting Italy's abundant resources. Self-consumption of households and SME enterprises was encouraged to achieve this (NECP IT, 2018). In contrast, domestic **dispatchable renewable sources** grew much less. Biomass capacity decreased slightly reflecting EU sustainability legislation. Other already dispatchable electricity sources mostly stagnated during the 2020-2050 period: hydropower added less than 5% and geothermal electricity production remained steady, although pumped storage capacity increased (SEN, 2017). Additionally, Italy saw the development of its first commercial CSP projects, generating 1% of electricity in 2030, later expanding CSP further in line with the 2040 energy framework.

To increase the amount of available dispatchable renewable electricity and to balance the system as wind power and PV grew, Italy sought synergies with its neighbour countries to balance renewable electricity generation, using the existing interconnectors, and increasing them in line with EU planning (NECP IT, 2018). While in 2015, Italy imported about 15% of its electricity (RSE, 2018), imports decreased slowly while also changing in nature, from imports of bulk power to imports used to balance fluctuating domestic generation (D.Lgs. 3 March 2011 n.28, 2011; SEN, 2017). To stimulate renewable electricity imports, the Italian government introduced financial incentives, but lower than those allocated to domestic renewable sources (D.Lgs. 3 March 2011 n.28, 2011).

Italy did **not use any nuclear power** to decarbonise its power system: already after Chernobyl, Italians had decided against it, and the Fukushima disaster turned the public opinion against it even more. In the 2011 referendum, the Italian people rejected the development of new nuclear reactors, with a 94% vote against, and this option remained inaccessible for Italy throughout the decades (Ministerio dell' Interno, 2011).

The last Italian **coal power** stations were closed in 2025 (SEN, 2017). This was not legally enforced, but coal power plants were made less competitive through the EU ETS, assisted by a national carbon floor price (SEN, 2017). The lost capacity was compensated through an increased development of renewable electricity production, and through **grid reinforcement** to ensure power supply in southern Italy, including Sicily (SEN, 2017) as well as centralised battery storage facilities (NECP IT, 2018).

Regarding **electric mobility**, the Italian government implemented the EU directive on the deployment of alternative fuels infrastructure and additional charging stations (2014/94/EU; D.Lgs. 16 December 2016 n.257, 2016). Additionally to financial incentives to promote electrical mobility, mainly in form of purchasing eco-bonuses (D.Lgs. 22 June 2012 n.83, 2012), an enhanced charging infrastructure made it possible to increase electric vehicle deployment to 1.6 million BEVs in 2030 as well as several million plug-in hybrid vehicles, as a stepping stone towards a largely electric individual transport system in 2050 (SEN, 2017).

The Italian government introduced a law package to implement the European Directive on **energy efficiency** in 2014. This package reduced the primary energy annual consumption by 233 TWh by 2020, counted from 2010 (D.Lgs.4 July 2014 n. 102). This was driven by **demand-side measures**, mainly oriented to financial help for lower energy-consuming buildings. Additionally, this law made funds available for information campaigns directed to house owners and tenants on the different benefits and modalities of implementing renewable energy facilities in the housing sector. It also defined a frame for a white certificate scheme and supported a development fund through a small tax on electricity and gas. Later, the Italian government implemented the European directive on the Energy Performance of Buildings (2018/844/EU), requiring new buildings to be nearly zero-energy from 2021 and making the building stock carbon-neutral by 2050. In addition, mandatory requirements to use renewable energy for heating new buildings caused an increase of electricity consumption, mainly because of a larger use of heat pumps (SEN, 2017). The consumption increased about 45% over the period 2020-2050 and the electricity consumed for air conditioning increased 75% (RSE, 2018). Together these measures lead to an overall **growing electricity demand** adding about 10% between 2020 and 2030 and reaching 337 TWh (NECP IT, 2018).

By following the EU directives related to the energy transition, Italy decarbonised its electricity sector through policies targeted at raising the price of carbon as the main instrument to phase out coal power and increased the share of renewable in the consumed electricity (see Table 17). However, Italy never took on a pioneering role in the energy transition, but rather in a reactive position towards the different Directives formulated by the European Commission, within the context of the Euroepan internal market. Nevertheless, through the implementation of these measures, Italy reached a fully decarbonised national economy and electricity sector by 2050.

Table 17: Quantification of the Italian state-centred dominant policy pathway as described by currently valid policies of the Gentiloni government of the Partito Democratico *and the draft NECP.*

IT: Dominant	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	397 Mt CO_{2eq}			< 2030	-100% (1990)
ETS sector reduction targets	311 Mt CO_{2eq} (European emission allocation)	299 Mt CO_{2eq} (European emission allocation)	57% (GHG-2005)		
Non-ETS sectors emission reduction targets		13% (GHG-2005)	33% (GHG-2005)		
GHG reduction targets (electricity sector)					
Renewables targets (energy; % of final energy consumption)		17%	>30%	> 2030	>> 2030
Renewables targets (electricity; % of final energy consumption)	38%; 110 TWh; 52 GW		55.4% (187 TWh)	> 2030	>> 2030
Intermittent renewables	40 TWh; 29 GW		68.4 GW	> 2030	>> 2030
Wind onshore	18 TWh; 9 GW	18 TWh	38 TWh; 17.5 GW	> 2030	> 2040
Wind offshore	included above	0 TWh	2 TWh; 900 MW		
Solar PV	22 TWh; 19 GW	27 TWh	69 TWh (mainly decentral); 50 GW	> 2030	>> 2030

IT: Dominant	2016	2020	2030	2040	2050
Dispatchable renewables	70 TWh; 24 GW		24.8 GW	≥2030	≥2030
Biomass	17 TWh; 2 GW	16 TWh	15 TWh; 3.7 GW	= 2030	=2030
Hydro	44 TWh; 15 GW	49 TWh	50 TWh; 19.2 GW	> 2030	> 2030
CSP	0	0	3 TWh; 880 MW	≥2030	≥2030
Other renewables	9 TWh; 815 MW	7 TWh (Geothermal)	7 TWh; 950 MW (Geothermal)	= 2030	=2030
Traded renewables					
Physical import of renewables (cooperation)		> 2016	> 2016	> 2016	> 2016
Statistical transfer of renewables (cooperation)					
Explicit trade of CSP or hydropower					
Nuclear	0	0	0	0	0
Fossil fuels	180 TWh; 62 GW				
CCS	0	0	0	0	0
Lignite	0 TWh	0	0	0	0
Hard coal	36 TWh	37 TWh	2026: 0 TWh	0	0
Gas	129 TWh	117 TWh	118 TWh	< 2030	<< 2030
Petroleum	10 TWh	2 TWh	2 TWh	0	0
Other non-renewables	5 TWh	2 TWh (Waste)	2 TWh (Waste)		
Storage					
Battery					
Pumped Hydropower		> 2016	> 2016	> 2016	> 2016
Other storage					
Cross-border interconnection NTC		= in 2018	≥ 2020	≥ 2020	≥ 2020
Electrification of additional sectors					
Total heating demand incl. non-electric heating		< 2016	< 2020	< 2030	< 2040
Heating with electricity		1.18 TWh	1.39 TWh	1.51 TWh	1.74 TWh
Total cooling demand incl. non-electric cooling		< 2016	< 2020	< 2030	< 2040
Cooling with electricity		1.84 TWh	2.31 TWh	2.76 TWh	3.22 TWh
Electric mobility		> 2016	6 Mio EV (of which 1.6 Mio BEV)	>2030	>>2030 (largely electric personal mobility)
EV chargers					

IT: Dominant	2016	2020	2030	2040	2050
Gross electricity consumption	290 TWh	294 TWh	337 TWh	> 2030	> 2030
Final energy consumption		1354 TWh	1207 TWh		

4.5.3 Minority pathway: Grassroots-centred (Movimento Cinque Stelle)

In 2050, Italy had fully decarbonised its electricity system and done its share to keep global warming below 2°C, while also becoming energy independent from neighbouring countries. This was, and remains, the aim of the Italian grassroots' movement, the *Movimento Cinque Stelle* (M5S). This movement brought back the energy transition decision-making to the most local level, to communities and municipalities. The movement reshaped Italy as an ensemble of responsible and autonomous energy communities, leaving to the central national government the role of coordination of the transition with the European Union. This is a consequence of their belief that distributed generation fits better to the local, intermittent and technical aspects of renewable power. The pathway of M5S incorporated three main goals: deployment of renewable power generators, especially for distributed generation; a reduction of the primary energy consumption; and higher electrification rates in the final energy consumed, also for thermal energy (M5S, 2017).

To reach high shares of renewable power, the M5S banned **coal power** by 2021 (M5S, 2017). Moreover, they phased out the use of oil for all sectors, except transportation and agriculture, by 2030 by internalising the external costs of fossil fuel combustion, in form of costs of pollution and health impact, in the economic balance of energy generation, through a "disincentive" – specifically a tax – on carbon and energy (M5S, 2017). Finally, while the Italian gas power generation increased in the 2020s to compensate the increasing intermittent renewable power, gas power production decreased rapidly thereafter, and disappeared completely by 2050.

The M5S pursued a rapid expansion of **renewable power**, to increase independence, compensate for the closing fossil fuel stations, and to empower citizens. In this, wind power and PV were the largest contributors, with especially decentral PV growing by a stunning 10% per year, incentivised by regulations and carbon prices for all non-renewable energy production (M5S, 2017): by 2050, PV generated about 70% of all Italian electricity. Meanwhile, in addition to a light growth of hydropower and geothermal power, as the only explicitly supported dispatchable renewables, the movement supported the development of **distributed electricity storage** to balance the very high share of PV, especially in form of batteries, in addition to **demand-side management** devices to shift electricity loads in time (M5S, 2017).

The strategy of the M5S relied strongly on a reduction of the primary energy consumption, especially through **electrification**: by 2050, 65% of the primary energy consumption was electricity. This was mainly done through the increasing electrification of transport, reaching 90% in 2050 (M5S, 2017), but also due to savings in the heating sector, mainly through economic "disincentives" for fossil heating, making heat pumps and low temperature geothermic sources more attractive. Rather, insulation, biofuels, geothermal sources and solar heating enabled the by 2050 a fully decarbonised heating (M5S, 2017).

To compensate the intermittency of renewable electricity generation, the M5S took a pragmatic stance towards increasing the size of **interconnections** with neighbouring countries. The interconnections were only used to balance seasonal intermittent renewable power generation (M5S, 2017). The interconnectors were only be enhanced when there was a strong need, and instead the main balancing measures for the large PV fleet was storage, in particular batteries, and demand-side management; until around 2040, gas power was a key balancing option (M5S, 2017).

Italy reached a full decarbonisation of its electricity sector by 2050 through a complete decentralisation of its electricity system and a massive expansion of renewable power (see Table 18). In its energy transition, Italy took the lead of an approach based on the power of its citizens and local companies to make the transition happen, enabling a transition from the bottom. Through this approach, Italy gained a large energy independency, while also providing a large autonomy to its regions and different actors.

Table 18: Quantification of the Italian grassroots-centred minority policy pathway as described by Movimento Cinque Stelle, in the government coalition since 2018.

IT: Grassroots	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	397 Mt CO_{2eq}				
ETS sector reduction targets	311 Mt CO_{2eq} (European emission allocation)	299 Mt CO_{2eq} (European emission allocation)			
Non-ETS sectors emission reduction targets		13% (GHG-2005)	33% (GHG-2005)		
GHG reduction targets (electricity sector)		> 2016	> 2020	>> 2020	100%
Renewables targets (energy; % of final energy consumption)		17%			
Renewables targets (electricity; % of final energy consumption)	38%; 110 TWh; 52 GW	> 2016	>> 2016	>> 2016	100%
Intermittent renewables	40 TWh; 29 GW				
Wind onshore	18 TWh; 9 GW	9 GW; +3.4% per year	+3.4% per year	+3.4% per year	≥ 45 TWh
Wind offshore	included above				
Solar PV	22 TWh; 19 GW	20.06 GW; +9.3% per year	+9.3% per year (mainly decentral)	+9.3% per year (mainly decentral)	73% of the power mix; 420 TWh
Dispatchable renewables	70 TWh; 24 GW				
Biomass	17 TWh; 2 GW	23 GWh; +0.8% per year	+0.8% per year	+0.8% per year	30 TWh
Hydro	44 TWh; 15 GW	= 2016; +1% per year	+1% per year	+1% per year	+70 TWh (2016)
CSP	0	0	0	0	0

IT: Grassroots	2016	2020	2030	2040	2050
Other renewables	9 TWh	7 TWh (Geothermal)	8 TWh (Geothermal)	8-12 TWh (Geothermal)	12 TWh (Geothermal)
Traded renewables					
Physical import of renewables (cooperation)					
Statistical transfer of renewables (cooperation)					
Explicit trade of CSP or hydropower					
Nuclear	0	0	0	0	0
Fossil fuels	180 TWh; 62 GW				
CCS	0	0	0	0	0
Lignite	0 TWh	0	0	0	0
Hard coal	36 TWh	43 TWh	0 TWh	0 TWh	0 TWh
Gas	129 TWh	94 TWh	110 TWh	<< 2030	0 TWh
Petroleum	10 TWh	2% of total electricity prod.	0	0	0
Other non-renewables	5 TWh	3 TWh (Waste)	0 (Waste)	0 (Waste)	0 (Waste)
Storage					
Battery		= 2016	> 2020	> 2020	> 2020
Pumped Hydropower		≤ 2016	≤ 2016	≤ 2016	≤ 2016
Other storage					
Cross-border interconnection NTC		> 2016	~ 2020	~ 2020	~ 2020
Electrification of additional sectors					
Total heating demand incl. non-electric heating		< 2016; 1035 TWh	791 TWh	547 TWh	279 TWh
Heating with electricity		0	0	0	0
Total cooling demand incl. non-electric cooling					
Cooling with electricity					
Electric mobility		2%	> 2020	>> 2030	90%
EV chargers					
Gross electricity consumption	290 TWh	285 TWh	385 TWh	485 TWh	580 TWh
Final energy consumption					

4.6 Switzerland

4.6.1 Representative organisations

In Switzerland, state policy is very different from other European countries. First, the government is not composed of representatives of the strongest parties in parliament, but follows the *principle of concordance*: the government is made up of seven representatives from all parties somewhat relative to their share of seats in the National Council (see Table 19). Consequentially, policies are typically compromises and are thus highly inclusive, holding elements appealing to the different worldviews represented in government. State policies are thus rarely extreme or ideologically "clean"; in Foxon's triangle (see Figure 3), they will often be positioned in the centre, and not in the corners. Second, as Switzerland has direct democracy, all major policy strategies must be approved in a popular vote, and it is possible for citizens to bring new policies to a popular vote. Increasingly, such popular initiatives are approved and voted on, strengthening the role of the citizens in Swiss policymaking, which Swiss policy-making, including energy policy making, a natural grassroots' component. These two peculiarities of Swiss governance lead to a culture of consensus and non-extreme policies: any too strong policy strategy is unlikely to succeed, either in government or in a popular vote.

Table 19: Main parties currently represented in the National Council.

Party	National Council election 2015
Schweizerische Volkspartei (SVP)	29.4%
Sozialdemokratische Partei der Schweiz (SP)	18.8%
Freisinnig-Demokratische Partei – Die Liberalen (FDP)	16.4%
Christlischdemokratische Volkspartei der Schweiz (CVP)	11.6%
Grüne Partei der Schweiz	7.1%
Grünliberale Partei der Schweiz (GLP)	4.6%
Bürgerlich-Demokratische Partei Schweiz (BDP)	4.1%

Due to the principle of concordance, the dominant energy policy pathway of Switzerland, the one consisting of currently valid strategies and policies implemented by the federal government, is a compromise between the positions of the main parties in parliament. Due to this, it is somewhat skewed toward the market corner of Foxon's triangle, due to the majority of right parties in the parliament and in the government, and as most parties are strongly or moderately pro-market: a market approach is the least common denominator in Swiss energy policy.

As extreme positions are rarely rewarded in Swiss policy, the energy positions of most parties are relatively moderate; in addition, most parties do not have very clear energy political positions, in part because the electricity supply is already practically carbon-neutral and the remaining energy supply is perceived as secure.

A pure market-centred approach to the energy transition is advocated by the *Free Democratic Party – The Liberals* and is formulated by the NGO *Swisscleantech*, which both seek to achieve the energy transition through minimal-invasive policies and cost-efficient instruments, in particular by internalising external costs. While there are other actors supporting a stronger market-orientation of the energy system (Economiesuisse, 2012; Swissmem, 2013). these are two of the most prominent and powerful actors to support a transition towards a fully renewable electricity system through a market approach. The Swiss People's Party (*Schweizerische Volkspartei*, SVP) represents a pathway that falls outside Foxon's triangle, by rejecting climate change and the need for an energy transition for ecological reasons, but instead strongly advocating energy autarky through nuclear and dispatchable renewables, to be achieved through a combination of market- and state-centred measures.

4.6.2 Dominant pathway: A compromise skewed towards the market (Swiss Federal Council)

In 2050, Switzerland has successfully **phased out nuclear electricity**, a transition triggered by the Fukushima disaster in 2011, and a mix of renewable electricity and energy demand reduction, added to combined-cycle gas has compensated the lost nuclear capacity (Prognos, 2012). By 2050, Switzerland had reduced its greenhouse gas emissions by almost 70% per capita, and plans were implemented to reach complete carbon-neutrality during the second half of the century. This was the aim of the Swiss government, the Federal Council, which does not represent one party in particular, but the same proportions of main parties of the parliament according to the principle of concordance. For the Federal Council, the energy transition must go in the interest of most parties. To reach this goal, the Energy strategy developed and implemented by the Federal Council was the result of a compromise of the goals of all large political parties. This absence of a partisan stance was the starting point for the development of renewable electricity generation and consumption to phase out nuclear energy. The pathway of the Federal Council towards a decarbonised and fully renewable electricity system had several lines of action: i) the nuclear power phase-out; ii). Deployment of renewable electricity capacity; iii) efficiency programs in various sectors (Prognos, 2012); as well as iv) a CO_2 levy (non-trading sector) and participation in the EU ETS from 2020 on (BAFU, 2017).

The time span between 2019 and 2034 was critical due to the successive shutdown of all the five Swiss nuclear plants: their technical lives was limited to 50 years, as decided in 2016 through a popular referendum. Within these 15 years, Switzerland lost about 40% of its domestic power generation capacity. However, this loss was compensated through a massive development of renewable power capacity, mainly solar and wind (Prognos, 2012). During the time frame 2020-2050 of the transition, the Swiss government developed several tools to achieve a timely phase out of the nuclear power, while still guaranteeing the security of electricity supply.

First, the government implemented a **plan for electricity demand reduction** in the household sector, supporting the use of heat pumps and improved insulation, where building had mandatory standards from 2020 onwards to be near-zero energy and to integrate renewable electricity generation capacity (*MuKEn* standards). For industry, CO_2 reduction boni contributed to incentivise greener technologies and processes, as did the successively increasing CO_2 levy, which penalised fossil fuel use in all (non-trading) sectors (Prognos, 2012).

Second, the government implemented an additional **levy on electricity** to financially support the expansion of **renewable electricity** capacity, mainly through wind and solar through a feed-in-tariff for large generators and direct subsidy for roof-top PV, which also enables a bottom-up development of solar energy in a country that has relatively little available space for renewable electricity infrastructure (EnG, 2018). However, the additional tax-income to support the development of renewable capacity was not enough to keep the FIT running beyond 2022 (BFE, 2018). After 2030, direct financial support continued to support the development of renewable power.

While still exchanging electricity with the European Union, the balance of electricity trade is neutral in 2050. The **interconnectors** were strengthened in the 2020s and were mainly used for balancing, including seasonal balancing of the hydropower fleet. Especially in the seasonal perspective, an expansion of **natural gas power** was necessary to stabilise the system in winter (Prognos, 2012). Additionally, the international trade has been increased, with a border crossing capacity increase: about 50% in both directions toward the North, about 30% for export and 70% for import from the South (Swissgrid, 2015).

The trade neutrality of the electricity sector in 2050 was also reached through a **stabilisation of the electricity consumption**, which remained largely constant over the time span, both in terms of average and peak demand. The gains in energy efficiency measures have been compensated by a moderate growth of the share of electric vehicles. In 2030, the share of battery-electric vehicles was about 13% and continued to grow moderately towards 2050 (BFE, 2017)

To compensate the intermittency of the renewable electricity generation, several Swiss electricity companies enhanced **their pumped hydropowerstorage capacity**, so that the capacity doubled by 2020 compared to 2010, and remained constant thereafter. While this development was initially foreseen to compensate inflexible generation in neighbouring countries, especially French nuclear power, these new plants were instead adapted to compensate the domestic and international intermittent generation of the renewable capacity deployed between 2020 and 2050 (see Table 20).

Table 20: Quantification of the Swiss dominant policy pathway as described by currently valid policies and the energy strategy of the Swiss Federal Council (Energy Strategy 2050, POM var. C+E).

CH: Dominant	2016	2020	2035	2050
GHG reduction targets (economy-wide)	46 Mt CO_{2eq}	-20% per inhabitant (GHG-2000)	-55.3% per inhabitant (GHG-2000)	-68.3% per inhabitant (GHG-2000)
ETS sector reduction targets	5.3 Mt CO_{2eq} per year	4.9 Mt CO_{2eq}; from 2020: -1.74% per year reduction (2010)		
Non-ETS sectors emission reduction targets				
GHG reduction targets (electricity sector)		+50%	+525%	+338%
Renewables targets (energy; % of final energy consumption)	22.1%			
Renewables targets (electricity; % of final energy consumption)	64%; 38 TWh	61.8%	75.5%	93.0%

CH: Dominant	2016	2020	2035	2050
Intermittent renewables				
Wind onshore		0.66 TWh	1.76 TWh	4.26 TWh
Wind offshore		0 TWh	0 TWh	0 TWh
Solar PV		0.52 TWh	4.44 TWh	11.12 TWh
Dispatchable renewables				
Biomass		0.6 TWh (wood); 0.46 TWh (biogas)	1.21 TWh (wood); 1.48 TWh (biogas)	1.24 TWh (wood); 1.58 TWh (biogas)
Hydro	36 TWh	41.96 TWh; 5.09 TWh (Mini-hydro)	43.02 TWh; 6.48 TWh (Mini-Hydro)	44.15 TWh; 8.57 TWh (Mini-Hydro)
CSP		0 TWh	0 TWh	0 TWh
Other renewables		0.2 TWh (Geothermal)	1.43 TWh (Geothermal)	4.39 TWh (Geothermal)
Traded renewables				
Physical import of renewables (cooperation)				
Statistical transfer of renewables (cooperation)				
Explicit trade of CSP or hydropower		0 TWh	0 TWh	0 TWh
Nuclear	20 TWh	2.9 GW; 21.68 TWh	0 GW	0 GW
Fossil fuels	3 TWh			
CCS		0 TWh	0 TWh	0 TWh
Lignite		0 TWh	0 TWh	0 TWh
Hard coal		0 TWh	0 TWh	0 TWh
Gas		3.1 TWh	15.2 TWh	10.7 TWh
Petroleum				
Other non-renewables		0.18 TWh (Waste)	0.38 TWh (Waste)	0.39 TWh (Waste)
Storage				
Battery				
Pumped Hydropower		7.5 TWh (energy for pumping)	7.5 TWh (energy for pumping)	7.5 TWh (energy for pumping)
Other storage				
Cross-border interconnection NTC				
Nord export	6.3 GW (2013)	9.7 GW by 2025	9.7 GW	= 2035
Nord import (max, winter)	5.3 GW (2013)	8.6 GW by 2025	8.6 GW	= 2035
Nord import (min, summer)	5.1 GW (2013)	8.6 GW by 2025	8.6 GW	= 2035
South export (max, winter)	4.2 GW (2013)	5.5 GW by 2025	5.5 GW	= 2035

CH: Dominant	2016	2020	2035	2050
South export (min, summer)	3.4 GW (2013)	4.7 GW by 2025	4.7 GW	= 2035
South import (max, winter)	1.8 GW (2013)	3.1 GW by 2025	3.1 GW	= 2035
South import (min, summer)	1.4 GW (2013)	2.7 GW by 2025	2.7 GW	= 2035
Electrification of additional sectors				
Total heating demand incl. non-electric heating		45.5 TWh	32.6 TWh	22.3 TWh
Heating with electricity		4.0 TWh	3.2 TWh	2.4 TWh
Total cooling demand incl. non-electric cooling				
Cooling with electricity		0.1 TWh	0.5 TWh	1.3 TWh
Electric mobility		10.6% of the fleet (2/3-PHEVs and 1/3-EVs), or 21,400 cars	38.2% of the fleet by 2030 (2/3-PHEVs and 1/3-EVs), or 76,900 cars	> 2035
EV chargers				
Gross electricity consumption		64 TWh	63 TWh	66 TWh
Final energy consumption	237 TWh			

4.6.3 Minority pathway: Market-centred pathway (Freisinnig-Demokratische Partei and Swisscleantech)

In 2050, Switzerland has reduced its climate footprint to one ton CO_{2eq} per capita. To achieve this, the electricity system is completely renewable, following a phase-out of both nuclear power and gas power, which had been used as a bridging technology, compensating the lost nuclear capacity. The core of this pathway revolved around an internalisation of the external costs of fossil fuels and a thinning of the state apparatus to steer the energy transition: less subventions, a full liberalisation of the electricity market, and fiscally neutral levies (FDP, 2018; Swisscleantech, 2014)

To reach high levels of energy efficiency, Switzerland increased the financial levies on electricity, since the energy consumption is elastic in the long term. For them, it was relevant to have **a market displaying the real costs of electricity** (Swisscleantech, 2014). The levies penalised the impact of less sustainable electricity sources compared to the cleaner ones. **Nuclear power** had to carry the full insurance costs in case of a nuclear disaster, in addition to the full costs of the nuclear waste treatment and burial. These additional costs made new nuclear power uncompetitive, so that the existing plants were not replaced as they reached the end of their economic life, and the last reactor closed in 2034.

Gas has been used as a bridging technology, filling the gap from the lost nuclear capacity, including in form of gas CHP. Later, these plants were used with either biogas or used for power-to-gas applications. Over the time towards 2050, the increasing CO_2 levy to internalise external environment costs and reflect the full societal cost of fossil fuels made natural gas CHP non-competitive. While the integration of the environmental costs put a stress on fossil fuels, additional costs for hydropower made also its price slightly higher, but not as much as for fossil sources. These additional costs entailed full insurance for dams, although much lower than for nuclear power, and costs to compensate the loss of biodiversity.

In addition to capacity to compensate for the intermittency of renewables, Switzerland has increased its electricity storage capacity through an expansion of its large pump-storage hydro. Additionally, Switzerland has achieved full penetration of smart grid technologies that make it possible to better control and steer demand, deploy battery storage to better support the system efficiency and, later, to efficiently utilise power-to gas technologies for balancing. Similarly, the slowly increasing **electric car fleet** was increasingly used for grid management, especially as a well-managed electricity sink.

As renewable electricity sources, especially solar power, were expensive in the late 2010s, Switzerland initially kept the feed-in-tariff scheme, even increasing its financial capacity through an increase of the levy on electricity to accelerate the implementation of renewable power. However, they reduced and then abandoned the feed-in tariff scheme in the 2020s, as prices of wind and solar power reached market parity. Renewable power was also affected by the internalisation of external costs, mainly in form of a compensation for biodiversity loss. Moreover, to limit the impact of renewable electricity facilities, the strategy limited the direct competition with agricultural land by incentivising the integration of PVs on existing and new buildings instead of on fields.

The growth of renewable electricity capacity required a costly **grid extension and additional interconnectors** to balance the intermittent renewable sources and increase cost efficiency of the power supply. To finance the needed grid expansion, Switzerland implemented an additional levy on distribution costs. The existing interconnections have been used to balance renewable electricity production in Switzerland with neighbouring countries, and were then somewhat expanded to give Switzerland the **role of an "electricity stabiliser" for Europe**, especially through its pumped hydropower storage capacity.

Through its various interventions on the electricity market, especially in form of steering levies, Switzerland managed to reach its climate and energy transition goals by 2050 (see Table 21).

Table 21: Quantification of the Swiss market-oriented policy pathway as described by the Free Democratic Party and Swisscleantech.

CH: Market	2016	2020	2035	2050
GHG reduction targets (economy-wide)	46 Mt CO_{2eq}	23.1% (GHG-1990)	59.0% (GHG-1990)	88.8% (GHG-1990)
ETS sector reduction targets	5.3 Mt CO_{2eq} per year	4.9 Mt CO_{2eq} ; from 2020: -1.74% per year (2010)		
Non-ETS sectors emission reduction targets				
GHG reduction targets (electricity sector)				100%
Renewables targets (energy; % of final energy consumption)	22.1%	30%	53%	81%
Renewables targets (electricity; % of final energy consumption)	64%; 38 TWh			100%
Intermittent renewables				
Wind onshore		0.4 TWh	3 TWh	5.2 TWh
Wind offshore				
Solar PV		3.5 TWh	12.7 TWh	16.4 TWh
Dispatchable renewables				
Biomass		0.4 TWh (wood) 1.1 TWh (biogas with CHP)	0.9 TWh (wood) 2.5 TWh (biogas with CHP)	1.3 TWh (wood) 2.4 TWh (biogas with CHP)
Hydro	36 TWh	30.4 TWh; 4 TWh mini-hydro	29.7 TWh; 4.7 TWh mini-hydro	28.8 TWh; 4.9 TWh (mini-hydro)
CSP				
Other renewables		0 (Geothermal)	0.9 TWh (Geothermal)	5.9 TWh (Geothermal)
Traded renewables				
Physical import of renewables (cooperation)				
Statistical transfer of renewables (cooperation)				
Explicit trade of CSP or hydropower				
Nuclear	20 TWh	19 TWh	0	0
Fossil fuels	3 TWh			
CCS				
Lignite				
Hard coal				
Gas		117.2 TWh	58.0 TWh	19.4 TWh

CH: Market	2016	2020	2035	2050
Petroleum				
Other non-renewables		1.7 TWh (Waste)	1.7 TWh (Waste)	1.6 TWh (Waste)
Storage				
Battery		> 2016	> 2020	> 2035
Pumped Hydropower		> 2016	> 2020	> 2035
Other storage		> 2016 (power-to-gas)	> 2020 (power-to-gas)	> 2035 (power-to-gas)
Cross-border interconnection NTC				
Nord export	6.3 GW (2013)	= 2016	> 2020	
Nord import (max, winter)	5.23 GW (2013)	= 2016	> 2020	
Nord import (min, summer)	5.1 GW (2013)	= 2016	> 2020	
South export (max, winter)	4.2 GW (2013)	= 2016	> 2020	
South export (min, summer)	3.4 GW (2013)	= 2016	> 2020	
South import (max, winter)	1.8 GW (2013)	= 2016	> 2020	
South import (min, summer)	1.4 GW (2013)	= 2016	> 2020	
Electrification of additional sectors				
Total heating demand incl. non-electric heating		< 2016	< 2020	-75% (TWh-2010)
Heating with electricity				
Total cooling demand incl. non-electric cooling				
Cooling with electricity				
Electric mobility		> 2016	> 2020	40% EV+PHEV (2010)
EV chargers				
Gross electricity consumption		66 TWh	72 TWh	70 TWh
Final energy consumption	237 TWh			

4.6.4 *Minority pathway: outside the energy transition logics framework (Schweizerische Volkspartei)*

In 2050, Switzerland has mainly decarbonised its electricity system and relies on an **autarkic power generation system**. While the *Schweizerische Volkspartei* (SVP) did not aim to reduce greenhouse gas emissions, it wanted to minimise the dependency on energy imports and make Switzerland energy autarkic, or at least electricity autarkic. The main vision of the SVP is a Switzerland in which citizens decide on their own fate through a strong federalist system, with decisions made at the lowest possible political level. In this context, Switzerland reduced its energy import dependency through a strong electrification of its economy and a transition towards a domestic electricity system mainly reliant on dispatchable sources: hydro, nuclear and (dispatchable) renewable power sources. The resulting carbon-neutrality of the power system was not the main aim of the SVP, which was and remains climate change-sceptic, but it was rather a side-effect of the energy autarky aim.

The pathway of the SVP massively relied on nuclear power to reduce its dependency on foreign countries (SVP, 2015), first by prolonging the life of the existing Swiss nuclear plants to at least 60 years (SVP, 2013). This life-extension gave them time to **build new state-of-the-art nuclear reactors** to reduce the Swiss energy import dependency, since the oldest nuclear plant was closed in 2029 and the newest existing in 2044. Although nuclear energy is not renewable, they see its capacity to store fuel for long times, potentially several decades, as a way to reach energy independency. Throughout the entire period, the power mix was dominated by **hydropower** and **nuclear power**, which both grew only slightly, and with a growing addition of **biomass power**.

The SVP heavily **relied on popular referenda to make decisions**, especially on the way Switzerland should fulfil its climate change mitigation commitments, and whether it should do so at all. If the people would have accepted a phase out of nuclear electricity, they would have replaced the power loss through fossil fuels, de facto retracting themselves from the Paris Agreement (SVP, 2013). In this pathway, we assume that the preferred option of the party, the expansion of nuclear power, was supported by the people.

To keep up with the growing electrification of its economy, Switzerland further developed **hydropower** by making it more competitive through a freeze of the amounts of taxes that had been in place in the 2010s to support renewable electricity development. Simultaneously, they completely halted the expansion of intermittent renewables in 2019, which had been supported by the funds raised by the tax. The federalist structure of Switzerland enabled each canton to decide by itself whether and how to further expand hydropower.

In addition to hydropowerand nuclear power, Switzerland financially supported renewable energy sources through **feed-in-tariff schemes, except for photovoltaics** because of the their low efficiency and inability to produce dispatchable electricity. These reduced support schemes would then mainly support the deployment of wind and bioenergy facilities. However, especially for wind power, the local population had the last word, through popular votes, on the final decisions whether renewable electricity plants have been built or not.

In the housing sector, Switzerland **renounced to any legal prescriptions and bans what could restrict the freedom of house owners**, and consequently the energy demand in buildings increased as the building space increased over time. In the same way, Switzerland renounced to any additional taxes or levies on energy, in order to keep the price of energy at its lowest to support its economy. A consequence of this was an increase of the consumption of electricity, which justified the need for new nuclear plants, as a way to decarbonise the electricity sector.

While the primary aim of the SVP was not to mitigate climate change, their drive to energy independency through a higher electrification of its energy sector made it possible to reduce their climatic impact (see Table 22). While nuclear fuel is per se not renewable, its high-energy content enabled Switzerland to have enough fuel reserve for longer times, avoiding the risk of short-term shortages of electricity.

Table 22: Quantification of the grassroots-oriented policy pathway as described by the party programmes and positions of the Schweizerische Volkspartei.

CH: Outside logic	2016	2020	2035	2050
GHG reduction targets (economy-wide)	46 Mt CO_{2eq}	< 2016 (GHG-1990)	< 2020 (GHG-1990)	< 2035 (GHG-1990)
ETS sector reduction targets	5.3 Mt CO_{2eq} per year	4.9 Mt CO_{2eq}; 1.74% reduction per year (2010)		
Non-ETS sectors emission reduction targets				
GHG reduction targets (electricity sector)				
Renewables targets (energy; % of final energy consumption)	22.1%			
Renewables targets (electricity; % of final energy consumption)	64%; 38 TWh	= 2016	By 2030: +6 TWh (2015)	
Intermittent renewables				
Wind onshore		= 2016	= 2016	= 2016
Wind offshore				
Solar PV		= 2016	= 2016	= 2016
Dispatchable renewables				
Biomass		> 2016 (wood) (biogas)	> 2020 (wood) (biogas)	
Hydro	36 TWh	= 2016; > 2016 (mini-hydro)	By 2030: +3 TWh (2015); > 2020 (mini-hydro)	> 2035; > 2035 (mini-hydro)
CSP				
Other renewables				
Traded renewables				
Physical import of renewables (cooperation)				
Statistical transfer of renewables (cooperation)				
Explicit trade of CSP or hydropower				
Nuclear	20 TWh	= 2016	> 2020	>> 2035
Fossil fuels	3 TWh			
CCS				
Lignite				
Hard coal				
Gas		< 2016	< 2020	< 2035
Petroleum				
Other non-renewables		= 2016 (Waste)	= 2016 (Waste)	= 2016 (Waste)

CH: Outside logic	2016	2020	2035	2050
Storage				
Battery				
Pumped Hydropower		= 2016	> 2020	> 2035
Other storage				
Cross-border interconnection NTC				
Nord export	6.3 GW (2013)			
Nord import (max, winter)	5.3 GW (2013)	= 2016	= 2020	= 2035
Nord import (min, summer)	5.1 GW (2013)	= 2016	= 2020	= 2035
South export (max, winter)	4.2 GW (2013)			
South export (min, summer)	3.4 GW (2013)			
South import (max, winter)	1.8 GW (2013)	= 2016	= 2020	= 2035
South import (min, summer)	1.4 GW (2013)	= 2016	= 2016	= 2016
Electrification of additional sectors				
Total heating demand incl. non-electric heating		> 2016	> 2020	> 2035
Heating with electricity				
Total cooling demand incl. non-electric cooling				
Cooling with electricity				
Electric mobility				
EV chargers				
Gross electricity consumption		> 2016	> 2020	> 2035
Final energy consumption	237 TWh			

5 DISCUSSION AND CONCLUSIONS

In this report, we set out to investigate the potential future need for and role of one of the main dispatchable renewable power options available in Europe – concentrating solar power (CSP) equipped with thermal storage – as a function of electricity policy decisions in a set of European national governments and of the European Commission. Here, we have identified the set of specific, actual or potential decisions, and described them in the form of narrative and quantified pathways. Our results in this report are to be seen as the first step towards answering this overarching question, by providing detailed data on the current strategies of 5 European countries and of the European Commission, as well as the visions of political parties currently not in government. This data will be used in the modelling steps of the MUSTEC project in 2019 and 2020.

In addition to providing the input data for the upcoming modelling and research steps, our results allow us to draw a range of conclusions relevant to both energy policymakers in Europe and to the (renewable) energy policy research community. A general observation is that although all pathways foresee strong power sector decarbonisation, the dominant pathways are very different in the different cases, both in terms of what they seek to achieve and how they want to achieve this. The differences across the visions suggest that there may be conflicts ahead, as the markets are increasingly integrated, institutionally and physically, for example between the nuclear-based pathways of France and the wind power- and PV-based pathways of Spain and Germany. Further, no dominant pathway, and only two minority pathways, are explicit about flexibility options: in almost all strategies and vision, the issue of balancing is greatly underspecified, and where there are statements, the level of ambition for new flexibility options is generally low. This suggests that the resulting power system may not be stable, and that there may be room for further inclusion of dispatchable renewables, including CSP with thermal storage. The modelling in MUSTEC will reveal the (non)seriousness of such potential problems, and on additions that can be made to the pathways to make them stable.

In the following, we draw seven high-level conclusions based on the data, both the qualitative narratives and the quantitative system data, we gathered for the six investigated cases.

5.1 All countries seek to strongly decarbonise their power systems

All investigated European countries and the European Commission have decarbonisation strategies for their energy and electricity sectors, although they are of different levels of ambition and detail. Of the implemented goals and strategies, as described in the dominant pathways, some but not all are consistent with the Paris Agreement, which requires the complete decarbonisation of the electricity sector by mid-century as a precondition for net-zero greenhouse gas emissions across the entire economy (IPCC, 2014, 2018b). Nevertheless, all dominant pathways foresee strong electricity system decarbonisation by 2050, and some – notably Italy and the European Union – foresee full decarbonisation. France sticks out with its comparably low 75% decarbonisation target, as does Switzerland: the Swiss focus on gas power even lets its power system emissions increase.

Given the relatively strong climate targets, it is not surprising that no dominant pathway, except the Swiss, foresee any mentionable amounts of fossil power, especially not coal power, from the 2040s onwards. To some extent, especially in the market-centred pathways (including the dominant EU pathway), the disappearance of coal power is a consequence of the climate target: there is simply no room for carbon-intensive generation as climate ambitions increase. In other cases, notably Spain and Germany, coal power is to be rapidly phased out by political decisions, mainly during the 2020s and 2030s.

5.2 All countries seek to greatly expand intermittent renewables

The main pillar for the decarbonisation of the power systems in all dominant pathways is wind and solar PV power. Only in some cases will the currently largest power sources remain, notably in Switzerland (hydropower remains dominant, and wind power remains small) and France (nuclear power is reduced but stays at 50% of power mix), but also there, intermittent renewables are responsible for the largest part of the envisioned supply-side changes. In the market-centred pathways, including both dominant and minority pathways, there are no quantitative statements of the relative share of each technology, but all indicate that wind power and PV will shoulder a large part of the transition because of their low costs. In Italy, the grassroots pathway seeks to achieve almost ¾ share for solar PV, and most of it in decentral, small-scale generators.

This dominance of PV and wind power is not surprising: they are the resources with the highest potential in Europe, and they are currently among the cheapest kilowatt-hours one can add to the power system (IRENA, 2018).

Nevertheless, there are differences between national pathways – differences that could cause conflicts. In particular, this is the case between France and its neighbours: although France in all pathways except the grassroots-centred seek to strongly increase renewables (to 25-50% of the power mix), they also foresee a large nuclear fleet covering 50-75% of the demand by 2050. In its neighbour countries Germany and Spain, and to some extent Italy, the dominance of intermittent renewables is very strong across most pathways. The power system modelling in MUSTEC will show whether and to what extent this will lead to problems in the power system and conflicts between national strategies; it appears likely, however, that such differences will be problematic due to the high need for flexibility in renewables-dominated power systems and the low flexibility of a nuclear-based system (especially in terms of frequently stopping and starting generation, if not in terms of ramping behaviour (Morris, 2018)). In many cases, strategies explicitly or implicity rely on balancing their supply with imports – but if all countries strongly expand intermittent renewables, this may not be easily possible, as there is simply too little flexibility available.

5.3 No country seeks to expand nuclear or to introduce CCS

We also observe that the conventional thermal electricity sources are losing political traction. No pathway seeks to increase the share of nuclear: only the minority pathways of the right-wing (climate sceptic pathways, outside the energy transition logics, see section 2.3.2) *Rassemblement National* (France) and *SVP* (Switzerland) seek to maintain the nuclear share compared to today, whereas all other seek to reduce it (the other French pathways), keep it at zero (Italy), or phase it out completely (all other pathways). A *nuclear renaissance* in Europe thus seems very improbable: currently, there are not even concrete plans for it, let alone any large-scale construction.

The rejection of CCS is even stronger: no dominant and only one minority pathway (PP, market-centred minority pathway for Spain) foresees any CCS. In many cases, CCS is explicitly rejected, whereas most pathways have no particular position on it. As all pathways have a critical view on especially coal and lignite, and a rather critical view on natural gas, it seems unlikely that CCS will resurface as a policy option soon. Although CCS is still prominent in energy modelling and scientific scenario analysis, it appears to have fallen off the political agenda, at least for the decarbonisation of the power system in the cases we investigated.

5.4 Flexibility is weakly, if at all, represented in the pathways

For the flexibility options needed to complement the strong and rapid expansion of fluctuating renewables we find much less developed proposals and visionary clarity. It is clear that most pathways support renewables and reject conventional power, but it is not clear how they envision the stabilisation of the future power system. There is no coherent policy preference for one flexibility option in our case studies, and many pathways are not explicit about expansion of any flexibility option at all. The magnitude and importance of this problem will be examined in detail in the modelling steps of MUSTEC.

As all countries seek to expand intermittent renewables and most foresee the more or less rapid elimination of dispatchable but carbon-emitting fossil fuel power, the issue of flexibility is on the policy agenda in all investigated countries. However, whereas all strategies – both dominant and minority pathways – discuss flexibility and ways to stabilise the power system with much higher shares of fluctuating supply, the strategies offer very little in terms of concrete measures increase flexibility. The main options – increasing dispatchable and carbon-free generation, deploying storage, or reinforcing grids and interconnections – are rarely specified and, when they are, the deployment levels are almost always low. The most common answer is grid expansion, but no pathway, dominant or minority, aims to go beyond the EU interconnection requirements for 2030: it appears that grid expansion is currently not an attractive option in any Member State.

Further, and closely related to the research questions of our project, we show that policy interest in CSP is weak, or non-existent, in all investigated cases. Spain, France and Italy have CSP in their dominant pathways, but only in very small amounts. In some cases, CSP is explicitly excluded as an option, especially in some grassroots-centred pathways, which instead emphasise small-scale, local power generation instead of large-scale trade and imports. Most pathways are CSP-agnostic and have no specific position on it, reflecting the currently weak political traction of CSP in Europe and across the world (Lilliestam *et al.*, 2018).

Similarly, no country foresees any mentionable use of the cooperation mechanisms and do not seek to rely on renewable power imports: as in the past, the idea of the cooperation mechanisms and outsourcing renewable power generation to other countries does not resonate well with European governments and parties, which instead seek to reap industry-political advantages of renewables policy (Caldés *et al.*, 2019; Lilliestam *et al.*, 2016; Schmidt *et al.*, 2019). Only the German grassroots pathway mentions imports of hydropower, but also constrains itself by emphasising that imports should be minimised in favour of local generation. However, several pathways – especially the market-centred ones – seek greatly expanded electricity trade, both to increase cost-efficiency and to balance fluctuating renewables. This is a clear opportunity to trade dispatchable renewables as well, including CSP (e.g. from Spain, Italy, or France), and the modelling in MUSTEC will show whether and to what extent this could fill a need in the envisioned future European power system.

Finally, the two issues that have been described as “the next big thing” for the energy transition – sector coupling (Olczak & Piebalgs, 2018) and storage (Fickling, 2018) – both remain largely unspecified in all pathways, except the minority pathways of *Rassemblement National* (France, foreseeing large-scale hydrogen production/storage and H_2 mobility) and the German Greens (foreseeing large-scale power-to-gas/gas-to-power as the main balancing technology). Most pathways allow for storage and emphasise in their texts that there is a future role for it, but no strategy is explicit about what type of storage it envisions, how much, and how a large-scale expansion is to happen. Similarly, all pathways mention sector-coupling, but it is not nearly described with the same precision as the changes of the supply side, especially not for heat. Some pathways envision strong expansion of electric mobility up to 100% of all personal mobility, and some for electric heating, but none have quantitative goals as to the impact on the power system. This has large implications for the potential of demand-response as a flexibility measure, which is only mentioned in the dominant EU pathway (and without much detail): as heat and car chargers are among the most flexible loads, large electricity demands from these sectors would greatly improve the flexibility of the power demand (Aryandoust & Lilliestam, 2017). Yet, the strategies and visions remain unspecific and vague. Hence, we conclude that storage and sector coupling may be the *next big thing*, but they are certainly not the *current big thing*.

The lack of explicit strategies to increase flexibility options and balance fluctuating sources is likely to be identified as a large problem in the modelling step. It is however also a key opportunity for dispatchable renewables, such for South European CSP for domestic use and export. There will be a future niche for technologies balancing fluctuating power generation, and so far this niche has not been occupied.

5.5 Minority pathways are more ambitious than the implemented policy strategies

Of the minority pathways, many are more radical than the dominant, often in terms of stronger and faster decarbonisation goals, and sometimes in terms of additional “visionary purity” such as relying entirely on market forces with a carbon price as the only policy instrument, or a desire for radical decentralisation in addition to decarbonisation. This is to be expected: the minority pathways are not actual, implemented policies and have not had to go through parliamentary negotiation processes but are relatively pure visions of best futures of various parties. This is consistent with both the energy transition logics framework and cultural theory, but we can here show with empirical data that the prediction holds also in the energy policy field: actual policies are compromises that result from the “tug-of-war” between proponents of each logic, whereas minority pathways can afford to be purer and stricter.

As most of the minority pathways have stronger decarbonisation goals than the dominant ones, many future government changes may bring stronger climate action, also in the electricity sector. However, to which extent they will be able to implement stronger targets remains to be seen: as mentioned, it is easier to claim radical goals as an opposition party than when in government. Yet, in most cases it appears unlikely that a government change would lead to much less ambitious goals.

In contrast to the “traditional” parties in opposition, which are more or less open for climate policy, the right-wing and/or populist parties emerging as new political forces across Europe often reject climate policy, or even deny the existence of climate change. In cases where they have gained government power, such as in some Eastern and Central European countries, climate and energy policies have sometimes been reduced in ambition. We here show two other facets of this family of parties.

First, the right-wing parties of most of our cases do not have real energy strategies. Although most countries have such parties, we were only able to reconstruct climate-sceptic minority pathways for *Rassemblement National* (France) and the *SVP* (Switzerland), whereas parties such as *AfD* (Germany) and *Lega* (Italy) have no elaborate or consistent energy strategies, beyond the rejection of renewables and climate protection in general.

Second, we show, with the (not right-wing) populist party *Movimento Cinque Stelle* (Italy) and the right-wing *SVP* (Switzerland) and *Rassemblement National* (France) that anti-establishment (M5S) and nationalist (RN, SVP) policies can be supportive of renewables – in the case of M5S, very radically so. Traditionally, many researchers (and probably policymakers) have viewed decarbonisation and renewables as a costly add-on to a functioning system in order to further soft values, such as environmental conditions – smelling somewhat of leftist policies and state intervention (which is likely a reason for some right-wing parties’ rejection of such policies). But there are other narratives supportive of decarbonisation. For example, RN is strongly nationalist, and seeks ways to make France *energy independent* – for which renewables are practically the only option, in addition to nuclear power (which they, and all other French parties, account for as domestic). In contrast, M5S seeks to *dismantle the establishment*, of which the energy industry and its giant companies are part – and decentralisation with renewables is a way of doing that. In addition, this is a strategy that likely resonates well with the nationalist Lega coalition partner: renewables are, like in France, the only large-scale Italian energy resource available, and hence they are a precondition for energy independence. Hence, there is not necessarily a contradiction between right-wing parties and renewables, but such parties tend to approach renewables from another direction as a tool for energy import indepencene.

5.6 The policy instruments in different countries may be conflicting

Across the pathways, we see that the planned or implemented policy instruments differ strongly, and may sometimes be in direct conflict to each other. For example, in their dominant pathways, Germany seeks to expand renewables through technology-specific auctions following pre-defined expansion trajectories, whereas Spain expands renewables through technology-neutral auctions, and Italy and Switzerland view carbon pricing as the main tool to get carbon-neutral electricity. These differences in aims and instruments are even larger when considering also the minority pathways. This suggests that elections leading to government change in one or several countries may cause even larger differences in energy trajectories, and stronger distortions between policies in different countries.

A particularly important difference in instrumentation affects the means for how to phase out fossil power. Some pathways, like the German dominant pathway, seek to close coal and lignite power stations by regulation, starting already in the 2020s. Others, such as the dominant Italian pathway, both EU pathways, and the French *En Marche* pathway, seek to push out fossil fuels and make renewables competitive through an increasing carbon price within the EU ETS. These instrument strategies may be at conflict: if the German coal is phased out (and especially if further countries does this too), the amount of verified emissions in the ETS will decrease, as will the price; the “missing” emissions could at least in the short term be so large that the CO_2 price crashes to zero, making the ETS-based phase-out strategies impossible to realise.

5.7 ”Optimality” has little to do with policy strategies

The presence of very different strategies and visions in the different cases shows that national policymakers value technological options very differently. French policymakers evidently believe that a nuclear-based pathway is beneficial for France, whereas German policymakers evidently disagree and instead view renewables as more beneficial. Energy modellers cannot resolve this question and say who is, in fact, right: what is *best* depends on beliefs, history, and path dependencies – both technical and social – and not on “objective” facts and costs. This suggests that energy system (optimisation) modelling that is not firmly based in the policy (narrative) setting of the relevant countries can be irrelevant, as such modelling does not consider the political realities that actually determine a country’s energy pathway. The “optimal” pathway for a country does not mean much, given that the visions of where to go and how to go there differ widely, between national governments as well as between political parties within a country. Quite likely, German policymakers would simply ignore a scenario saying that high shares of nuclear power are optimal, as it just does not fit the narrative of German energy policy making; for the same reason, French policy-makers would likely reject any scenario that finds a nuclear-free pathway to be optimal for their country.

Finally, it is very unlikely that the pathways that national governments view as the most beneficial for their respective countries will add up to something that is even close to “optimal” when aggregated into a full European electricity pathway trajectory. Quite likely, the power systems as specified by the pathways may not even be stable, both as the flexibility options are underspecified but also as the basic functioning and balancing of each national system may be in conflict with the neighbour systems. Again, the modelling in MUSTEC will show whether and to which extent the sum of all six pathways causes a functional or dysfunctional *European* power future.

Naturally, the strategies countries currently follow have a great impact on the future they will create, but the issue of ideological visions as drivers of policy is absent in most scenario analyses and models and never investigated to the detail we enable with this deliverable. Hence, we see this report as a methodological contribution to the European energy policy research community: it is a first step towards a policy- and empirically-based analysis of energy policies and strategies that take not only the existing system but also existing narratives and contexts into account.

5.8 Next steps

This report holds data and narratives for multiple possible energy transition pathways for five national, Western European countries and for the European Union as a whole. This data is an update of a previuos report (MUSTEC 7.2) based on the draft National Climate and Energy Plans performed in July-August 2019.

In the next steps of the MUSTEC project, modellers will work with the data and narratives we produced here, to see what the effects of the measures decided and proposed would be when imposed on the national and European electricity systems. Possibly, some futures will not work technically, as they rule out too many options. In other cases, they may work but be very costly and require the addition of large amounts of single flexibility options. We will see how specific decisions in one country affects its neighbouring countries, and how national policies influence the option space of other countries. Importantly, the modelling will answer our overarching research question and show how specific national and European-level policy decisions determine the potential future role of intra-European (renewable) cooperation and trade with dispatchable renewables, such as CSP with thermal storage.

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7 Appendix: List of Abbreviations

CCS	Carbon capture and storage
CH	Switzerland
CSP	Concentrating solar power
CT	Cultural theory
DE	Germany
ES	Spain
ETS	(European Union) Emissions Trading Scheme
EU	European Union
EU-28	Referring to the EU with its 28 Member States as of fall 2018
EV	Electric vehicle (includes plug-in hybrid and battery-electric vehicles)
FE	Final energy
FR	France
GHG	Greenhouse gas
ICE	Internal combustion engine vehicle
IT	Italy
MS	Member State (of the European Union)
Mt CO_{2eq}	Greenhouse gas emissions in million tons of carbon dioxide equivalents
NTC	Net Transfer Capacity: capacity of interconnector between two countries
PE	Primary energy
PHEV	Plug-in hybrid vehicle
PV	Photovoltaics
RES-C	Cooling with renewable energy sources, including renewable electricity
RES-E	Electricity generated from renewable sources, including wind, sun, water, and biomass
RES-H	Heat generated from renewable energy sources, including renewable electricity
RES-T	Transport with renewable energy sources, including renewable electricity
TSO	Transmission System Operator
TYNDP	Ten-Year-Network-Development plan developed by ENTSO-E
(I)-(V)	Indicates the quality of a source (see section 3.3)

For explanation of other table entries: see section 3.3.

MUSTEC
Market Uptake of Solar Thermal Electricity

8 APPENDIX: FULLY REFERENCED DATA TABLES

8.1 EU

8.1.1 Dominant pathway: market-centred (European Commission)

Table 23: Quantification of the European market-centred dominant policy pathway as described by currently valid policies of the European Commission.

EU: Dominant	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	3989 Mt CO_{2eq} (EEA, 2018)	> 20% (GHG-1990) (I) (2009/28/EC)	> 40% (GHG-1990) (II) (2014/15/COM)	(V)	100% (II) (EC, 2018a)
ETS sector reduction targets	(V)	21% (GHG-2005) -1.74% per year (2009/29/EC)	43% (GHG-2005) (I) -2.2% per year (2014/15/COM; 2018/410/EC)	(V)	100% (II) (EC, 2018a)
Non-ETS sectors emission reduction targets	(V)	10% (GHG-2005) (II) (2009/28/EC)	30% (GHG-2005) (II) (2018/410/EC)	(V)	100% (II) (EC, 2018a)
GHG reduction targets (electricity sector)	(V)	(V)	57-65% (GHG-1990) (II) (2011/885/EC)	(V)	96-99% (GHG-1990) (II) (2011/885/EC)
Renewables targets (energy; % of final energy consumption)	(V)	20% (I) (2009/28/EC)	> 32% (I) (2018/2001/EC)	(V)	(V)
Renewables targets (electricity; % of final energy consumption)	30%; 981 TWh; 421 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Intermittent renewables	408 TWh; 255 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Wind onshore	303 TWh; 154 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Wind offshore	included above	(V)	(V)	(V)	(V)
Solar PV	105 TWh; 101 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Dispatchable renewables	573 TWh; 166 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Biomass	159 TWh; 29 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)

EU: Dominant	2016	2020	2030	2040	2050
Hydro	380 TWh; 106 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
CSP	6 TWh; 2 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Other renewables	28 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Traded renewables	(V)	≥ 5% all support schemes in 2023-2026 (2018/2001/EC)	≥ 10% in from 2027 2030 (2018/2001/EC)	(V)	(V)
Physical import of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Statistical transfer of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Explicit trade of CSP or hydropower	(V)	(V)	(V)	(V)	(V)
Nuclear	840 TWh; 122 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Fossil fuels	1433 TWh; 456 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
CCS	0	(V)	(V)	(V)	(V)
Lignite	300 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Hard coal	386 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Gas	642 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Petroleum	61 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Other non-renewables	43 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Storage	(V)	(V)	(V)	(V)	(V)
Battery	(V)	(V)	(V)	(V)	(V)
Pumped Hydropower	(V)	(V)	(V)	(V)	(V)
Other storage	(V)	(V)	(V)	(V)	(V)
Cross-border interconnection NTC	(V)	≥ 10% of yearly power production (II) (2015/82/COM, 2015)	≥ 15% of yearly power production (II) (2018/2001/EC)	(V)	(V)

EU: Dominant	**2016**	**2020**	**2030**	**2040**	**2050**
Electrification of additional sectors	(V)	(V)	(V)	(V)	(V)
Total heating demand incl. non-electric heating	(V)	< 2016 (I) (2018/844/EU)	< 2020 (I) (2018/844/EU)	< 2030 (I) (2018/844/EU)	-90% (GHG-1990) (2011/144/EC)
Heating with electricity	(V)	Each MS: +1.3% (RES-H-2020) (I) (2018/2001/EC)	> 2020 (I) (2018/844/EU)	> 2030(I) (2018/844/EU)	> 2040 (I) (2018/844/EU)
Total cooling demand incl. non-electric cooling	(V)	< 2016 (I) (2018/844/EU)	< 2020 (I) (2018/844/EU)	< 2030 (I) (2018/844/EU)	< 2040 (I) (2018/844/EU)
Cooling with electricity	(V)	Each MS: +1.3% (RES-C-2020) (I) (2018/2001/EC) , Art 23	(V)	(V)	(V)
Electric mobility	(V)	10% (RES-T) (II) (2009/28/EC, §4)	> 14% (RES-T) (2018/2001/EC) , Art. 25	(V)	-60% (GHG-1990) 65% (RES-E) (2011/144/EC)
EV chargers	(V)	1 public charger for every 10 cars (II) (2014/94/EU)(2016/864/COM) Readiness for new buildings (2018/844/EU)	> 2020 (II) (2016/864/COM)	> 2030 (II) (2016/864/COM)	> 2040 (II) (2016/864/COM)
Smart meters	(V)	200 million (72% of households) (II) (2014/0356/COM)	> (II) (2016/864/COM, Art. 21)	> (II) (2016/864/COM, Art. 21)	> (II) (2016/864/COM, Art. 21)
Gross electricity consumption	3254 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Final energy consumption	(V)	-20% (baseline projection) (I) (2012/27/EU)	-26% (PE-2005) -20% (FE-2005) (-0.8% FE per year) -32.5% (compared to baseline projection); upward revision in 2023 (I) (2018/2002/EC) , Art 1	-0.8% FE per year (2030-40 if not found to be unnecessary) (I) (2018/2002/EC) , Art 7	-0.8% FE per year (2040-50 if not found to be unnecessary (I) (2018/2002/EC), Art 7

8.1.2 Minority pathway: grassroot-centred (CAN Europe)

Table 24: Quantification of the European grassroot-centred minority policy pathway as described by CAN Europe.

EU: Grassroots	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	3989 Mt CO_{2eq} (EEA, 2018)	30% (GHG-1990) (IV) (CAN Europe, 2013)	>55% (GHG-1990) (IV) (CAN Europe, 2013)	100% (GHG-1990) (CAN Europe, 2018b)	100% (V)
ETS sector reduction targets	(V)	(V)	(V)	100% (IV)	(V)
Non-ETS sectors emission reduction targets	(V)	(V)	45% (GHG-2005) (IV) (CAN Europe, 2016a)	100% (IV)	(V)
GHG reduction targets (electricity sector)	(V)	(V)	100% (GHG-1990) (IV) (CAN Europe, 2015d)	(V)	(V)
Renewables targets (energy; % of final energy consumption)	(V)	(V)	>45% (GHG-1990) (IV) (CAN Europe, 2017)	(V)	100% (GHG-1990) (III) (CAN Europe, 2017)
Renewables targets (electricity; % of final energy consumption)	30%; 981 TWh; 421 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Intermittent renewables	408 TWh; 255 GW (EUROSTAT, 2018)	> 2016 (IV) (CAN Europe, 2015d)	> 2020 (IV) (CAN Europe, 2015d)	(V)	(V)
Wind onshore	303 TWh; 154 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Wind offshore	included above	(V)	(V)	(V)	(V)
Solar PV	105 TWh; 101 GW (EUROSTAT, 2018)	(decentralised)	(decentralised)	(decentralised)	(decentralised)
Dispatchable renewables	573 TWh; 166 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Biomass	159 TWh; 29 GW (EUROSTAT, 2018)	(sustainable)	(sustainable)	(sustainable)	(sustainable)
Hydro	380 TWh; 106 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
CSP	6 TWh; 2 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)

EU: Grassroots	2016	2020	2030	2040	2050
Other renewables	28 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Traded renewables	(V)	(V)	(V)	(V)	(V)
Physical import of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Statistical transfer of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Explicit trade of CSP or hydropower	(V)	(V)	(V)	(V)	(V)
Nuclear	840 TWh; 122 GW (EUROSTAT, 2018)	(V)	(V)	(V)	0 (IV)
Fossil fuels	1433 TWh; 456 GW (EUROSTAT, 2018)	< 2016 (V)	0 (IV) (CAN Europe, 2015d)	0 (IV)	0 (IV)
CCS	0	(V)	(V)	(V)	(V)
Lignite	300 TWh (EUROSTAT, 2018)	< 2016 (GHG-1990) (IV)	0 (IV)	0 (IV)	0 (IV)
Hard coal	386 TWh (EUROSTAT, 2018)	< 2016 (GHG-1990) (IV)	0 (IV)	0 (IV)	0 (IV)
Gas	642 TWh (EUROSTAT, 2018)	< 2016 (GHG-1990) (IV)	0 (IV)	0 (IV)	0 (IV)
Petroleum	61 TWh (EUROSTAT, 2018)	< 2016 (GHG-1990) (IV)	0 (IV)	0 (IV)	0 (IV)
Other non-renewables	43 TWh (EUROSTAT, 2018)	< 2016 (GHG-1990) (IV)	0 (IV)	0 (IV)	0 (IV)
Storage	(V)	(V)	(V)	(V)	(V)
Battery	(V)	(V)	(V)	(V)	(V)
Pumped Hydropower	(V)	(V)	(V)	(V)	(V)
Other storage	(V)	(V)	(V)	(V)	(V)
Cross-border interconnection NTC	(V)	(V)	(V)	(V)	(V)
Electrification of additional sectors	(V)	(V)	(V)	(V)	(V)
Total heating demand incl. non-electric heating	(V)	(V)	(V)	(V)	(V)
Heating with electricity	(V)	> 2016 (IV) (CAN Europe, 2015c)	> 2020 (IV) (CAN Europe, 2015c)	100% RES-H (CAN Europe, 2015c)	(V)
Total cooling demand incl. non-electric cooling	(V)	< 2016 (IV) (CAN Europe, 2015c)	< 2020 (IV)) (CAN Europe, 2015c)	< 2030 (IV)) (CAN Europe, 2015c)	< 2040 (IV)) (CAN Europe, 2015c)
Cooling with electricity	(V)	> 2016 (IV) (CAN Europe, 2015c)	> 2020 (IV) (CAN Europe, 2015c)	100% RES-C (CAN Europe, 2015c)	>

EU: Grassroots	2016	2020	2030	2040	2050
Electric mobility	(V)	> 2016 (IV) (CAN Europe, 2016b)	> 2020 (IV) (CAN Europe, 2016b)	> 2030 (IV) (CAN Europe, 2016b)	100% (RES-T) (IV) (CAN Europe, 2016b).
EV chargers	(V)	(V)	(V)	(V)	(V)
Gross electricity consumption	3254 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Final energy consumption	(V)	< 2016 (IV) (CAN Europe, 2016d)	-1.5% FE per year (IV) (CAN Europe, 2016d)	-1.5% FE per year (IV) (CAN Europe, 2016d)	-1.5% FE per year (IV) (CAN Europe, 2016d)

8.2 Spain

8.2.1 Dominant pathway: state-centred (PSOE)

Table 25: Quantification of the Spanish state-centred dominant policy pathway as described by currently valid policies of the Partido Socialista Obrero Español and its government

ES: Dominant	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	283 Mt CO_{2eq} (EEA, 2018)	327 MtCO_{2eq} (II) (NECP Spain, 2019) Pag 34	227 Mt CO_{2eq} 21% (GHG-1990) (II) (NECP Spain, 2019) Pag 34	(V)	≥90% (GHG-1990) (II) (NECP Spain, 2019) Pag 34
ETS sector reduction targets	229 Mt CO_{2eq} (European annual emission allocation)	219 Mt CO_{2eq} (European annual emission allocation) (I) (2013/162/EU)	60% (GHG-2005) (II) (NECP Spain, 2019)Pag 36	(V)	(V)
Non-ETS sectors emission reduction targets	(V)	10% (GHG-2005) (2009/406/EC)	38% (GHG-2005) (II) (NECP Spain, 2019)Pag 36	(V)	(V)
GHG reduction targets (electricity sector)	(V)	63.5 Mt CO_{2eq} 4% (GHG 1990) (II) (NECP Spain, 2019) Pag 34	19.7 Mt CO_{2eq} (II); 70% (GHG 1990) (NECP Spain, 2019) Pag 34	(V)	(V)
Renewables targets (energy; % of final energy consumption)	(V)	20% (I) (European Union, 2009)	42% (II) (NECP Spain, 2019)	(V)	100% (II) (NECP Spain, 2019) Pag 167
Renewables targets (electricity; % of final energy consumption)	39% 108 TWh 49 GW (EUROSTAT, 2018)	40% (II) (NECP Spain, 2019) Pag 174	>74% (II) (NECP Spain, 2019) Pag 174	(V)	100% (II) (NECP Spain, 2019) Pag 35
Intermittent renewables	57 TWh; 28 GW (EUROSTAT, 2018)	36.4 GW; 75.7 TWh (II) (NECP Spain, 2019)	87.1 GW; 182.5 TWh (II) (NECP Spain, 2019)	≥ 2030	≥ 2040
Wind onshore	49 TWh; 23 GW (EUROSTAT, 2018)	60.5 TWh; 28.0 GW(II)(NECP Spain, 2019) Pag 174	116.1 TWh; 50.3 GW (II)(NECP Spain, 2019) Pag 174	(V)	(V)
Wind offshore	included above	included above	included above	(V)	(V)
Solar PV	8 TWh; 5 GW (EUROSTAT, 2018)	15.1 TWh; 8.4 GW (II)(NECP Spain, 2019) Pag 174	66.4 TWh; 36.9 GW (II) (NECP Spain, 2019) Pag 174	> 2030	> 2030
Dispatchable renewables	51 TWh; 21 GW (EUROSTAT, 2018)	24.0 GW; 42.8 TWh (including hydro pumping) (II) (NECP Spain, 2019)	33.8 GW; 72.3 TWh (including hydro pumping) (II) (NECP Spain, 2019)	≥ 2030	≥ 2040

ES: Dominant	2016	2020	2030	2040	2050
Biomass	5 TWh; 1 GW (EUROSTAT, 2018)	5.3 TWh;1.6 GW(II) (NECP Spain, 2019) Pag 171 and 174	13.2 TWh;2.4 GW (II) (NECP Spain, 2019) Pag 171 and 174	(V)	(V)
Hydro (without pumping)	40 TWh; 14 GW (EUROSTAT, 2018)	28.3 TWh; 14.1 GW (II) (NECP Spain, 2019)Pag 171 and 174	29 TWh;14.6 GW (II) (NECP Spain, 2019) Pag 171 and 174	(V)	(V)
CSP	6 TWh; 2 GW (EUROSTAT, 2018)	5 TWh, 2.3 GW (II) (NECP Spain, 2019) Pag 171 and 174	22.6 TWh,7.3 GW (II) (NECP Spain, 2019) Pag 171 and 174	≥ 2030	≥ 2040
Other renewables	1 TWh (EUROSTAT, 2018)	0 (II) (NECP Spain, 2019) Pag 171 and 174	0.3 TWh, 0.1 GW (II) (NECP Spain, 2019) Pag 171 and 174	(V)	(V)
Traded renewables	(V)	(V)	(V)	(V)	(V)
Physical import of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Statistical transfer of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Explicit trade of CSP or hydropower	(V)	(V)	(V)	(V)	(V)
Nuclear	59 TWh; 7 GW (EUROSTAT, 2018)	57.7 TWh; 7.4 GW (II) (NECP Spain, 2019) Pag 171 and 174	24.8 TWh; 3.2 GW (II) (NECP Spain, 2019) Pag 171 and 174	0 (II) (NECP Spain, 2019) Pag 171	0 (II) (NECP Spain, 2019) Pag 171 and 174
Fossil fuels	108 TWh; 48 GW (EUROSTAT, 2018)	112 TWh; 45.1 GW (II) (NECP Spain, 2019) Pag 171 and 174	55 TWh;32.5 GW (II) (NECP Spain, 2019) Pag 171 and 174	(V)	0 (II) (NECP Spain, 2019) Pag 35
CCS	0	0 (NECP Spain, 2019) Pag 171 and 174	0 (NECP Spain, 2019) Pag 171 and 174	(V)	(V)
Lignite	0 TWh (EUROSTAT, 2018)	0	0	0	0
Hard coal	36 TWh (EUROSTAT, 2018)	47.2 TWh; 10.5 GW (II) (NECP Spain, 2019) Pag 171 and 174	0 TWh; 0-1.3 GW (II)(NECP Spain, 2019) Pag 171 and 174		0(II)(NECP Spain, 2019) Pag 35
Gas	54 TWh (EUROSTAT, 2018)	56.8 TWh; 31.2 GW (II) (NECP Spain, 2019) Pag 171 and 174	50.5 TWh 30.2 GW (II)(NECP Spain, 2019) Pag 171 and 174	(V)	0 (II)(NECP Spain, 2019) Pag 35

ES: Dominant	2016	2020	2030	2040	2050
Petroleum	16 TWh (EUROSTAT, 2018)	7.4 TWh; 3.4 GW (II)(NECP Spain, 2019) Pag 171 and 174	4.7 TWh;2.3 GW (II)(NECP Spain, 2019) Pag 171 and 174	(V)	0 (II)(NECP Spain, 2019) Pag 35
Other non-renewables	1 TWh (EUROSTAT, 2018)	0.7 TWh (II) (NECP Spain, 2019) Pag 174	1.5 TWh (II) (NECP Spain, 2019) Pag 174	(V)	0 (II) (NECP Spain, 2019) Pag 35
Storage	(V)	(V)	(V)	(V)	(V)
Battery	(V)	(V)	2.5 GW (II) (NECP Spain, 2019) Pag 42	(V)	(V)
Pumped Hydropower	3.3 GW (2015) (II) (NECP Spain, 2019) Pag 171	3.3 GW (II) (NECP Spain, 2019) Pag 171	6.8 GW(II) (NECP Spain, 2019) Pag 171	(V)	(V)
Other storage	(V)	(V)	(V)	(V)	(V)
Cross-border interconnection NTC	2750 MW (France) 2800 MW (Portugal) 800 MW (Morocco) (II) (NECP Spain, 2019)Pag 187	2900 MW (France) 3500 MW (Portugal) 800 MW (Morocco) (II) (NECP Spain, 2019) Pag 187	8000 MW (France) 4300 MW (Portugal) (II)(NECP Spain, 2019)Pag 1871200 MW (Morocco)(IV) (Montel, 2019)	=2030(V)	=2040(V)
Electrification of additional sectors	(V)	(V)	(V)	(V)	(V)
Total heating demand incl. non-electric heating	(V)	(V)	(V)	(V)	(V)
Heating with electricity (energy supplied by heat pumps) COP>3	4.1 TWh (II)(NECP Spain, 2019) Pag 167	7.6 TWh (II) (NECP Spain, 2019) Pag 167	47.4 TWh (II) (NECP Spain, 2019) Pag 167	(V)	(V)
Total cooling demand incl. non-electric cooling	(V)	(V)	< 2018 (II) (Ministerio para la Transición Ecológica, 2018)	(V)	(V)
Cooling with electricity	(V)	(V)	< 2018 (II) (Ministerio para la Transición Ecológica, 2018)	(V)	(V)

ES: Dominant	2016	2020	2030	2040	2050
Electric mobility	6.6 TWh (II) (NECP Spain, 2019) Pag 180	4.9 TWh (II) (NECP Spain, 2019) Pag 180	20.7 TWh; 5 million EV (II)(NECP Spain, 2019)Pag 180	>> 2030 (II) Ban on ICE sales (Ministerio para la Transición Ecológica, 2018)	>> 2030 (II) Ban on ICE circulation (Ministerio para la Transición Ecológica, 2018)
EV chargers	4974 (2017) (Spöttle *et al.*, 2018)	> 2017 (II) (Ministerio para la Transición Ecológica, 2018)	>>2020 (II) (Ministerio para la Transición Ecológica, 2018)	>> 2030 (II) (Ministerio para la Transición Ecológica, 2018)	>> 2040 (II) ((Ministerio para la Transición Ecológica, 2018)
Gross electricity consumption	275 TWh (EUROSTAT, 2018)	267 TWh (II) (NECP Spain, 2019) Pag 174	284 TWh (II) (NECP Spain, 2019) Pag 174	(V)	(V)
Final energy consumption	983 TWh (2015) (II) (NECP Spain, 2019) Pag 214	1035 TWh (II) (NECP Spain, 2019) Pag 214	922TWh (II) (NECP Spain, 2019) Pag 214	(V)	(V)

8.2.2 *Minority pathway: grassroot-centred (Podemos)*

Table 26: Quantification of the Spanish grassroots-centred minority policy pathway as described by Podemos.

ES: Grassroots	**2016**	**2020**	**2030**	**2040**	**2050**
GHG reduction targets (economy-wide)	283 Mt CO2eq (EEA, 2018)	(V)	35% (1990) (III) (Unidas Podemos, 2018)	70% (1990) (III) (Unidas Podemos, 2018)	95% (1990) (III) (Unidas Podemos, 2018)
ETS sector reduction targets	229 Mt CO2eq (European annual emission allocation)(EU/2017/1471, 2017)	219 Mt CO2eq (European annual emission allocation) (EU/2017/1471, 2017)	(V)	(V)	(V)
Non-ETS sectors emission reduction targets		10% (GHG-2005) (406/2009/EC, 2009) (I)	26% (GHG-2005) (I) (EU/2018/842, 2018)	(V)	(V)
GHG reduction targets (electricity sector)	(V)	(V)	(V)	(V)	(V)
Renewables targets (energy; % of final energy consumption)	(V)	20% (I) (European Union, 2009)	45% (III) (Unidas Podemos, 2018)	60% (III) (Unidas Podemos, 2018)	100% (III) (Unidas Podemos, 2018)
Renewables targets (electricity; % of final energy consumption)	39%; 108 TWh; 49 GW(Eurostat, 2018)	> 2016 (V)	80% (III) (Unidas Podemos, 2018)	(V)	100% (by 2045) (III) (Unidas Podemos, 2018)
Intermittent renewables	57 TWh; 28 GW(Eurostat, 2018)	> 2016 (III) (Unidas Podemos, 2018)	> 2020 (III) (Unidas Podemos, 2018)	> 2030 (III) (Unidas Podemos, 2018)	> 2040 (III) (Unidas Podemos, 2018)
Wind onshore	49 TWh; 23 GW (Eurostat, 2018)	> 2016 (III) (Unidas Podemos, 2018)	> 2020 (III) (Unidas Podemos, 2018)	> 2030 (III) (Unidas Podemos, 2018)	> 2040 (III) (Unidas Podemos, 2018)
Wind offshore	included above	= 2016 (III) (Unidas Podemos, 2018)	= 2016 (III) (Unidas Podemos, 2018)	= 2016 (III) (Unidas Podemos, 2018)	= 2016 (III) (Unidas Podemos, 2018)
Solar PV	8 TWh; 5 GW (Eurostat, 2018)	>> 2016 (mainly decentralised) (III) (Unidas Podemos, 2018)	>> 2020 (mainly decentralised) (III) (Unidas Podemos, 2018)	>> 2030 (mainly decentralised) (III) (Unidas Podemos, 2018)	>> 2040 (mainly decentralised) (III) (Unidas Podemos, 2018)

ES: Grassroots	2016	2020	2030	2040	2050
Dispatchable renewables	51 TWh; 21 GW (Eurostat, 2018)	> 2016 (III) (Unidas Podemos, 2018)	> 2020 (III) (Unidas Podemos, 2018)	> 2030 (III) (Unidas Podemos, 2018)	> 2040 (III) (Unidas Podemos, 2018)
Biomass	5 TWh; 1 GW (Eurostat, 2018)	> 2016 (III) (Unidas Podemos, 2018)	> 2020 (III) (Unidas Podemos, 2018)	> 2030 (III) (Unidas Podemos, 2018)	> 2040 (III) (Unidas Podemos, 2018)
Hydro	40 TWh; 14 GW (Eurostat, 2018)	> 2016 (III) (Unidas Podemos, 2018)	> 2020 (III) (Unidas Podemos, 2018)	> 2030 (III) (Unidas Podemos, 2018)	> 2040 (III) (Unidas Podemos, 2018)
CSP	6 TWh; 2.3 GW (Eurostat, 2018)	> 2016 (III) (Unidas Podemos, 2018)	> 2020 (III) (Unidas Podemos, 2018)	> 2030 (III) (Unidas Podemos, 2018)	> 2040 (III) (Unidas Podemos, 2018)
Other renewables	1 TWh (Eurostat, 2018)	(V)	(V)	(V)	(V)
Traded renewables	As little as possible	As little as possible	As little as possible	As little as possible	As little as possible
Physical import of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Statistical transfer of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Explicit trade of CSP or hydropower	(V)	(V)	(V)	(V)	(V)
Nuclear	59 TWh; 7 GW (Eurostat, 2018)	Phase-out as licences expire: Almaraz I, II, Vandellós II (2020); Ascó I, II, Cofrentes (2021); Trillo (2024) (III) (Unidas Podemos, 2018)	0 (by 2025) (III) (Unidas Podemos, 2018)	0 (III) (Unidas Podemos, 2018)	0 (III) (Unidas Podemos, 2018)
Fossil fuels	108 TWh; 48 GW (Eurostat, 2018)	(V)	(V)	(V)	(V)
CCS	0	(V)	(V)	(V)	(V)
Lignite	0 TWh (Eurostat, 2018)	<< 2016 (III) (Unidas Podemos, 2018)	0 (by 2025) (III) (Unidas Podemos, 2018)	0 (III) (Unidas Podemos, 2018)	0 (III) (Unidas Podemos, 2018)

ES: Grassroots	2016	2020	2030	2040	2050
Hard coal	36 TWh (Eurostat, 2018)	<< 2016 (III) (Unidas Podemos, 2018)	0 (by 2025) (III) (Unidas Podemos, 2018)	0 (III) (Unidas Podemos, 2018)	0 (III) (Unidas Podemos, 2018)
Gas	54 TWh (Eurostat, 2018)	< 2016 (III) (Unidas Podemos, 2018)	< 2020 (III) (Unidas Podemos, 2018)	< 2030 (III) (Unidas Podemos, 2018)	< 2040 (III) (Unidas Podemos, 2018)
Petroleum	16 TWh (Eurostat, 2018)	< 2016 (III) (Unidas Podemos, 2018)	< 2020 (III) (Unidas Podemos, 2018)	< 2030 (III) (Unidas Podemos, 2018)	0 (III) (Unidas Podemos, 2018)
Other non-renewables	1 TWh (Eurostat, 2018)	≥ 2016 (Waste) (III) (Unidas Podemos, 2018)	≥ 2020 (III) (Unidas Podemos, 2018)	(V)	(V)
Storage	(V)	(V)	(V)	(V)	(V)
Battery	(V)	> 2016 (III) (Unidas Podemos, 2018)	> 2020 (III) (Unidas Podemos, 2018)	> 2030 (III) (Unidas Podemos, 2018)	> 2040 (III) (Unidas Podemos, 2018)
Pumped Hydropower	(V)	(V)	(V)	(V)	(V)
Other storage	(V)	> 2016 (III) (Unidas Podemos, 2018)	> 2020 (III) (Unidas Podemos, 2018)	> 2030 (III) (Unidas Podemos, 2018)	> 2040 (III) (Unidas Podemos, 2018)
Cross-border interconnection NTC	(V)	≥ 10% of installed capacity (III) (Unidas Podemos, 2018)	≥ 15% of installed capacity (III) (Unidas Podemos, 2018)	= 2030 (III) (Unidas Podemos, 2018)	= 2040 (III) (Unidas Podemos, 2018)
Electrification of additional sectors	(V)	(V)	(V)	(V)	(V)
Total heating demand incl. non-electric heating	(V)	(V)	(V)	(V)	(V)
Heating with electricity		Same as dominant	Same as dominant	(V)	(V)
Total cooling demand incl. non-electric cooling	(V)	(V)	(V)	(V)	(V)
Cooling with electricity		Same as dominant	Same as dominant		

ES: Grassroots	2016	2020	2030	2040	2050
Electric mobility		3% of new vehicles are EV (by 2020) , 25% EV (by 2025) (III) (Unidas Podemos, 2018) 4.9 TWh (same as dominant)	70% (EV) (III) (Unidas Podemos, 2018) 16.8 TWh *(20% less than dominant)	100% (EV) (III) (Unidas Podemos, 2018)(same as dominant)	
EV chargers		>> 2016 (III) (Unidas Podemos, 2018)	> 2020 (III) (Unidas Podemos, 2018)	> 2030 (III) (Unidas Podemos, 2018)	≥ 2040 (III) (Unidas Podemos, 2018)
Gross electricity consumption	275 TWh (Eurostat, 2018)	267 TWh (same as dominant)	280 TWh**	(V)	(V)
Final energy consumption	983 TWh	1035 TWh (same as dominant)	927 TWh***	***	(V)

* 3% of new vehicles as electric vehicles in 2020, 25% in 2025 and 70% in 2030 lead to a cumulative EV fleet of around 4.2 million vehicles, 19% less than in the dominant pathway.

** Same as dominant but slightly lower electrification of transport leads to slightly lower electricity demand

*** 40% reduction in primary energy demand vs 39.6% in dominant and 3% more of renewables in final energy (2030) 45% primary energy demand reduction compared to reference scenario (2040).

8.2.3 *Minority pathway: market-centred (Partido Popular)*

Table 27: Quantification of the Spanish market-centred minority policy pathway as described by Partido Popular.

ES: Market	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	283 Mt CO2eq (EEA, 2018)	10% (GHG-2005) (III) (Partido Popular, 2018)	Non-ETS 26% (III) (Partido Popular, 2018)	> 2030 (III) (Partido Popular, 2018)	80% (III) (Partido Popular, 2018)
ETS sector reduction targets	229 Mt Mt CO2eq (European annual emission allocation) (I) (EU/2017/1471, 2017)	219 Mt Mt CO_{2eq} (European annual emission allocation) (I) (EU/2017/1471, 2017)	(V)	(V)	(V)
Non-ETS sectors emission reduction targets		10% (GHG-2005) (406/2009/EC, 2009) (I)	26% (GHG-2005) (I) (EU/2018/842, 2018)	(V)	(V)
GHG reduction targets (electricity sector)	(V)	(V)	(V)	(V)	(V)
Renewables targets (energy; % of final energy consumption)	(V)	20% (I) (European Union, 2009)	> 2020 (III) (Partido Popular, 2018)	(V)	(V)
Renewables targets (electricity; % of final energy consumption)	39%; 108 TWh; 49 GW(Eurostat, 2018)	> 2016 (III) (Partido Popular, 2018)	> 2020 (III) (Partido Popular, 2018)	> 2030 (III) (Partido Popular, 2018)	> 2040 (III) (Partido Popular, 2018)
Intermittent renewables	57 TWh; 28 GW(Eurostat, 2018)	(V)	(V)	(V)	(V)
Wind onshore	49 TWh; 23 GW (Eurostat, 2018)	> 2016 (III) (Partido Popular, 2018)	> 2020 (III) (Partido Popular, 2018)	> 2030 (III) (Partido Popular, 2018)	> 2040 (III) (Partido Popular, 2018)
Wind offshore	included above	> 2016 (III) (Partido Popular, 2018)	> 2020 (III) (Partido Popular, 2018)	> 2030 (III) (Partido Popular, 2018)	> 2040 (III) (Partido Popular, 2018)
Solar PV	8 TWh; 5 GW (Eurostat, 2018)	> 2016 (III) (Partido Popular, 2018)	> 2020 (III) (Partido Popular, 2018)	> 2030 (III) (Partido Popular, 2018)	> 2040 (III) (Partido Popular, 2018)
Dispatchable renewables	51 TWh; 21 GW (Eurostat, 2018)	> 2016 (III) (Partido Popular, 2018)	> 2020 (III) (Partido Popular, 2018)	> 2030 (III) (Partido Popular, 2018)	> 2040 (III) (Partido Popular, 2018)
Biomass	5 TWh; 1 GW (Eurostat, 2018)	(V)	(V)	(V)	(V)
Hydro	40 TWh; 14 GW (Eurostat, 2018)	(V)	(V)	(V)	(V)

ES: Market	2016	2020	2030	2040	2050
CSP	6 TWh; 2.3 GW (Eurostat, 2018)	(V)	(V)	(V)	(V)
Other renewables	1 TWh (Eurostat, 2018)	(V)	(V)	(V)	(V)
Traded renewables	(V)	(V)	(V)	(V)	(V)
Physical import of renewables (cooperation)	(V)	> 2016 (III) (Partido Popular, 2018)	> 2020 (III) (Partido Popular, 2018)	> 2030 (III) (Partido Popular, 2018)	> 2040 (III) (Partido Popular, 2018)
Statistical transfer of renewables (cooperation)	(V)	≥ 2016 (III) (Partido Popular, 2018)	≥ 2016 (III) (Partido Popular, 2018)	≥ 2016 (III) (Partido Popular, 2018)	≥ 2016 (III) (Partido Popular, 2018)
Explicit trade of CSP or hydropower	(V)	(V)	(V)	(V)	(V)
Nuclear	59 TWh 7 GW (Eurostat, 2018)	= 2016 (IV) (Sociedad Nuclear Española, 2015; Público, 2018)	= 2016 (IV) (Sociedad Nuclear Española, 2015; Público, 2018)	= 2016 (IV) (Sociedad Nuclear Española, 2015; Público, 2018)	=2016 (IV) (Sociedad Nuclear Española, 2015; Público, 2018)
Fossil fuels	108 TWh; 48 GW (Eurostat, 2018)	(V)	(V)	(V)	(V)
CCS	0	> 2016 (III) (Partido Popular, 2018)	> 2020 (III) (Partido Popular, 2018)	> 2030 (III) (Partido Popular, 2018)	> 2040 (III) (Partido Popular, 2018)
Lignite	0 TWh (Eurostat, 2018)	≤ 2016 (IV) (La Nueva Crónica, 2018)	≤ 2016 (IV) (La Nueva Crónica, 2018)	(V)	(V)
Hard coal	36 TWh (Eurostat, 2018)	≤ 2016(IV) (La Nueva Crónica, 2018)	≤ 2016 (IV) (La Nueva Crónica, 2018)	(V)	(V)
Gas	54 TWh (Eurostat, 2018)	≥ 2016 (III) (Popular, 2016)	≥ 2016 (III) (Popular, 2016)	≥ 2016 (III) (Popular, 2016)	≥ 2016 (III) (Popular, 2016)
Petroleum	16 TWh (Eurostat, 2018)	(V)	(V)	(V)	(V)
Other non-renewables	1 TWh (Eurostat, 2018)	(V)	(V)	(V)	(V)
Storage	(V)	(V)	(V)	(V)	(V)
Battery	(V)	> 2016 (Partido Popular, 2018)	> 2020 (Partido Popular, 2018)	> 2030 (Partido Popular, 2018)	> 2040 (Partido Popular, 2018)
Pumped Hydropower	(V)	> 2016 (Partido Popular, 2018)	> 2020 (Partido Popular, 2018)	> 2030 (Partido Popular, 2018)	> 2040 (Partido Popular, 2018)
Other storage	(V)	(V)	(V)	(V)	(V)

ES: Market	2016	2020	2030	2040	2050
Cross-border interconnection NTC	(V)	≥ 10% of installed capacity	≥ 15% of installed capacity (III) (Partido Popular, 2018)	≥ 2030 (III) (Partido Popular, 2018)	≥ 2030 (III) (Partido Popular, 2018)
Electrification of additional sectors	(V)	(V)	(V)	(V)	(V)
Total heating demand incl. non-electric heating	(V)	(V)	(V)	(V)	(V)
Heating with electricity		Same as dominant	Less than dominant*	(V)	(V)
Total cooling demand incl. non-electric cooling	(V)	(V)	(V)	(V)	(V)
Cooling with electricity		Same as dominant	Less than dominant*	(V)	(V)
Electric mobility	480 ktoe	Same as dominant	Less than dominant*	(V)	(V)
EV chargers		> 2016 (III) (Partido Popular, 2018)	> 2020 (III) (Partido Popular, 2018)	> 2030 (III) (Partido Popular, 2018)	> 2040 (III) (Partido Popular, 2018)
Gross electricity consumption	275 TWh (Eurostat, 2018)	270 TWh; Same as dominant	279 TWh**Lower than dominant	(V)	(V)
Final energy consumption	983 TWh	1035 TWhSame as dominant	987 TWh***	(V)	(V)

*No specific policies addressing the electrification of other sectors. No specific EV promotion policies.
** Lower than the dominant due to lower electrification of end use sectors. Taken as the trend scenario of the NECP.
*** calculated using a 32.5% reduction of primary energy from the reference scenario and a factor to convert PE to FE higher than in the dominant due to the reduced penetration of renewable energies (32% vs 42% in the dominant)

8.3 France

8.3.1 Dominant pathway: state-centred (Hollande and Macron governments)

Table 28: Quantification of the French state-centred dominant policy pathway as described by currently valid policies of both (first) the Parti Socialiste and (then) En Marche and their respective governments.

FR: Dominant	**2016**	**2020**	**2030**	**2040**	**2050**
GHG reduction targets (economy-wide)	421 Mt CO_{2eq} (EEA, 2018)	-20% (GHG-1990) (Grenelle I Law, 2009; Grenelle II Law, 2010)	-40% (GHG-1990) (ETL, 2015; French Republic, 2018)	(V)	-75% (GHG-1990) / Max. 140 Mt CO_{2eq} (ETL, 2015; French Republic Prime Minister's Office, 2012; Grenelle I Law, 2009; Grenelle II Law, 2010)
ETS sector reduction targets	393 Mt CO_{2eq} (European annual emission allocation)	355 Mt CO_{2eq} (European annual emission allocation) (2013/162/EU)	(V)	(V)	(V)
Non-ETS sectors emission reduction targets	(V)	14% (GHG-2005) (2009/406/EC)	37% (GHG-2005) (I) (2018/842)	(V)	(V)
GHG reduction targets (electricity sector)	(V)	(V)	(V)	(V)	(V)
Renewables targets (energy; % of final energy consumption)	(V)	23% (Grenelle I Law, 2009; Grenelle II Law, 2010) 71-78 GW by 2023); 150-167 TWh by 2023 (MEP, 2016)	34% (NECP FR, 2019)	(V)	(V)
Renewables targets (electricity; % of final energy consumption)	18%; 102 TWh; 40 GW (EUROSTAT, 2018)	(V)	40% (French Republic, 2018; Ministry of Ecological and Solidary Transition, 2017)	Close to but below 50% (Viennot, 2015)	50% (Viennot, 2015)
Intermittent renewables	30 TWh; 19 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)

FR: Dominant	2016	2020	2030	2040	2050
Wind onshore	21 TWh; 11 GW (EUROSTAT, 2018)	(V)	4-to-1 ratio (wind onshore to PV) (Ministry of Ecological and Solidary Transition, 2018)	4-to-1 ratio (wind onshore to PV) (Ministry of Ecological and Solidary Transition, 2018)	4-to-1 ratio (wind onshore to PV) (Ministry of Ecological and Solidary Transition, 2018)
Wind offshore	included above	(V)	(V)	(V)	(V)
Solar PV	8 TWh; 7 GW (EUROSTAT, 2018)	(V)	4-to-1 ratio (wind onshore to PV) (Ministry of Ecological and Solidary Transition, 2018)	4-to-1 ratio (wind onshore to PV) (Ministry of Ecological and Solidary Transition, 2018)	4-to-1 ratio (wind onshore to PV) (Ministry of Ecological and Solidary Transition, 2018)
Dispatchable renewables	73 TWh; 21 GW (EUROSTAT, 2018)	≥ 2020 (2023) (ADEME, 2016a)	≥ 2023 (ADEME, 2016a)	≥ 2030 (ADEME, 2016a)	≥ 2040 (ADEME, 2016a)
Biomass	5 TWh; 1 GW (EUROSTAT, 2018)	≥ 2020 (2023) (ADEME, 2016a)	≥ 2023 (ADEME, 2016a)	≥ 2030 (ADEME, 2016a)	≥ 2040 (ADEME, 2016a)
Hydro	65 TWh; 18 GW (EUROSTAT, 2018)	≥ 2016 (2023) (TWh); =2016 (GW) (ADEME, 2016a)	≥ 2016 (2023) (TWh); =2016 (GW) (ADEME, 2016a)	≥ 2016 (2023) (TWh); =2016 (GW) (ADEME, 2016a)	≥ 2016 (2023) (TWh); =2016 (GW) (ADEME, 2016a)
CSP	0 TWh; 0 GW (EUROSTAT, 2018)	(V)	(V)	(V)	0.4 GW (II) (ADEME, 2016a)
Other renewables	3 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Traded renewables	(V)	(V)	(V)	(V)	(V)
Physical import of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Statistical transfer of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Explicit trade of CSP or hydropower	(V)	(V)	(V)	(V)	(V)
Nuclear	403 TWh; 63 GW (EUROSTAT, 2018)	(V)	By 2025: 50% of mix; 63.2 GW (AFP, 2017; ETL, 2015; MEP, 2016)	= 2030 (AFP, 2017; ETL, 2015; MEP, 2016)	=2030 (AFP, 2017; ETL, 2015; MEP, 2016)
Fossil fuels	51 TWh; 23 GW (EUROSTAT, 2018)	(V)	-30% (GW-2012) (ETL, 2015; French Republic, 2018; MEP, 2016)	(V)	(V)

FR: Dominant	2016	2020	2030	2040	2050
CCS	0	(V)	(V)	(V)	(V)
Lignite	0 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Hard coal	8 TWh (EUROSTAT, 2018)	By 2023 -37% (GW-2012) (MEP, 2016)	(V)	(V)	(V)
Gas	37 TWh (EUROSTAT, 2018)	By 2023 -15.8% (GW-2012) (MEP, 2016)	(V)	(V)	(V)
Petroleum	2 TWh (EUROSTAT, 2018)	By 2023: -22.4% (GW-2012) (MEP, 2016)	(V)	(V)	(V)
Other non-renewables	3 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Storage		(V)	(V)	(V)	(V)
Battery	(V)	(V)	(V)	(V)	Technologically unspecified direct storage interweekly and interdaily >> 2016 (II) (ADEME, 2016a)
Pumped Hydropower	(V)	= 2016 (ADEME, 2016a)	= 2016 (ADEME, 2016a)	= 2016 (ADEME, 2016a)	= 2016 (ADEME, 2016a)
Other storage	(V)	(V)	(V)	(V)	200 TWh (Power-to-gas) (II) 10-46 TWh (Gas-to-power) (II) (ADEME, 2016a, 2018)
Cross-border interconnection NTC	(V)	≥ 2016 (Ministry of Ecological and Solidary Transition, 2016b)	≥ 15% of yearly power production (Ministry of Ecological and Solidary Transition, 2016b)	= 2030 (Ministry of Ecological and Solidary Transition, 2016b)	= 2030 (Ministry of Ecological and Solidary Transition, 2016b)
Electrification of additional sectors	(V)	(V)	(V)	(V)	(V)

FR: Dominant	2016	2020	2030	2040	2050
Total heating demand incl. non-electric heating	(V)	By 2023: +50% (TWh-2014) (MEP, 2016)	Growth rate of heating and cooling by RETs: +1%/year between 2020 and 2030 (NECP FR, 2019)	(V)	(V)
Heating with electricity	(V)	(V)	38% (RES-E) (Ministry of Ecological and Solidary Transition, 2017)	(V)	(V)
Total cooling demand incl. non-electric cooling	(V)	(V)	(V)	(V)	(V)
Cooling with electricity	(V)	(V)	(V)	(V)	(V)
Electric mobility	(V)	By 2023: 2.4 million EV (MEP, 2016)	4 million EV (MEP, 2016)	Ban on new ICE (Le Monde, 2017)	(V)
EV chargers	(V)	(V)	7 million Chargers (MEP, 2016)	(V)	(V)
Gross electricity consumption	556 TWh (EUROSTAT, 2018)	(V)	-20% (2012) (II) (French Republic, 2018)	(V)	420 TWh (II) (French Republic, 2018)
Final energy consumption	(V)	1528 TWh (NECP FR, 2019)	1368 TWh (EU target applied to France in the NECP) (NECP FR, 2019)	<1368 TWh (NECP FR, 2019)	<<1368 TWh (NECP FR, 2019)

8.3.2 *Minority pathway: outside the energy logics framework (Rassemblement National)*

Table 29: Quantification of the French minority policy pathway (outside the transition logics framework) as described by Rassemblement National.

FR: Outside logic	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	421 Mt CO_{2eq} (EEA, 2018)	(V)	(V)	(V)	(V)
ETS sector reduction targets	393 Mt CO_{2eq} (European annual emission allocation)	(V)	(V)	(V)	(V)
Non-ETS sectors emission reduction targets	(V)	14% (GHG-2005) (2009/406/EC)	37% (GHG-2005) (I) (2018/842)	(V)	(V)
GHG reduction targets (electricity sector)	(V)	(V)	(V)	(V)	(V)
Renewables targets (energy; % of final energy consumption)	(V)	(V)	(V)	(V)	(V)
Renewables targets (electricity; % of final energy consumption)	18%; 102 TWh; 40 GW (EUROSTAT, 2018)	(V)	(V)	(V)	All that is not covered by nuclear power. Applies to solar and biomass (III) (Dupin, 2017b)
Intermittent renewables	30 TWh; 19 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Wind onshore	21 TWh; 11 GW (EUROSTAT, 2018)	= 2018 (III) (Durox, 2018; Odoul, 2018)	= 2018 (III) (Durox, 2018; Odoul, 2018)	= 2018 (III) (Durox, 2018; Odoul, 2018)	= 2018 (III) (Durox, 2018; Odoul, 2018)
Wind offshore	included above	= 2018 (III) (Durox, 2018; Odoul, 2018)	= 2018 (III) (Durox, 2018; Odoul, 2018)	= 2018 (III) (Durox, 2018; Odoul, 2018)	= 2018 (III) (Durox, 2018; Odoul, 2018)
Solar PV	8 TWh; 7 GW (EUROSTAT, 2018)	= 2018 (III) (Dupin, 2017b; Rassemblement National, 2017)	= 2018 (III) (Dupin, 2017b; Rassemblement National, 2017)	> 2030 (III) (Dupin, 2017b; Rassemblement National, 2017)	> 2040 (III) (Dupin, 2017b; Rassemblement National, 2017)
Dispatchable renewables	73 TWh; 21 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Biomass	5 TWh; 1 GW (EUROSTAT, 2018)	(V)	= 2018 (III) (Dupin, 2017b; Rassemblement National, 2017)	> 2030 (III) (Dupin, 2017b; Rassemblement National, 2017)	> 2040 (III) (Dupin, 2017b; Rassemblement National, 2017)

FR: Outside logic	2016	2020	2030	2040	2050
Hydro	65 TWh; 18 GW (EUROSTAT, 2018)	= 2018 (III) (Aliot, 2018; Coativy, 2018)	= 2018 (III) (Aliot, 2018; Coativy, 2018)	= 2018 (III) (Aliot, 2018; Coativy, 2018)	= 2018 (III) (Aliot, 2018; Coativy, 2018)
CSP	0 TWh; 0 GW (EUROSTAT, 2018)	0 (Joffre, 2017)	0 (Joffre, 2017)	0 (Joffre, 2017)	0 (Joffre, 2017)
Other renewables	3 TWh (EUROSTAT, 2018)	0 (Joffre, 2017)	0 (Joffre, 2017)	0 (Joffre, 2017)	0 (Joffre, 2017)
Traded renewables	(V)	(V)	(V)	(V)	(V)
Physical import of renewables (cooperation)	(V)	0 (III) (Brezet, 2017b)	0 (III) (Brezet, 2017b)	0 (III) (Brezet, 2017b)	0 (III) (Brezet, 2017b)
Statistical transfer of renewables (cooperation)	(V)	0 (III) (Brezet, 2017b)	0 (III) (Brezet, 2017b)	0 (III) (Brezet, 2017b)	0 (III) (Brezet, 2017b)
Explicit trade of CSP or hydropower	(V)	0 (Joffre, 2017)	0 (Joffre, 2017)	0 (Joffre, 2017)	0 (Joffre, 2017)
Nuclear	403 TWh; 63 GW (EUROSTAT, 2018)	75% of mix (III) (Astier, 2017; Brezet, 2017b; Dupin, 2017b)	75% of mix (III) (Astier, 2017; Brezet, 2017b; Dupin, 2017b)	75% of mix (III) (Astier, 2017; Brezet, 2017b; Dupin, 2017b)	75% of mix (III) (Astier, 2017; Brezet, 2017b; Dupin, 2017b)
Fossil fuels	51 TWh; 23 GW (EUROSTAT, 2018)	(V)	(V)	By 2035: -50% (FE-2017) (III) (Barroux, 2016a)	0 (III) (Joffre, 2017)
CCS	0	(V)	(V)	(V)	(V)
Lignite	0 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	0 (III) (Joffre, 2017)
Hard coal	8 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	0 (III) (Joffre, 2017)
Gas	37 TWh (EUROSTAT, 2018)	(V)	(V)	-50% (ref. 2018) (III) (Joffre, 2017)	0 (III) (Joffre, 2017)
Petroleum	2 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	0 (III) (Joffre, 2017)
Other non-renewables	3 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Storage		(V)	(V)	(V)	(V)
Battery	(V)	(V)	(V)	(V)	(V)
Pumped Hydropower	(V)	(V)	(V)	(V)	(V)
Other storage	(V)	(V)	(V)	> 2016 (III) (hydrogen for mobility) (Brezet, 2017b)	> 2040 (III) (hydrogen for mobility) (Brezet, 2017b)
Cross-border interconnection NTC	(V)	(V)	= 2016 (III) (Brezet, 2017b)	= 2016 (III) (Brezet, 2017b)	= 2016 (III) (Brezet, 2017b)
Electrification of additional sectors	(V)	(V)	(V)	(V)	(V)

FR: Outside logic	2016	2020	2030	2040	2050
Total heating demand incl. non-electric heating	(V)	(V)	(V)	(V)	(V)
Heating with electricity	(V)	(V)	(V)	(V)	(V)
Total cooling demand incl. non-electric cooling	(V)	(V)	(V)	(V)	(V)
Cooling with electricity	(V)	(V)	(V)	(V)	(V)
Electric mobility	(V)	0 EV (Astier, 2017)	0 EV (Astier, 2017)	0 EV (Astier, 2017)	0 EV (Astier, 2017)
EV chargers	(V)	(V)	(V)	(V)	(V)
Gross electricity consumption	556 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Final energy consumption	(V)	(V)	(V)	(V)	(V)

8.3.3 Minority pathway: grassroot-centred (Europe Écologie – Les Verts)

Table 30: Quantification of the French grassroot-centred minority policy pathway as described by Europe Écologie – Les Verts.

FR: Grassroots	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	421 Mt CO_{2eq} (EEA, 2018)	-30% (GHG-1990) (III) (EELV, 2012)	-40% (GHG-1990) (III) (EELV, 2012, 2018d)	(V)	-85% (GHG-1990) (III) (EELV, 2012, 2018d)
ETS sector reduction targets	393 Mt CO_{2eq} q (European annual emission allocation)	355 Mt CO_{2eq} (European annual emission allocation) (2013/162/EU)	(V)	(V)	(V)
Non-ETS sectors emission reduction targets	(V)	14% (GHG-2005) (2009/406/EC)	37% (GHG-2005) (I) (2018/842)	(V)	(V)
GHG reduction targets (electricity sector)	(V)	(V)	(V)	(V)	(V)
Renewables targets (energy; % of final energy consumption)	(V)	(V)	(V)	(V)	(V)
Renewables targets (electricity; % of final energy consumption)	18%; 102 TWh; 40 GW (EUROSTAT, 2018)	40% of mix; 175 TWh (III) (EELV, 2012, 2018b)	(V)	(V)	100% (III) (EELV, 2012, 2018b)
Intermittent renewables	30 TWh; 19 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Wind onshore	21 TWh; 11 GW (EUROSTAT, 2018)	10-60 TWh (incl. offshore) / 14% (III) (EELV, 2012, 2018b)	≥ 2020 (III) (EELV, 2012, 2018b)	≥ 2030 (III) (EELV, 2012, 2018b)	≥ 2040 (III) (EELV, 2012, 2018b)
Wind offshore	included above	≥ 2016 (III) (EELV, 2012, 2018b)	≥ 2020(III) (EELV, 2012, 2018b)	≥ 2030 (III) (EELV, 2012, 2018b)	≥ 2040 (III) (EELV, 2012, 2018b)
Solar PV	8 TWh; 7 GW (EUROSTAT, 2018)	25 TWh (6%) (mainly decentral) (III) (EELV, 2012, 2018b)	≥ 2020 (mainly decentral) (III) (EELV, 2012, 2018b)	≥ 2030 (mainly decentral) (III) (EELV, 2012, 2018b)	≥ 2040 (mainly decentral) (III) (EELV, 2012, 2018b)
Dispatchable renewables	73 TWh; 21 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Biomass	5 TWh; 1 GW (EUROSTAT, 2018)	4.5% (III) (EELV, 2012, 2018b)	≥ 2020 (III) (EELV, 2012, 2018b)	≥ 2020 (III) (EELV, 2012, 2018b)	≥ 2020 (III) (EELV, 2012, 2018b)
Hydro	65 TWh; 18 GW (EUROSTAT, 2018)	70 TWh (16% of mix) (III) (EELV, 2012, 2018b)	= 2020 (III) (EELV, 2012, 2018b)	= 2020 (III) (EELV, 2012, 2018b)	= 2020 (III) (EELV, 2012, 2018b)

FR: Grassroots	2016	2020	2030	2040	2050
CSP	0 TWh; 0 GW (EUROSTAT, 2018)	0 (III) (EELV, 2018b)	0 (III) (EELV, 2018b)	0 (III) (EELV, 2018b)	0 (III) (EELV, 2018b)
Other renewables	3 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Traded renewables	(V)	(V)	(V)	(V)	(V)
Physical import of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Statistical transfer of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Explicit trade of CSP or hydropower	(V)	(V)	(V)	(V)	(V)
Nuclear	403 TWh; 63 GW (EUROSTAT, 2018)	40% (III) (EELV, 2012, 2018b)	0 by 2032 (III) (EELV, 2012)	0 (III) (EELV, 2012)	0 (III) (EELV, 2012)
Fossil fuels	51 TWh; 23 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
CCS	0	0 (III) (EELV, 2018b)	0 (III) (EELV, 2018b)	0 (III) (EELV, 2018b)	0 (III) (EELV, 2018b)
Lignite	0 TWh (EUROSTAT, 2018)	0 (III) (EELV, 2018b)	0 (III) (EELV, 2018b)	0 (III) (EELV, 2018b)	0 (III) (EELV, 2018b)
Hard coal	8 TWh (EUROSTAT, 2018)	0 (III) (EELV, 2018b)	0 (III) (EELV, 2018b)	0 (III) (EELV, 2018b)	0 (III) (EELV, 2018b)
Gas	37 TWh (EUROSTAT, 2018)	20% of mix (combined cycle) (III) (EELV, 2018b)	0 (III) (EELV, 2018b)	0 (III) (EELV, 2018b)	0 (III) (EELV, 2018b)
Petroleum	2 TWh (EUROSTAT, 2018)	0 (III) (EELV, 2018b)	0 (III) (EELV, 2018b)	0 (III) (EELV, 2018b)	0 (III) (EELV, 2018b)
Other non-renewables	3 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Storage		(V)	(V)	(V)	(V)
Battery	(V)	> 2016 (decentralised) (III) (EELV, 2018b)	> 2020 (decentralised) (III) (EELV, 2018b)	> 2030 (decentralised) (III) (EELV, 2018b)	> 2040 (III) (decentralised) (EELV, 2018b)
Pumped Hydropower	(V)	≥ 2016 (III) (EELV, 2018b)	≥ 2016 (III) (EELV, 2018b)	≥ 2016 (III) (EELV, 2018b)	≥ 2016 (III) (EELV, 2018b)
Other storage	(V)	> 2016(III) (EELV, 2018b)	> 2020 (III) (EELV, 2018b)	> 2030 (III) (EELV, 2018b)	> 2040 (III) (EELV, 2018b)
Cross-border interconnection NTC	(V)	≥ 2016 (III) (AFP & Sciences et Avenir, 2018; EELV, 2018d)	≥ 2020 (III) (AFP & Sciences et Avenir, 2018; EELV, 2018d)	≥ 2030 (III) (AFP & Sciences et Avenir, 2018; EELV, 2018d)	≥ 2040 (III) (AFP & Sciences et Avenir, 2018; EELV, 2018d)

FR: Grassroots	2016	2020	2030	2040	2050
Electrification of additional sectors	(V)	(V)	(V)	(V)	(V)
Total heating demand incl. non-electric heating	(V)	(V)	(V)	(V)	(V)
Heating with electricity	(V)	40% RES (III)) (EELV, 2018b)	≥ 2020 (III) (EELV, 2018b)	≥ 2030 (III) (EELV, 2018b)	≥ 2040 (III) (EELV, 2018b)
Total cooling demand incl. non-electric cooling	(V)	(V)	(V)	(V)	(V)
Cooling with electricity	(V)	(V)	(V)	(V)	(V)
Electric mobility	(V)	By 2025: -20% (GHG-1990) (III) (mainly e-mobility and reduced demand) (EELV, 2018c)	-45% (GHG-1990) (III) (mainly e-mobility and reduced demand) (EELV, 2018c)	(V)	(V)
EV chargers	(V)	(V)	(V)	(V)	(V)
Gross electricity consumption	556 TWh (EUROSTAT, 2018)	-15% (2009) (III) (EELV, 2012, 2018d)	< 2020 (III) (EELV, 2012, 2018d)	< 2030 (III) (EELV, 2012, 2018d)	-50% (2009) 360 TWh (III) (EELV, 2012, 2018d)
Final energy consumption	(V)	(V)	(V)	(V)	(V)

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8.3.4 *Minority pathway: market-centred (La République en Marche)*

Table 31: Quantification of the French market-centred minority policy pathway as described by La République en Marche.

FR: Market-centred	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	421 Mt CO_{2eq} (EEA, 2018)	(V)	-40% (GHG-1990) (III) (De Ravignan, 2018)	(V)	-75% (GHG-1990) Max. 140 million tons CO_{2eq} (III) (De Ravignan, 2018; En Marche, 2017b)
ETS sector reduction targets	393 Mt CO_{2eq} (European annual emission allocation)	355 Mt CO_{2eq} (European annual emission allocation) (2013/162/EU)	(V)	(V)	(V)
Non-ETS sectors emission reduction targets	(V)	14% (GHG-2005)(2009/406/EC)	37% (GHG-2005) (I) (2018/842)	(V)	(V)
GHG reduction targets (electricity sector)	(V)	(V)	(V)	(V)	(V)
Renewables targets (energy; % of final energy consumption)	(V)	(V)	32% (III) (Energie Plus, 2017)	(V)	(V)
Renewables targets (electricity; % of final energy consumption)	18%; 102 TWh; 40 GW (EUROSTAT, 2018)	(V)	40% (III) (Qualit-EnR, 2017)	(V)	(V)
Intermittent renewables	30 TWh; 19 GW (EUROSTAT, 2018)	By 2022: +26 GW / + 32 TWh (III) (En Marche, 2017b)	≥ 2020 (III) (En Marche, 2017b, 2018)	≥ 2030 (III) (En Marche, 2017b, 2018)	≥ 2040 (III) (En Marche, 2017b, 2018)
Wind onshore	21 TWh; 11 GW (EUROSTAT, 2018)	By 2022: +100% (2018) (III) (Energie Plus, 2017)	≥ 2020 (III) (En Marche, 2017b, 2018)	≥ 2030 (III) (En Marche, 2017b, 2018)	≥ 2040 (III) (En Marche, 2017b, 2018)
Wind offshore	included above	(V)	(V)	(V)	(V)
Solar PV	8 TWh; 7 GW (EUROSTAT, 2018)	By 2022: +100% (2018) (III) (Energie Plus, 2017)	≥ 2020 (III) (En Marche, 2017b, 2018)	≥ 2030 (III) (En Marche, 2017b, 2018)	≥ 2040 (III) (En Marche, 2017b, 2018)
Dispatchable renewables	73 TWh; 21 GW (EUROSTAT, 2018)	> 2017 (III) (En Marche, 2017b, 2018)	> 2020 (III) (En Marche, 2017b, 2018)	> 2030 (III) (En Marche, 2017b, 2018)	> 2040 (III) (En Marche, 2017b, 2018)
Biomass	5 TWh; 1 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)

FR: Market-centred	2016	2020	2030	2040	2050
Hydro	65 TWh; 18 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
CSP	0 TWh; 0 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Other renewables	3 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Traded renewables	(V)	(V)	(V)	(V)	(V)
Physical import of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Statistical transfer of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Explicit trade of CSP or hydropower	(V)	(V)	(V)	(V)	(V)
Nuclear	403 TWh; 63 GW (EUROSTAT, 2018)	(V)	By 2025: 50% of electricity mix (III) (Energie Plus, 2017; Qualit-EnR, 2017)	= 2025 (III) (Energie Plus, 2017; Qualit-EnR, 2017)	= 2025 (III) (Energie Plus, 2017; Qualit-EnR, 2017)
Fossil fuels	51 TWh; 23 GW (EUROSTAT, 2018)	(V)	Min. -30% (2012) (III) (En Marche, 2017b)	(V)	(V)
CCS	0	By 2023: 0 (III) (En Marche, 2017b)	0 (III) (En Marche, 2017b)	0 (III) (En Marche, 2017b)	0 (III) (En Marche, 2017b)
Lignite	0 TWh (EUROSTAT, 2018)	By 2023: 0 (III) (En Marche, 2017b)	0 (III) (En Marche, 2017b)	0 (III) (En Marche, 2017b)	0 (III) (En Marche, 2017b)
Hard coal	8 TWh (EUROSTAT, 2018)	By 2023: 0 (III) (En Marche, 2017b)	0 (III) (En Marche, 2017b)	0 (III) (En Marche, 2017b)	0 (III) (En Marche, 2017b)
Gas	37 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Petroleum	2 TWh (EUROSTAT, 2018)	By 2023: 0 (III) (En Marche, 2017b)	0 (III) (En Marche, 2017b)	0 (III) (En Marche, 2017b)	0 (III) (En Marche, 2017b)
Other non-renewables	3 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Storage		≥ 2016 (En Marche, 2017b, 2018)	≥ 2020 (En Marche, 2017b, 2018)	≥ 2030 (En Marche, 2017b, 2018)	≥ 2040 (En Marche, 2017b, 2018)
Battery	(V)	(V)	(V)	(V)	(V)
Pumped Hydropower	(V)	(V)	(V)	(V)	(V)

FR: Market-centred	2016	2020	2030	2040	2050
Other storage	(V)	(V)	(V)	(V)	(V)
Cross-border interconnection NTC	(V)	≥ 2016 (III) (En Marche, 2017b)	≥ 2020 (III) (En Marche, 2017b)	≥ 2030 (III) (En Marche, 2017b)	≥ 2040 (III) (En Marche, 2017b)
Electrification of additional sectors	(V)	(V)	(V)	(V)	(V)
Total heating demand incl. non-electric heating	(V)	By 2022: 1 million buildings insulated (III) (Brezet, 2017a; Qualit-EnR, 2017)	(V)	(V)	(V)
Heating with electricity	(V)	(V)	(V)	(V)	(V)
Total cooling demand incl. non-electric cooling	(V)	(V)	(V)	(V)	(V)
Cooling with electricity	(V)	(V)	(V)	(V)	(V)
Electric mobility	(V)	By 2023: 2.4 million EVs (III) (Brezet, 2017a; En Marche, 2017b)	4 million EVs (III) (Brezet, 2017a; En Marche, 2017b)	Ban on sale of any ICE vehicle (En Marche, 2017b)	(V)
EV chargers	(V)	(V)	7 million chargers (III) (Brezet, 2017a)	(V)	(V)
Gross electricity consumption	556 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Final energy consumption	(V)	(V)	(V)	(V)	(V)

8.4 Germany

8.4.1 Dominant pathway: state-centred (Christian Democrats/Social Democrats)

Table 32: Quantification of the German state-centred dominant policy pathway as described by currently valid policies of the current and previous Christian Democrat/Social Democrat government.

DE: Dominant	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	894 Mt CO_{2eq} (EEA, 2018)	40% (GHG-1990) (II) (BMUB, 2016)	55-56% (GHG-1990) (II) (BMUB, 2016) <562 Mt CO_2 (NECP DE, 2018)	> 70% (GHG-1990) (II) (BMUB, 2016) <375 Mt CO_2 (III) (NECP DE, 2018)	80-95% (GHG-1990) (II) (BMUB, 2016) 263-62.5 Mt CO_2 (III) (NECP DE, 2018)
ETS sector reduction targets	474 Mt CO_{2eq} (European annual emission allocation)	431 Mt CO_{2eq} (European annual emission allocation) (2013/162/EU)	EU: 43 % (2005)	(V)	(V)
Non-ETS sectors emission reduction targets	(V)	14% (GHG-2005) (2009/406/EC)	38% (GHG-2005) (I) (2018/842)	(V)	(V)
GHG reduction targets (electricity sector)	(V)	(V)	61-62% (GHG-1990) (II) (BMUB, 2016)	(V)	100% (GHG-1990) (II) (BMUB, 2016)
Renewables targets (energy; % of final energy consumption)	(V)	18% (II) (BMWi & BMU, 2010; CDU/CSU/SPD, 2018)	30% (II) (BMWi & BMU, 2010)	45% (II) (BMWi & BMU, 2010)	60% (II) (BMWi & BMU, 2010)
Renewables targets (electricity; % of final energy consumption)	30%; 194 TWh; 108 GW (EUROSTAT, 2018)	By 2025: 40-45% (I) (EEG, 2017, §1)	65% (III) (NECP DE, 2018) (CDUCSUSPD, 2018-Koalitionsvertrag) 360-400 TWh (III) (NECP DE, 2018)	>65% (I) (EEG, 2017, §1)	>80% (I) (EEG, 2017, §1)
Intermittent renewables	117 TWh; 90 GW (EUROSTAT, 2018)	(V)	180-220 GW (III) (NECP DE, 2018)	(V)	(V)
Wind onshore	79 TWh; 50 GW (EUROSTAT, 2018)	+2.8 GW per year (I) (2017-19) (EEG, 2017, §4.1a); +2.9 GW per year (I) (EEG, 2017, §4.1b)	+2.9GW per year 74-85.5GW (BNA, 2018b)	≥74-85.5GW	≥74-85.5GW

DE: Dominant	2016	2020	2030	2040	2050
Wind offshore	included above	6.5 GW(I) (EEG, 2017, §4.1b)	15 GW(I) (EEG, 2017, §4.1b)	≥17-20 GW	≥17-20 GW
Solar PV	38 TWh; 41 GW (EUROSTAT, 2018)	+2.8 GW per year (I) (EEG, 2017, §4.1a)	72.9GW-104.5GW	≥72.9GW-104.5GW	≥72.9GW-104.5GW
Dispatchable renewables	77 TWh; 18 GW (EUROSTAT, 2018)	(V)	14.9 GW (III) (BNA, 2018b)	(V)	(V)
Biomass	45 TWh; 7 GW (EUROSTAT, 2018)	+150 MW per year (2017-19) (EEG, 2017, §4.4a); +200 MW per year (2020-2022) (EEG, 2017, §4.4b)	6.0 GW (BNA, 2018b)	=6.0 GW	=6.0 GW
Hydro	26 TWh; 5 GW (EUROSTAT, 2018)	(V)	5.6 GW (BNA, 2018b)	=5.6GW	=5.6 GW
CSP	0 TWh; 0 GW (EUROSTAT, 2018)	=0 (IV)	=0 (IV)	=0 (IV)	=0 (IV)
Other renewables	6 TWh (EUROSTAT, 2018)	(V)	1.3 GW	=1.3 GW	=1.3 GW
Traded renewables	(V)	(V)	(V)	(V)	(V)
Physical import of renewables (cooperation)	(V)	Up to 5% of auction volume available to foreign bidders (EEG, 2017, §5)	≥2020 (V)	≥2020 (V)	≥2020 (V)
Statistical transfer of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Explicit trade of CSP or hydropower	(V)	(V)	(V)	(V)	(V)
Nuclear	85 TWh; 11GW (EUROSTAT, 2018)	31.12.19 Philippsburg 2 (I) (AtG, 2017, §7)	31.12.2021: Grohnde, Grundremmingen C, Brokdorf 31.12.2022: Isar 2, Emsland, Neckarwestheim 2 By 2023: 0 GW (I) (AtG, 2017, §7)	0 (I) (AtG, 2017, §1)	0 (I) (AtG, 2017, §1)

DE: Dominant	2016	2020	2030	2040	2050
Fossil fuels	371 TWh; 96GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
CCS	0	0 (I) (KSpG, 2012, §2)	0 (I) (KSpG, 2012, §2)	0 (I) (KSpG, 2012, §2)	0 (I) (KSpG, 2012, §2)
Lignite	150 TWh (EUROSTAT, 2018)	(V)	(V).	By 2038: 0 (II) (KWSB, 2019)	(V).
Hard coal	112 TWh (EUROSTAT, 2018)	(V)	(V)	By 2038: 0 (II) (KWSB, 2019)	(V)
Gas	94 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Petroleum	5 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Other non-renewables	10 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Storage	(V)	(V)	(V)	(V)	(V)
Battery	(V)	(V)	8-12.5 GW (IV) (BNA, 2018b)	(V)	(V)
Pumped Hydropower	(V)	(V)	11.6 GW (IV) (BNA, 2018b)	(V)	(V)
Other storage	(V)	(V)	1-3 GW (IV) (Power-to-Gas) (BNA, 2018b)	(V)	(V)
Cross-border interconnection NTC	(V)	≥ 10% of yearly power production (II) (2015/82/COM , 2015)	≥ 15% of yearly power production (II) (2018/2001/EC)	(V)	(V)
Electrification of additional sectors	(V)	(V)	(V)	(V)	(V)
Total heating demand incl. non-electric heating	(V)	-20% (TWh-2008) 2% renovation rate (II) (BMWi & BMU, 2010)	681-766 TWh (2453-2757 PJ) (III) (NECP DE, 2018) -67-66% (GHG-1990) (II) (BMUB, 2016)	546 -685 TWh (1966-2465 PJ) (III) (NECP DE, 2018)	444-623 TWh (1597-2243 PJ) (III) (NECP DE, 2018) -80% (TWh-2008)-(II) (BMWi, 2015)
Heating with electricity	(V)	14% RES-H (I) (EEWärmeG, 2008)	1.1-4.1 million heat pumps (IV) (BNA, 2017a, p22) 27% RES-H (III) (NECP DE, 2018)	> 2030	> 2040 -100% (GHG-1990) (II) (BMWi, 2015)
Total cooling demand incl. non-electric cooling	(V)	(V)	(V)	(V)	(V)

DE: Dominant	2016	2020	2030	2040	2050
Cooling with electricity	(V)	(V)	(V)	(V)	(V)
Electric mobility	(V)	All transport: -10% (PE-2005) (II) (BMWi & BMU, 2010)	-42-40% (GHG-1990) (II) (BMUB, 2016); 1-6 million EV (IV) (BNA, 2017a, p22) Double number of train passengers (2018) (CDU/CSU/SPD, 2018); 14% RES-T (III) (NECP DE, 2018)	(V)	All transport: -40% (PE-2005)(II) (BMWi & BMU, 2010)
EV chargers	(V)	+100,000 Charging points (III) (CDU/CSU/SPD, 2018)	>2020 (V)	>2030 (V)	>2040 (V)
Gross electricity consumption	596.9 TWh (AGEE, 2018)	557.19 TWh (equals -10% (2008)) (NAPE, 2014)+ new demand from Sector coupling(NAPE, 2014)(NAPE, 2014)	554-615TWh (NECP DE, 2018) (BNA, 2018b)	<2030	464.3 TWh (equals -25% (2008)) (NAPE, 2014)+ new demand from Sector coupling
Final energy consumption	(V)	(V)	(V)	(V)	(V)

8.4.2 *Minority pathway: grassroot-centred (Bündnis 90/Die Grünen)*

Table 33: Quantification of the German grassroot-centred minority policy pathway as described by Bündnis 90/Die Grünen.

DE: Grassroot	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	894 Mt CO_{2eq} (EEA, 2018)	(V)	>55% (IV) (GHG-1990) (Bündnis 90/Die Grünen, 2018)		> 95% (IV) (GHG-1990) (Bündnis 90/Die Grünen, 2018)
ETS sector reduction targets	474 Mt CO_{2eq} (European annual emission allocation)	431 Mt CO_{2eq} (European annual emission allocation) (2013/162/EU)	(V)	(V)	(V)
Non-ETS sectors emission reduction targets	(V)	14% (GHG-2005) (I) (2009/406/EC)	38% (GHG-2005) (I) (2018/842)	(V)	(V)
GHG reduction targets (electricity sector)	(V)	(V)	100% (III) (Bündnis 90/Die Grünen, 2016)	100% (III) (Bündnis 90/Die Grünen, 2016)	100%(III) (Bündnis 90/Die Grünen, 2016)
Renewables targets (energy; % of final energy consumption)	(V)	(V)	(V)	(V)	(V)
Renewables targets (electricity; % of final energy consumption)	30%; 194 TWh; 108 GW (EUROSTAT, 2018)	+100% (2013) (IV) (Bündnis 90/Die Grünen, 2013)	100% (IV) (Bündnis 90/Die Grünen, 2016, 2018)	100% (IV)	100% (IV)
Intermittent renewables	117 TWh; 90 GW (EUROSTAT, 2018)	>> 2016 (V)	>> 2020 (V)	> 2030 (V)	(V)
Wind onshore	79 TWh; 50 GW (EUROSTAT, 2018)	≥ +5 GW per year (IV) (Bündnis 90/Die Grünen, 2019c)	≥ +5 GW per year (IV) (Bündnis 90/Die Grünen, 2019c)	(V)	(V)
Wind offshore	included above	6-8 GW (Kabel, 2018)	20 GW in 2030 and 30 GW in 2035 (Kabel, 2018)	(V)	(V)
Solar PV	38 TWh; 41 GW (EUROSTAT, 2018)	≥ +5 GW per year (mainly decentral) (IV)(Bündnis 90/Die Grünen, 2019c)	≥ +5 GW per year (mainly decentral) (IV) (Bündnis 90/Die Grünen, 2019c)	(V)	(V)
Dispatchable renewables	77 TWh; 18 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)

DE: Grassroot	2016	2020	2030	2040	2050
Biomass	45 TWh; 7 GW (EUROSTAT, 2018)	≥ 2016 (IV) (sustainable) (Bündnis 90/Die Grünen, 2011); 25% (Biomass with mini-CHP) (Bündnis 90/Die Grünen, 2013)	≥ 2020 (IV) (sustainable) (Bündnis 90/Die Grünen, 2011) ; ≥ z2020 (Biomass with mini-CHP) (IV) (Bündnis 90/Die Grünen, 2013)	≥ 2030 (IV) it (sustainable) (Bündnis 90/Die Grünen, 2011); ≥2030 (Biomass with mini-CHP) (IV) (Bündnis 90/Die Grünen, 2013)	≥ 2040 (V) it (sustainable) (Bündnis 90/Die Grünen, 2011); ≥ 2040 (Biomass with mini-CHP) (IV) (Bündnis 90/Die Grünen, 2013)
Hydro	26 TWh; 5 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
CSP	0 TWh; 0 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Other renewables	6 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Traded renewables	(V)	(V)	(V)	(V)	(V)
Physical import of renewables (cooperation)	(V)	≥ 2016 (IV) As local as possible (Bündnis 90/Die Grünen, 2013)	≥ 2016 (IV) As local as possible (Bündnis 90/Die Grünen, 2013)	(V) ≥ 2016 (IV) As local as possible (Bündnis 90/Die Grünen, 2013)	≥ 2016 (IV) As local as possible (Bündnis 90/Die Grünen, 2013)
Statistical transfer of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Explicit trade of CSP or hydropower	(V)	Trade hydropower from Scandinavia and the Alps (III) (Bündnis 90/Die Grünen, 2013)	Trade hydropower from Scandinavia and the Alps (III) (Bündnis 90/Die Grünen, 2013)	Trade hydropower from Scandinavia and the Alps (III) (Bündnis 90/Die Grünen, 2013)	Trade hydropower from Scandinavia and the Alps (III) (Bündnis 90/Die Grünen, 2013)
Nuclear	85 TWh; 11GW (EUROSTAT, 2018)	(V)	In 2023: **0** (I) (AtG, 2017)	**0** (I) (AtG, 2017)	**0** (I) (AtG, 2017)
Fossil fuels	371 TWh; 96GW (EUROSTAT, 2018)	(V)	0 (III) (Bündnis 90/Die Grünen, 2010)	0 (III) (Bündnis 90/Die Grünen, 2010)	0 (III) (Bündnis 90/Die Grünen, 2010)
CCS	0	0 (III) (Bündnis 90/Die Grünen, 2009)	0 (III) (Bündnis 90/Die Grünen, 2009)	0 (III) (Bündnis 90/Die Grünen, 2009))	0 (III) (Bündnis 90/Die Grünen, 2009)

DE: Grassroot	2016	2020	2030	2040	2050
Lignite	150 TWh (EUROSTAT, 2018)	By 2022: at least -3 GW (2017) (III) (Bündnis 90/Die Grünen, 2019a)	0 (III) (Bündnis 90/Die Grünen, 2010)	0 (III) (Bündnis 90/Die Grünen, 2010)	0 (III) (Bündnis 90/Die Grünen, 2010)
Hard coal	112 TWh (EUROSTAT, 2018)	By 2022: at least -4 GW (2017) (III) (Bündnis 90/Die Grünen, 2019a)	0 (III) (Bündnis 90/Die Grünen, 2010)	0 (III) (Bündnis 90/Die Grünen, 2010)	0 (III) (Bündnis 90/Die Grünen, 2010)
Gas	94 TWh (EUROSTAT, 2018)	(V); 25% (Decentralised mini-CHP with gas) (III) CHP electricity (Bündnis 90/Die Grünen, 2013)	0 (III) (Bündnis 90/Die Grünen, 2010); Micro CHP only with renewable gas (Bündnis 90/Die Grünen, 2013)	0 (III) (Bündnis 90/Die Grünen, 2010)	0 (III) (Bündnis 90/Die Grünen, 2010)
Petroleum	5 TWh (EUROSTAT, 2018)	< 2016 (V)	0	0	0
Other non-renewables	10 TWh (EUROSTAT, 2018)	< 2016 (V)	0	0	0
Storage	(V)	(V)	(V)	(V)	(V)
Battery	(V)	100,000 batteries (decentralised) (IV) (Bündnis 90/Die Grünen, 2016)	>> 2020 (V)	> 2030 (V)	(V)
Pumped Hydropower	(V)	(V)	(V)	(V)	(V)
Other storage	(V)	Emphasis on Power to gas (Wind gas) (Sterner *et al.*, 2015) & Power to Heat (Bündnis 90/Die Grünen, 2010)	>> 2020 (V)	> 2030 (V)	(V)
Cross-border interconnection NTC	(V)	Less additions than dominant pathway (Bündnis 90/Die Grünen, 2013) Super-Smart grid (Grünen, 2011)	Sustainable cross-border connection (no import of nuclear electricity) (Bündnis 90/Die Grünen, 2013)	(V)	(V)

DE: Grassroot	2016	2020	2030	2040	2050
Electrification of additional sectors	(V)	> 2016 (V)	> 2020 (V)	> 2030 (V)	> 2040 (V)
Total heating demand incl. non-electric heating	(V)	<< 2016 (III) (Bündnis 90/Die Grünen, 2017a)	<< 2020 (III) (Bündnis 90/Die Grünen, 2017a)	<< 2030 (III) (Bündnis 90/Die Grünen, 2017a)	<<2040 (III) (Bündnis 90/Die Grünen, 2017a)
Heating with electricity	(V)	25% RES-H (III) (Bündnis 90/Die Grünen, 2013)	(V)	-100% (GHG-1990) (III) (Bündnis 90/Die Grünen, 2013)	(V)
Total cooling demand incl. non-electric cooling	(V)	<< 2016 (III) (Bündnis 90/Die Grünen, 2017a)	<< 2020 (III) (Bündnis 90/Die Grünen, 2017a)	<< 2030 (III) (Bündnis 90/Die Grünen, 2017a)	<<2040 (III) (Bündnis 90/Die Grünen, 2017a)
Cooling with electricity	(V)	< 2016 (III) (Bündnis 90/Die Grünen, 2017a)	<< 2020 (III) (Bündnis 90/Die Grünen, 2017a)	< 2030 (III) (Bündnis 90/Die Grünen, 2017a)	< 2040 (III) (Bündnis 90/Die Grünen, 2017a)
Electric mobility	(V)	>> 2016 (IV) (Kühn & Özdemir, 2019)	>> 2020 (IV) (Kühn & Özdemir, 2019) Ban on new ICE vehicles (IV) (Bündnis 90/Die Grünen, 2017b)	>> 2030 (V) (Bündnis 90/Die Grünen, 2017b)	>2040(V)
EV chargers	(V)	>> 2016 (IV) (Kühn & Özdemir, 2019)	>> 2020 (IV) (Kühn & Özdemir, 2019)	> 2030 (V)	> 2040 (V)
Gross electricity consumption	649 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Final energy consumption	(V)	(V)	(V)	(V)	50% (PE-2017) (Bündnis 90/Die Grünen, 2017a)

8.4.3 *Minority pathway: market-centred (*Freie Demokratische Partei*)*

Table 34: Quantification of the German market-centred minority policy pathway as described by the Freie Demokratische Partei.

DE: Market	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	894 Mt CO_{2eq} (EEA, 2018)	(V)	40% (GHG-1990) (IV) (FDP, 2017b)	(V)	80% (GHG-1990) (IV) (or EU-Goals if higher) (FDP, 2017b)
ETS sector reduction targets	474 Mt CO_{2eq} (European emission allocation)	Mt CO_{2eq} (European emission allocation) (2013/162/EU)	(V)	(V)	(V)
Non-ETS sectors emission reduction targets	(V)	14% (GHG-2005) (2009/406/EC)	38% (GHG-2005) (I) (2018/842)	(V)	(V)
GHG reduction targets (electricity sector)	(V)	(IV) No sector-specific goals (FDP, 2017a)	(IV) No sector-specific goals (FDP, 2017a)	(IV) No sector-specific goals (FDP, 2017a)	(IV) No sector-specific goals (FDP, 2017a)
Renewables targets (energy; % of final energy consumption)	(V)	(IV) No sector-specific goals (FDP, 2017a)	(IV) No sector-specific goals (FDP, 2017a)	(IV) No sector-specific goals (FDP, 2017a)	(IV) No sector-specific goals (FDP, 2017a)
Renewables targets (electricity; % of final energy consumption)	30% 194 TWh 108 GW (EUROSTAT, 2018)	(IV) No sector-specific goals (FDP, 2017a)	(IV) No sector-specific goals (FDP, 2017a)	(IV) No sector-specific goals (FDP, 2017a)	(IV) No sector-specific goals (FDP, 2017a)
Intermittent renewables	117 TWh; 90 GW (EUROSTAT, 2018)	(IV) No sector-specific goals (FDP, 2017a)	(IV) No sector-specific goals (FDP, 2017a)	(IV) No sector-specific goals (FDP, 2017a)	(IV) No sector-specific goals (FDP, 2017a)
Wind onshore	79 TWh; 50 GW (EUROSTAT, 2018)	< less expansion than dominant: strict regulation to reduce available areas (10x height) (FDP, 2017a)	(V) No technology specific goals (FDP, 2017a)	(V) No technology specific goals. (FDP, 2017a)	(V) No technology specific goals. (FDP, 2017a)
Wind offshore	included above	(V) No technology specific goals. (FDP, 2017a)	(V) No technology specific goals. (FDP, 2017a)	(V) No technology specific goals. (FDP, 2017a)	(V) No technology specific goals. (FDP, 2017a)
Solar PV	38 TWh; 41 GW (EUROSTAT, 2018)	(V) No technology specific goals. (FDP, 2017a)	(V) No technology specific goals. (FDP, 2017a)	(V) No technology specific goals. (FDP, 2017a)	(V) No technology specific goals. (FDP, 2017a)
Dispatchable renewables	77 TWh; 18 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Biomass	45 TWh; 7 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)

DE: Market	2016	2020	2030	2040	2050
Hydro	26 TWh; 5 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
CSP	0 TWh; 0 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Other renewables	6 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Traded renewables	(V)	(V)	(V)	(V)	(V)
Physical import of renewables (cooperation)	(V)	> 2016 (IV) (FDP, 2017a)	> 2020 (IV) (FDP, 2017a)	> 2030 (IV) (FDP, 2017a)	> 2040 (IV) (FDP, 2017a)
Statistical transfer of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Explicit trade of CSP or hydropower	(V)	in favour of *DESERTEC* (IV) *(FDP, 2013)*	(V)	(V)	(V)
Nuclear	85 TWh; 11 GW (EUROSTAT, 2018)	(V)	By 2023: 0 (I) (AtG, 2017; FDP, 2017a)	By 2023: 0 (I) (AtG, 2017) (FDP, 2017a)	By 2023: 0 (I) (AtG, 2017) (FDP, 2017a)
Fossil fuels	371 TWh; 96 GW (EUROSTAT, 2018)	(V)	(V)	(V)	>0 (III) (FDP, 2017a)
CCS	0	(V)	(V)	(V)	(V)
Lignite	150 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	> 0 (III) (FDP NRW, 2016)
Hard coal	112 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Gas	94 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Petroleum	5 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Other non-renewables	10 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Storage	(V)	(V)	(V)	(V)	(V)
Battery	(V)	(V)	(V)	(V)	(V)
Pumped Hydropower	(V)	(V)	(V)	(V)	(V)
Other storage	(V)	(V)	(V)	(V)	(V)
Cross-border interconnection NTC	(V)	> 2016 (IV) (FDP, 2017a)	> 2020 (IV) (FDP, 2017a)	> 2030 (IV) (FDP, 2017a)	> 2040 (IV) (FDP, 2017a)
Electrification of additional sectors	(V)	(V)	(V)	(V)	(V)
Total heating demand incl. non-electric heating	(V)	(V)	(V)	(V)	(V)
Heating with electricity	(V)	(V)	(V)	(V)	(V)

DE: Market	2016	2020	2030	2040	2050
Total cooling demand incl. non-electric cooling	(V)	(V)	(V)	(V)	(V)
Cooling with electricity	(V)	(V)	(V)	(V)	(V)
Electric mobility	(V)	(V)	(V)	(V)	(V)
EV chargers	(V)	(V)	(V)	(V)	(V)
Gross electricity consumption	649 TWh (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Final energy consumption	(V)	(V)	(V)	(V)	(V)

8.5 Italy

8.5.1 Dominant pathway: state-centred (Partito Democratico)

Table 35: Quantification of the Italian state-centred dominant policy pathway as described by currently valid policies of the Gentiloni government of the Partito Democratico.

IT: Dominant	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	397 Mt CO_{2eq} (EEA, 2018)	(V)	(V)	< 2030 (II) (SEN, 2017)	-100% (III) (1990) (NECP IT, 2018)
ETS sector reduction targets	311 Mt CO_{2eq} (European annual emission allocation)	299 Mt CO_{2eq} (European annual emission allocation) (I) (2013/162/EU)	57% (GHG-2005) (II) (SEN, 2017)	(V)	(V)
Non-ETS sectors emission reduction targets	(V)	13% (GHG-2005) (I) (2009/406/EC)	33% (GHG-2005) (II) (SEN, 2017)	(V)	(V)
GHG reduction targets (electricity sector)	(V)	(V)	(V)	(V)	(V)
Renewables targets (energy; % of final energy consumption)	(V)	17% (I) (D.Lgs. 3 March 2011 n.28, 2011)	>30% (III) (NECP IT, 2018)	> 2030 (II) (RSE, 2018)	>> 2030 (II) (RSE, 2018)
Renewables targets (electricity; % of final energy consumption)	38% 110 TWh 52 GW (EUROSTAT, 2018)	(V)	55.4% (III) (187 TWh) (NECP IT, 2018)	> 2030 (II) (SEN, 2017)	>> 2030 (II) (SEN, 2017)
Intermittent renewables	40 TWh; 29 GW (EUROSTAT, 2018)	(V)	68.4 GW (III) (NECP IT, 2018)	(V)	(V)
Wind onshore	18 TWh; 9 GW (EUROSTAT, 2018)	18 TWh (II) (RSE, 2018)	38 TWh (II) (RSE, 2018); 17.5 GW (III) (NECP IT, 2018)	> 2030 (II) (SEN, 2017)	> 2040 (II) (SEN, 2017)
Wind offshore	included above	0 TWh (II) (RSE, 2018)	2 TWh (II) (RSE, 2018); 900 MW (III) (NECP IT, 2018)	(V)	(V)
Solar PV	22 TWh; 19 GW (EUROSTAT, 2018)	27 TWh (II) (SEN, 2017)	69 TWh (mainly decentral) (II) (RSE, 2018); 50 GW (III) (NECP IT, 2018)	> 2030 (II) (SEN, 2017)	>> 2030 (II) (SEN, 2017)
Dispatchable renewables	70 TWh; 24 GW (EUROSTAT, 2018)	(V)	24.8 GW (V)	≥ 2030 (V)	≥ 2030 (V)

IT: Dominant	2016	2020	2030	2040	2050
Biomass	17 TWh; 2 GW (EUROSTAT, 2018)	16 TWh (II) (SEN, 2017)	15 TWh (II) (RSE, 2018); 3.7 GW (III) (NECP IT, 2018)	= 2030 (V)	=2030 (V)
Hydro	44 TWh; 15 GW (EUROSTAT, 2018)	49 TWh (II) (SEN, 2017)	50 TWh (II) (RSE, 2018); 19.2 GW (III) (NECP IT, 2018)	> 2030 (V)	> 2030 (V)
CSP	0 TWh; 0 GW (EUROSTAT, 2018)	0 TWh (II) (RSE, 2018)	3 TWh (II) (RSE, 2018); 880 MW (III) (NECP IT, 2018)	≥ 2030 (V)	≥ 2030 (V)
Other renewables	9 TWh (EUROSTAT, 2018); 815 MW (NECP IT, 2018)	7 TWh (Geothermal) (II) (SEN, 2017)	7 TWh (II) (RSE, 2018); 950 MW (Geothermal) (III) (NECP IT, 2018)	= 2030 (V)	=2030 (V)
Traded renewables	(V)	(V)	(V)	(V)	(V)
Physical import of renewables (cooperation)	(V)	> 2016 (I) (D.Lgs. 3 March 2011 n.28, 2011)	> 2016 (I) (D.Lgs. 3 March 2011 n.28, 2011)	> 2016 (I) (D.Lgs. 3 March 2011 n.28, 2011)	> 2016 (I) (D.Lgs. 3 March 2011 n.28, 2011)
Statistical transfer of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Explicit trade of CSP or hydropower	(V)	(V)	(V)	(V)	(V)
Nuclear	0 TWh; 0 GW (EUROSTAT, 2018)	0 (II) (RSE, 2018)	0 (II) (RSE, 2018)	0 (II) (RSE, 2018)	0 (II) (RSE, 2018)
Fossil fuels	180 TWh; 62 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
CCS	0	0 (II) (RSE, 2018)	0 (II) (RSE, 2018)	0 (II) (RSE, 2018)	0 (II) (RSE, 2018)
Lignite	0 TWh (EUROSTAT, 2018)	0 (II) (RSE, 2018)	0 (II) (RSE, 2018)	0 (II) (RSE, 2018)	0 (II) (RSE, 2018)
Hard coal	36 TWh (EUROSTAT, 2018)	37 TWh (II) (RSE, 2018)	By 2026: 0 TWh (III) (NECP IT, 2018)	0 (II) (SEN, 2017)	0 (II) (SEN, 2017)
Gas	129 TWh (EUROSTAT, 2018)	117 TWh (II) (RSE, 2018)	118 TWh (II) (SEN, 2017)	< 2030 (II) (SEN, 2017)	<< 2030 (II) (SEN, 2017)
Petroleum	10 TWh (EUROSTAT, 2018)	2 TWh (II) RSE2017	2 TWh (II) (SEN, 2017)	0 (II) (SEN, 2017)	0 (II) (SEN, 2017)

IT: Dominant	2016	2020	2030	2040	2050
Other non-renewables	5 TWh (EUROSTAT, 2018)	2 TWh (Waste) (II) (RSE, 2018)	2 TWh (Waste) (II) (RSE, 2018)	(V)	(V)
Storage	(V)	(V)	(V)	(V)	(V)
Battery	(V)	(V)	(V)	(V)	(V)
Pumped Hydropower	(V)	> 2016 (II) (SEN, 2017)	> 2016 (II) (SEN, 2017)	> 2016 (II) (SEN, 2017)	> 2016 (II) (SEN, 2017)
Other storage	(V)	(V)	(V)	(V)	(V)
Cross-border interconnection NTC	(V)	= in 2018 (I) (D.Lgs. 3 March 2011 n.28, 2011)	≥ 2020 (II) (SEN, 2017)	≥ 2020 (II) (SEN, 2017)	≥ 2020 (II) (SEN, 2017)
Electrification of additional sectors	(V)	(V)	(V)	(V)	(V)
Total heating demand incl. non-electric heating	(V)	< 2016 (I) (D.Lgs.4 July 2014 n. 102)	< 2020 (V)	< 2030 (V)	< 2040 (V)
Heating with electricity	(V)	1.18 TWh (II) (RSE, 2018)	1.39 TWh (II) (RSE, 2018)	1.51 TWh (II) (RSE, 2018)	1.74 TWh (II) (RSE, 2018)
Total cooling demand incl. non-electric cooling	(V)	< 2016 (I) (D.Lgs.4 July 2014 n. 102)	< 2020 (V)	< 2030 (V)	< 2040 (V)
Cooling with electricity	(V)	1.84 TWh (II) (RSE, 2018)	2.31 TWh (II) (RSE, 2018)	2.76 TWh (II) (RSE, 2018)	3.22 TWh (II) (RSE, 2018)
Electric mobility	(V)	> 2016 (II) (SEN, 2017)	6 Mio EV (of which 1.6 Mio BEV) (III) (NECP IT, 2018)	> 2030 (V)	>> 2030 (V)
EV chargers	(V)	(V)	(V)	(V)	(V)
Gross electricity consumption	290 TWh (EUROSTAT, 2018)	294 TWh (III) (NECP IT, 2018)	337.3 TWh (III) (NECP IT, 2018)	> for 2030 (II) (SEN, 2017)	> 350 TWh (II) (SEN, 2017)
Final energy consumption	(V)	1353.7 TWh (III) (NECP IT, 2018)	1207.2 TWh (III) (NECP IT, 2018)	(V)	(V)

8.5.2 Minority pathway: grassroot-centred (Movimento Cinque Stelle)

Table 36: Quantification of the Italian grassroots-centred minority policy pathway as described by Movimento Cinque Stelle *(in the government coalition since 2018).*

IT: Grassroots	2016	2020	2030	2040	2050
GHG reduction targets (economy-wide)	397 Mt CO_{2eq} (EEA, 2018)	(V)	(V)	(V)	(V)
ETS sector reduction targets	311 Mt CO_{2eq} (European annual emission allocation)	299 Mt CO_{2eq} (European annual emission allocation) (2013/162/EU)	(V)	(V)	(V)
Non-ETS sectors emission reduction targets	(V)	13% (GHG-2005) (I) (2009/406/EC)	33% (GHG-2005) (I) (2018/842)	(V)	(V)
GHG reduction targets (electricity sector)	(V)	> 2016 (III) (M5S, 2017)	> 2020 (III) (M5S, 2017)	>> 2020 (III) (M5S, 2017)1	100% (III) (M5S, 2017)
Renewables targets (energy; % of final energy consumption)	(V)	17% (I) (D.Lgs. 3 March 2011 n.28, 2011)	(V)	(V)	(V)
Renewables targets (electricity; % of final energy consumption)	38% 110 TWh 52 GW (EUROSTAT, 2018)	> 2016 (III) (M5S, 2017)	>> 2016 (III) (M5S, 2017)	>> 2016 (III) (M5S, 2017)	100% (III) (M5S, 2017)
Intermittent renewables	40 TWh; 29 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Wind onshore	18 TWh; 9 GW (EUROSTAT, 2018)	8.96 GW; +3.4% per year from 2021 to 2050 (III) (M5S, 2017)	+3.4% per year (III) (M5S, 2017)	+3.4% per year (III) (M5S, 2017)	≥ 45 TWh (III) (M5S, 2017)
Wind offshore	included above	(V)	(V)	(V)	(V)
Solar PV	22 TWh; 19 GW (EUROSTAT, 2018)	20.06 GW; +9.3% per year from 2021 to 2050, (mainly decentral) (III) (M5S, 2017)	+9.3% per year (mainly decentral) (III) (M5S, 2017)	+9.3% per year (mainly decentral) (III) (M5S, 2017)	73% of the power mix, 420 TWh (III) (M5S, 2017)
Dispatchable renewables	70 TWh; 24 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
Biomass	17 TWh; 2 GW (EUROSTAT, 2018)	23 GWh (III) (M5S, 2017)	+0.8% per year from 2021 to 2050 (III) (M5S, 2017)	+0.8% per year (III) (M5S, 2017)	30 TWh (III) (M5S, 2017)
Hydro	44 TWh; 15 GW (EUROSTAT, 2018)	= 2016 (III) (M5S, 2017)	+1% per year from 2021 to 2050 (III) (M5S, 2017)	+1% per year (III) (M5S, 2017)	+70 TWh (2017) (III) (M5S, 2017)2

IT: Grassroots	**2016**	**2020**	**2030**	**2040**	**2050**
CSP	0 TWh; 0 GW (EUROSTAT, 2018)	0 (III) (M5S, 2017)	0 (III) (M5S, 2017)	0 (III) (M5S, 2017)	0 (III) (M5S, 2017)
Other renewables	9 TWh (EUROSTAT, 2018)	7 TWh (Geothermal) (III) (M5S, 2017)	8 TWh (Geothermal) (III) (M5S, 2017)	8-12 TWh (Geothermal) (III) (M5S, 2017)	12 TWh (Geothermal) (III) (M5S, 2017)
Traded renewables	(V)	(V)	(V)	(V)	(V)
Physical import of renewables (cooperation)	(V)	(V)	(V)	(V)	(V)
Statistical transfer of renewables (cooperation)	(V)	(V)	(V)	(V)	0 (III) (M5S, 2017)0
Explicit trade of CSP or hydropower	(V)	(V)	(V)	(V)	(V)
Nuclear	0 TWh; 0 GW (EUROSTAT, 2018)	0 (III) (M5S, 2017)	0 (III) (M5S, 2017)	0 (III) (M5S, 2017)	0 (III) (M5S, 2017)
Fossil fuels	180 TWh; 62 GW (EUROSTAT, 2018)	(V)	(V)	(V)	(V)
CCS	0	0 (III) (M5S, 2017)	0 (III) (M5S, 2017)	0 (III) (M5S, 2017)	0 (III) (M5S, 2017)
Lignite	0 TWh (EUROSTAT, 2018)	0 (III) (M5S, 2017)	0 (III) (M5S, 2017)	0 (III) (M5S, 2017)	0 (III) (M5S, 2017)
Hard coal	36 TWh (EUROSTAT, 2018)	43 TWh (III) (M5S, 2017)	0 TWh (III) (M5S, 2017)	0 TWh (III) (M5S, 2017)	0 TWh (III) (M5S, 2017)
Gas	129 TWh (EUROSTAT, 2018)	94 TWh (III) (M5S, 2017)	110 TWh (III) (M5S, 2017)	<< 2030 (III) (M5S, 2017)	0 TWh(III) (M5S, 2017)
Petroleum	10 TWh (EUROSTAT, 2018)	2% of total electricity prod. (III) (M5S, 2017)	0 (III) (M5S, 2017)	0 (III) (M5S, 2017)	0 (III) (M5S, 2017)
Other non-renewables	5 TWh (EUROSTAT, 2018)	3 TWh (Waste) (III) (M5S, 2017)	0 (Waste) (III) (M5S, 2017)	0 (Waste) (III) (M5S, 2017)	0 (Waste) (III) (M5S, 2017)
Storage	(V)	(V)	(V)	(V)	(V)
Battery	(V)	= 2016 (III) (M5S, 2017)	> 2020 (III) (M5S, 2017)	> 2020 (III) (M5S, 2017)	> 2020 (III) (M5S, 2017)
Pumped Hydropower	(V)	≤ 2016 (III) (M5S, 2017)	≤ 2016 (III) (M5S, 2017)	≤ 2016 (III) (M5S, 2017)	≤ 2016 (III) (M5S, 2017)
Other storage	(V)	(V)	(V)	(V)	(V)
Cross-border interconnection NTC	(V)	> 2016 (I) (D.Lgs. 3 March 2011 n.28, 2011)	~ 2020 (III) (M5S, 2017)	~ 2020 (III) (M5S, 2017)	~ 2020 (III) (M5S, 2017)
Electrification of additional sectors	(V)	(V)	(V)	(V)	(V)

IT: Grassroots	2016	2020	2030	2040	2050
Total heating demand incl. non-electric heating	(V)	< 2016 (I) (D.Lgs.4 July 2014 n. 102); 1035 TWh (III) (M5S, 2017)	791 TWh (III) (M5S, 2017)	547 TWh (III) (M5S, 2017)	279 TWh (III) (M5S, 2017)
Heating with electricity	(V)	0 (III) (M5S, 2017)	0 (III) (M5S, 2017)	0 (III) (M5S, 2017)	0 (III) (M5S, 2017)
Total cooling demand incl. non-electric cooling	(V)	(V)	(V)	(V)	(V)
Cooling with electricity	(V)	(V)	(V)	(V)	(V)
Electric mobility	(V)	2% (III) (M5S, 2017)	> 2020 (III) (M5S, 2017)	>> 2030 (III) (M5S, 2017)	90% (III) (M5S, 2017)
EV chargers	(V)	(V)	(V)	(V)	(V)
Gross electricity consumption	290 TWh (EUROSTAT, 2018)	285 TWh (III) (M5S, 2017)	385 TWh (III) (M5S, 2017)	485 TWh (III) (M5S, 2017)	580 TWh (III) (M5S, 2017)
Final energy consumption	(V)	(V)	(V)	(V)	(V)

8.6 Switzerland

8.6.1 Dominant pathway: state-centred (Swiss Federal Council)

Table 37: Quantification of the Swiss dominant policy pathway as described by currently valid policies and the energy strategy of the Swiss Federal Council (Energy Strategy 2050, POM var. C+E).

CH: Dominant	2016	2020	2035	2050
GHG reduction targets (economy-wide)	46 Mt CO_{2eq} (EEA, 2018)	-20%/inhabitant (GHG-2000) (II) (Prognos, 2012)	-55.3 %/inhabitant (GHG-2000) (II) (Prognos, 2012)	-68.3 %/inhabitant (GHG-2000) (II) (Prognos, 2012)
ETS sector reduction targets	5.3 Mt CO_{2eq} per year	4.9 Mt CO_{2eq}; from 2020: -1.74% per year reduction (compared to 2010) (BAFU, 2019)	(V)	(V)
Non-ETS sectors emission reduction targets	(V)	(V)	(V)	(V)
GHG reduction targets (electricity sector)	(V)	+50% (III) (Prognos, 2012)	+525% (III) (Prognos, 2012)	+338% (III) (Prognos, 2012)
Renewables targets (energy; % of final energy consumption)	22.10%	(V)	(V)	(V)
Renewables targets (electricity; % of final energy consumption)	64%; 38 TWh (BFS, 2018)	61.8% (III) (Prognos, 2012)	75.5% (III) (Prognos, 2012)	93.0% (III) (Prognos, 2012)
Intermittent renewables	(V)	(V)	(V)	(V)
Wind onshore	(V)	0.66 TWh (II) (Prognos, 2012)	1.76 TWh (II) (Prognos, 2012)	4.26 TWh (II) (Prognos, 2012)
Wind offshore	(V)	0 TWh (II) (Prognos, 2012)	0 TWh (II) (Prognos, 2012)	0 TWh (II) (Prognos, 2012)
Solar PV	(V)	0.52 TWh (II) (Prognos, 2012)	4.44 TWh (II) (Prognos, 2012)	11.12 TWh (II) (Prognos, 2012)
Dispatchable renewables	(V)	(V)	(V)	(V)
Biomass		0.6 TWh (wood) (II) (Prognos, 2012); 0.46 TWh (biogas) (II) (Prognos, 2012)	1.21 TWh (wood) (II) (Prognos, 2012); 1.48 TWh (biogas) (II) (Prognos, 2012)	1.24 TWh (wood) (II) (Prognos, 2012); 1.58 TWh (biogas) (II) (Prognos, 2012)
Hydro	36 TWh (BFS, 2018)	41.96 TWh (II) (Prognos, 2012); 5.09 TWh (Mini-hydro) (II) (Prognos, 2012)	43.02 TWh (II) (Prognos, 2012); 6.48 TWh (Mini-Hydro) (II) (Prognos, 2012)	44.15 TWh (II) (Prognos, 2012); 8.57 TWh (II) (Mini-Hydro) (Prognos, 2012)
CSP	(V)	0 TWh (II) (Prognos, 2012)	0 TWh (II) (Prognos, 2012)	0 TWh (II) (Prognos, 2012)
Other renewables	(V)	0.2 TWh (Geothermal) (II) (Prognos, 2012)	1.43 TWh (Geothermal) (II) (Prognos, 2012)	4.39 TWh (Geothermal) (II) (Prognos, 2012)
Traded renewables	(V)	(V)	(V)	(V)
Physical import of renewables (cooperation)	(V)	(V)	(V)	(V)
Statistical transfer of renewables (cooperation)	(V)	(V)	(V)	(V)
Explicit trade of CSP or hydropower	(V)	0 TWh (II) (Prognos, 2012)	0 TWh (II) (Prognos, 2012)	0 TWh (II) (Prognos, 2012)

CH: Dominant	2016	2020	2035	2050
Nuclear	20 TWh (BFS, 2018)	2.9 GW (III) (Prognos, 2012); 21.68 TWh (II) (Prognos, 2012)	0 GW (III) (Prognos, 2012)5	0 GW (III) (Prognos, 2012)5
Fossil fuels	3 TWh (BFS, 2018)	(V)	(V)	(V)
CCS	(V)	0 TWh (II) (Prognos, 2012)	0 TWh (II) (Prognos, 2012)	0 TWh (II) (Prognos, 2012)
Lignite	(V)	0 TWh (II) (Prognos, 2012)	0 TWh (II) (Prognos, 2012)	0 TWh (II) (Prognos, 2012)
Hard coal	(V)	0 TWh (II) (Prognos, 2012)	0 TWh (II) (Prognos, 2012)	0 TWh (II) (Prognos, 2012)
Gas	(V)	3.13 TWh (II) (Prognos, 2012)	15.21 TWh (II) (Prognos, 2012)	10.65 TWh (II) (Prognos, 2012)
Petroleum	(V)	(V)	(V)	(V)
Other non-renewables	(V)	0.18 TWh (Waste) (II) (Prognos, 2012)	0.381 TWh (Waste) (II) (Prognos, 2012)	0.385 TWh (Waste) (II) (Prognos, 2012)
Storage	(V)	(V)	(V)	(V)
Battery	(V)	(V)	(V)	(V)
Pumped Hydropower	(V)	7.54 TWh (energy for pumping) (II) (Prognos, 2012)	7.54 TWh (energy for pumping) (II) (Prognos, 2012)	7.54 TWh (energy for pumping) (II) (Prognos, 2012)
Other storage	(V)	(V)	(V)	(V)
Cross-border interconnection NTC	(V)	(V)	(V)	(V)
Nord export	6.3 GW (2013)	9.74 GW by 2025 (III) (Swissgrid, 2015)	9.74 GW (III) (Swissgrid, 2015)	= 2035 (III) (Swissgrid, 2015)
Nord import (max, winter)	5.274 GW (2013)	8.6 GW by 2025 (III) (Swissgrid, 2015)	8.6 GW (III) (Swissgrid, 2015)	= 2035 (III) (Swissgrid, 2015)
Nord import (min, summer)	5.074 GW (2013)	8.6 GW by 2025 (III) (Swissgrid, 2015)	8.6 GW (III) (Swissgrid, 2015)	= 2035 (III) (Swissgrid, 2015)
South export (max, winter)	4.24 GW (2013)	5.54 GW by 2025 (III) (Swissgrid, 2015)	5.54 GW (III) (Swissgrid, 2015)	= 2035 (III) (Swissgrid, 2015)
South export (min, summer)	3.42 GW (2013)	4.72 GW by 2025 (III) (Swissgrid, 2015)	4.72 GW (III) (Swissgrid, 2015)	= 2035 (III) (Swissgrid, 2015)
South import (max, winter)	1.81 GW (2013)	3.11 GW by 2025 (III) (Swissgrid, 2015)	3.11 GW (III) (Swissgrid, 2015)	= 2035 (III) (Swissgrid, 2015)
South import (min, summer)	1.44 GW (2013)	2.74 GW by 2025 (III) (Swissgrid, 2015)	2.74 GW (III) (Swissgrid, 2015)	= 2035 (III) (Swissgrid, 2015)
Electrification of additional sectors	(V)	(V)	(V)	(V)
Total heating demand incl. non-electric heating	(V)	45.47 TWh (III) (Prognos, 2012)	32.61 TWh (III) (Prognos, 2012)	22.33 TWh (III) (Prognos, 2012)
Heating with electricity	(V)	4.02 TWh (III) (Prognos, 2012)	3.17 TWh (III) (Prognos, 2012)	2.36 TWh (III) (Prognos, 2012)
Total cooling demand incl. non-electric cooling	(V)	(V)	(V)	(V)

CH: Dominant	2016	2020	2035	2050
Cooling with electricity	(V)	0.11 TWh (III) (Prognos, 2012)	0.47 TWh (III) (Prognos, 2012)	1.31 TWh (III) (Prognos, 2012)
Electric mobility	(V)	10.6% of the fleet (2/3-PHEVs and 1/3-EVs), or 21.400 cars (BFE, 2017)	38.2% of the fleet by 2030 (2/3-PHEVs and 1/3-EVs), or 76’900 cars (BFE, 2017)	> 2035 (BFE, 2017)
EV chargers	(V)	(V)	(V)	(V)
Gross electricity consumption	(V)	64 TWh (II) (Prognos, 2012)	62.98 TWh (II) (Prognos, 2012)	65.95 TWh (II) (Prognos, 2012)
Final energy consumption	237 TWh (BFS, 2018)	(V)	(V)	(V)

8.6.2 *Minority pathway: market-centred (Freisinnig-Demokratische Partei & swisscleantech)*

Table 38: Quantification of the Swiss market-oriented minority policy pathway as described by the Freisinnig-Demokratische Partei and swisscleantech.

CH: Market	**2016**	**2020**	**2035**	**2050**
GHG reduction targets (economy-wide)	46 Mt CO_{2eq} (EEA, 2018)	23.1 % (GHG-1990) (III) (Swisscleantech, 2014)	59.0 % (GHG-1990) (III) (Swisscleantech, 2014)	88.8 % (GHG-1990) (III) (Swisscleantech, 2014)
ETS sector reduction targets	5.3 Mt CO_{2eq} per year	4.9 Mt CO_{2eq}: from 2020: -1.74% per year (2010 baseline) (BAFU, 2019)	(V)	(V)
Non-ETS sectors emission reduction targets	(V)	(V)	(V)	(V)
GHG reduction targets (electricity sector)	(V)	(V)	(V)	100 % (III) (Swisscleantech, 2014)
Renewables targets (energy; % of final energy consumption)	22.10%	30.0 % (III) (Swisscleantech, 2014)	53.0 % (III) (Swisscleantech, 2014)	80.6 % (III) (Swisscleantech, 2014)
Renewables targets (electricity; % of final energy consumption)	64%; 38 TWh (BFS, 2018)	(V)	(V)	100 % (III) (Swisscleantech, 2014)
Intermittent renewables	(V)	(V)	(V)	(V)
Wind onshore	(V)	0.39 TWh (III) (Swisscleantech, 2014)	2.99 TWh (III) (Swisscleantech, 2014)	5.18 TWh (III) (Swisscleantech, 2014)
Wind offshore	(V)	(V)	(V)	(V)
Solar PV	(V)	3.53 TWh (III) (Swisscleantech, 2014)	12.66 TWh (III) (Swisscleantech, 2014)	16.38 TWh (III) (Swisscleantech, 2014)
Dispatchable renewables	(V)	(V)	(V)	(V)
Biomass		0.37 TWh (wood) 1.13 TWh (biogas with CHP) (III) (Swisscleantech, 2014)	0.91 TWh (wood) 2.45 TWh (biogas with CHP) (III) (Swisscleantech, 2014)	1.29 TWh (wood) 2.38 TWh (biogas with CHP) (III) (Swisscleantech, 2014)
Hydro	36 TWh (BFS, 2018)	30.39 TWh 3.97 TWh (mini-hydro) (III) (Swisscleantech, 2014)	29.73 TWh 4.70 TWh (mini-hydro) (III) (Swisscleantech, 2014)	28.80 TWh 4.91 TWh (mini-hydro) (III) (Swisscleantech, 2014)
CSP	(V)	(V)	(V)	(V)
Other renewables	(V)	0 (Geothermal) (III) (Swisscleantech, 2014)	0.92 TWh (Geothermal) (III) (Swisscleantech, 2014)	5.88 TWh (Geothermal) (III) (Swisscleantech, 2014)
Traded renewables	(V)	(V)	(V)	(V)
Physical import of renewables (cooperation)	(V)	(V)	(V)	(V)
Statistical transfer of renewables (cooperation)	(V)	(V)	(V)	(V)

CH: Market	2016	2020	2035	2050
Explicit trade of CSP or hydropower	(V)	(V)	(V)	(V)
Nuclear	20 TWh (BFS, 2018)	19.0 TWh (III) (Swisscleantech, 2014)	0 (III) (Swisscleantech, 2014)	0 (III) (Swisscleantech, 2014)
Fossil fuels	3 TWh (BFS, 2018)	(V)	(V)	(V)
CCS	(V)	(V)	(V)	(V)
Lignite	(V)	(V)	(V)	(V)
Hard coal	(V)	(V)	(V)	(V)
Gas	(V)	117.2 TWh (III) (Swisscleantech, 2014)	58.0 TWh (III) (Swisscleantech, 2014)	19.4 TWh (III) (Swisscleantech, 2014)
Petroleum	(V)	(V)	(V)	(V)
Other non-renewables	(V)	1.71 TWh (Waste) (III) (Swisscleantech, 2014)	1.67 TWh (Waste) (III) (Swisscleantech, 2014)	1.62 TWh(Waste) (III) (Swisscleantech, 2014)
Storage	(V)	(V)	(V)	(V)
Battery	(V)	> 2016 (III) (Swisscleantech, 2014)	> 2020 (III) (Swisscleantech, 2014)	> 2035 (III) (Swisscleantech, 2014)
Pumped Hydropower	(V)	> 2016 (III) (Swisscleantech, 2014)	> 2020 (III) (Swisscleantech, 2014)	> 2035 (III) (Swisscleantech, 2014)
Other storage	(V)	> 2016 (power-to-gas) (III) (Swisscleantech, 2014)	> 2020 (power-to-gas) (III) (Swisscleantech, 2014)	> 2035 (power-to-gas) (III) (Swisscleantech, 2014)
Cross-border interconnection NTC	(V)	(V)	(V)	(V)
Nord export	6.3 GW (2013)	= 2016 (III) (Swisscleantech, 2014)	> 2020 (III) (Swisscleantech, 2014)	(V) (III) (Swisscleantech, 2014)
Nord import (max, winter)	5.274 GW (2013)	= 2016 (III) (Swisscleantech, 2014)	> 2020 (III) (Swisscleantech, 2014)	(V) (III) (Swisscleantech, 2014)
Nord import (min, summer)	5.074 GW (2013)	= 2016 (III) (Swisscleantech, 2014)	> 2020 (III) (Swisscleantech, 2014)	(V) (III) (Swisscleantech, 2014)
South export (max, winter)	4.24 GW (2013)	= 2016 (III) (Swisscleantech, 2014)	> 2020 (III) (Swisscleantech, 2014)	(V) (III) (Swisscleantech, 2014)
South export (min, summer)	3.42 GW (2013)	= 2016 (III) (Swisscleantech, 2014)	> 2020 (III) (Swisscleantech, 2014)	(V) (III) (Swisscleantech, 2014)
South import (max, winter)	1.81 GW (2013)	= 2016 (III) (Swisscleantech, 2014)	> 2020 (III) (Swisscleantech, 2014)	(V) (III) (Swisscleantech, 2014)
South import (min, summer)	1.44 GW (2013)	= 2016 (III) (Swisscleantech, 2014)	> 2020 (III) (Swisscleantech, 2014)	(V) (III) (Swisscleantech, 2014)
Electrification of additional sectors	(V)	(V)	(V)	(V)

CH: Market	2016	2020	2035	2050
Total heating demand incl. non-electric heating	(V)	< 2016 (III) (Swisscleantech, 2014)	< 2020 (III) (Swisscleantech, 2014)	-75% (TWh-2010) (III) (Swisscleantech, 2014)
Heating with electricity	(V)	(V)	(V)	(V)
Total cooling demand incl. non-electric cooling	(V)	(V)	(V)	(V)
Cooling with electricity	(V)	(V)	(V)	(V)
Electric mobility	(V)	> 2016 (III) (Swisscleantech, 2014)	> 2020 (III) (Swisscleantech, 2014)	40% EV+PHEV, basis: 2010 (III) (Swisscleantech, 2014)
EV chargers	(V)	(V)	(V)	(V)
Gross electricity consumption	(V)	66 TWh (III) (Swisscleantech, 2014)	72 TWh (III) (Swisscleantech, 2014)	70 TWh (III) (Swisscleantech, 2014)
Final energy consumption	237 TWh (BFS, 2018)	(V)	(V)	(V)

8.6.3 *Minority pathway: outside the energy logics framework (Swiss People's Party)*

Table 39: Quantification of the Swiss minority policy pathway (outside the transition logics framework) as described by the Swiss People's Party.

CH: Outside logic	2016	2020	2035	2050
GHG reduction targets (economy-wide)	46 Mt CO_{2eq} (EEA, 2018)	< 2016 (GHG-1990) (III) (SVP, 2015)	< 2020 (GHG-1990) (III) (SVP, 2015)	< 2035 (GHG-1990) (III) (SVP, 2015)
ETS sector reduction targets	5.3 Mt CO_{2eq}	4.9 Mt CO_{2eq} ; 1.74% reduction per year (2010 baseline) (BAFU, 2019)	(V)	(V)
Non-ETS sectors emission reduction targets	(V)	(V)	(V)	(V)
GHG reduction targets (electricity sector)	(V)	(V)	(V)	(V)
Renewables targets (energy; % of final energy consumption)	22.10%	(V)	(V)	(V)
Renewables targets (electricity; % of final energy consumption)	64%; 38 TWh (BFS, 2018)	= 2016 (III) (SVP, 2015)	BY 2030: +6 TWh (2015) (III) (SVP, 2013)	(V)
Intermittent renewables	(V)	(V)	(V)	(V)
Wind onshore	(V)	= 2016 (III) (SVP, 2015)	= 2016 (III) (SVP, 2015)	= 2016 (III) (SVP, 2015)
Wind offshore	(V)	(V)	(V)	(V)
Solar PV	(V)	= 2016 (III) (SVP, 2015)	= 2016 (III) (SVP, 2015)	= 2016 (III) (SVP, 2015)
Dispatchable renewables	(V)	(V)	(V)	(V)
Biomass		> 2016 (wood) (biogas) (III) (SVP, 2013)	> 2020 (wood) (biogas) (III) (SVP, 2013)	(V)
Hydro	36 TWh (BFS, 2018)	= 2016 (III) (SVP, 2015); > 2016 (mini-hydro) (III) (SVP, 2015)	By 2030: +3 TWh (2015) (III) (SVP, 2013); > 2020 (mini-hydro) (III) (SVP, 2015)	> 2035 (III); > 2035 (mini-hydro) (SVP, 2015)
CSP	(V)	(V)	(V)	(V)
Other renewables	(V)	(V)	(V)	(V)
Traded renewables	(V)	(V)	(V)	(V)
Physical import of renewables (cooperation)	(V)	(V)	(V)	(V)
Statistical transfer of renewables (cooperation)	(V)	(V)	(V)	(V)
Explicit trade of CSP or hydropower	(V)	(V)	(V)	(V)
Nuclear	20 TWh (BFS, 2018)	= 2016 (III) (SVP, 2013)	> 2020 (III) (SVP, 2013)	>> 2035 (III) (SVP, 2013)
Fossil fuels	3 TWh (BFS, 2018)	(V)	(V)	(V)
CCS	(V)	(V)	(V)	(V)
Lignite	(V)	(V)	(V)	(V)
Hard coal	(V)	(V)	(V)	(V)

CH: Outside logic	2016	2020	2035	2050
Gas	(V)	< 2016 (III) (SVP, 2015)	< 2020 (III) (SVP, 2015)	< 2035 (III) (SVP, 2015)
Petroleum	(V)	(V)	(V)	(V)
Other non-renewables	(V)	= 2016 (Waste) (III) (SVP, 2015)	= 2016 (Waste) (III) (SVP, 2015)	= 2016 (Waste) (III) (SVP, 2015)
Storage	(V)	(V)	(V)	(V)
Battery	(V)	(V)	(V)	(V)
Pumped Hydropower	(V)	= 2016 (III) (SVP, 2015)	> 2020 (III) (SVP, 2015)	> 2035 (III) (SVP, 2015)
Other storage	(V)	(V)	(V)	(V)
Cross-border interconnection NTC	(V)	(V)	(V)	(V)
Nord export	6.3 GW (2013)	(V)	(V)	(V)
Nord import (max, winter)	5.274 GW (2013)	= 2016 (III) (SVP, 2015)	= 2020 (III) (SVP, 2015)	= 2035 (III) (SVP, 2015)
Nord import (min, summer)	5.074 GW (2013)	= 2016 (III) (SVP, 2015)	= 2020n (III) (SVP, 2015)	= 2035 (III) (SVP, 2015)
South export (max, winter)	4.24 GW (2013)	(V)	(V)	(V)
South export (min, summer)	3.42 GW (2013)	(V)	(V)	(V)
South import (max, winter)	1.81 GW (2013)	= 2016 (III) (SVP, 2015)	= 2020 (III) (SVP, 2015)	= 2035 (III) (SVP, 2015)
South import (min, summer)	1.44 GW (2013)	= 2016 (III) (SVP, 2015)	= 2016 (III) (SVP, 2015)	= 2016 (III) (SVP, 2015)
Electrification of additional sectors	(V)	(V)	(V)	(V)
Total heating demand incl. non-electric heating	(V)	> 2016 (III) (SVP, 2015)	> 2020 (III) (SVP, 2015)	> 2035 (III) (SVP, 2015)
Heating with electricity	(V)	(V)	(V)	(V)
Total cooling demand incl. non-electric cooling	(V)	(V)	(V)	(V)
Cooling with electricity	(V)	(V)	(V)	(V)
Electric mobility	(V)	(V)	(V)	(V)
EV chargers	(V)	(V)	(V)	(V)
Gross electricity consumption	(V)	> 2016 (III) (SVP, 2015)	> 2020 (III) (SVP, 2015)	> 2035 (III) (SVP, 2015)
Final energy consumption	237 TWh (BFS, 2018)	(V)	(V)	(V)

MUSTEC
Market Uptake of Solar Thermal Electricity

WHO WE ARE

The MUSTEC consortium consists of nine renowned institutions from six European countries and includes many of the most prolific researchers in the European energy policy community, with very long track records of research in European and nationally funded energy policy research projects. The project is coordinated by Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas-CIEMAT.

Name	Country	Logo
Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas – **CIEMAT**	ES	
University of Piraeus Research Center – **UPRC**	GR	
Institute for Advanced Sustainability Studies – **IASS***	DE	
Technische Universität Wien - **TU WIEN**	AT	
European Solar Thermal Electricity Association – **ESTELA**	BE	
COBRA Instalaciones y Servicios S.A – **COBRA**	ES	
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Agencia Estatal Consejo Superior de Investigaciones Cientificas - **CSIC**	ES	
Fundacion Real Instituto Elcano de Estudios Internacionales y Estrategicos – **ELCANO**	ES	

*IASS is not yet an official project partner but will replace ETH Zürich as MUSTEC partner, pending the approvement of an amendment of the project Grant Agreement.

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