SHURA Energy Transition Center

Agora Energiewende

Lessons from global experiences for accelerating energy transition in Turkey through solar and wind power

About SHURA Energy Transition Center

SHURA Energy Transition Center, founded by the European Climate Foundation (ECF), Agora Energiewende and Istanbul Policy Center (IPC) at Sabancı University, contributes to decarbonisation of the energy sector via an innovative energy transition platform. It caters the need for a sustainable and broadly recognized platform for discussions on technological, economic and policy aspects of Turkey's energy sector. SHURA supports the debate on the transition to a low-carbon energy system through energy efficiency and renewable energy by using fact-based analysis and best available data. Taking into account all relevant perspectives by a multitude of stakeholders, it contributes to an enhanced understanding of the economic potential, technical feasibility and the relevant policy tools for this transition.

About Agora Energiewende

Agora Energiewende develops evidence-based and politically viable strategies for ensuring the success of the clean energy transition in Germany, Europe, and the rest of the world. As a think tank and policy laboratory, Agora aims to share knowledge with stakeholders in the worlds of politics, business, and academia while enabling a productive exchange of ideas. As a non-profit foundation primarily financed through philanthropic donations, Agora is not beholden to narrow corporate or political interests but rather to its commitment to confronting climate change.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF BOXES

LIST OF ABBREVIATIONS

°C	degrees Celsius
ACEEE	American Council for an Energy-Efficient Economy
AMEE	Moroccan Agency for Energy Efficiency
ARPA-E	Advanced Research Projects Agency-Energy
AWEA	American Wind Energy Association
BNetzA	Bundesnetzagentur
BOOT	build, own, operate and transfer
CECRE	Control Centre for Renewables
CEL	Clean Energy Certificate
CENACE	National Center for Energy Control
CENER	National Renewable Energy Centre of Spain
CFE	Mexican Federal Energy Commission
CN	China
CO_2	carbon dioxide
COP	Conference of the Parties
CPUC	California Public Utilities Commission
CREZ	Competitive Renewable Energy Zones
CSP	concentrated solar power
CSPE	contribution au service public de l'électricité
ct	cents
DE	Germany
DK	Denmark
DSO	Distribution System Operator
EC	European Commission
EED	Energy Efficiency Directive
EEG	Renewable Energy Act
EERS	Energy Efficiency Resource Standard
EFRCs	Energy Frontier Research Centers
EIA	environmental impact assessment
EPBD	Energy Performance of Buildings Directive
ERCOT	Electric Reliability Council of Texas
ES	Spain
ESCOs	energy service companies
ETS	emissions trading system
EU	European Union
EUR	Euro
EV	electric vehicle
FiP	feed-in premium
FiT	feed-in tariff
FR	France
G20	Group of Twenty
GHG	Greenhouse gas
Gt	Gigatons
GW	Gigawatt
GWEC	Global Wind Energy Council
GSE	Gestore dei Servizi Energetici
GWh	Gigawatt-hour
IAMs	integrated assessment models

IEA	International Energy Agency
IEEFA	Institute for Energy Economics and Financial Analysis
IOUs	investor-owned utilities
IPP	independent power producer
IRENA	International Renewable Energy Agency
IT	Italy
ITC	investment tax credit
JP	Japan
kWh	kilowatt-hour
LCOE	levelised cost of electricity
LRAS	Large Ramp Alert System
LTE	Electricity Industry Law
LTPA	long-term power auction
MASEN	Moroccan Agency for Sustainable Energy
MENA	Middle East and North Africa
METI	Ministry of Economy, Trade, and Industry
MEXICO2	Mexican Platform for CO_2
MO	Morocco
Mtoe	million tonnes of oil equivalent
MW	megawatt
MWh	megawatt-hour
MX	Mexico
NDC	Nationally Determined Contribution
NES	National Energy Strategy
NREAP	National Renewable Energy Action Plan
NREL	National Renewable Energy Laboratory
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
ONEE	Office National De L’electricite Et De L’eau Potable
PEMEX	Petróleos Mexicanos
PEV	plug-in electric vehicle
PM	particulate matter
PPE	Programmation Pluriannuelle de l’énergie
PRODESEN	Program for the Development of the National Electricity System
PRONASE	National Program for the Sustainable Use of Energy
PSA	Plataforma Solar de Almería
PSO	Public Service Obligation
PTC	production tax credit
PV	photovoltaic
R&D	research and development
REBA	Renewable Energy Buyers Alliance
REC	renewable energy credit
RED	Renewable Energy Directive
REE	Red Eléctrica de España
REN21	Renewable Energy Policy Network for the 21st Century
REZ	renewable energy zones
RPS	renewable portfolio standards
SDGs	Sustainable Development Goals
SEMARNAT	Ministry of the Environment and Natural Resources
SENER	Mexican Energy Secretariat

SMEs	small- and medium-sized enterprises
SNBC	Stratégie Nationale Bas-Carbone
TOE	tonnes of oil equivalent
TPES	total primary energy supply
TSO	transmission system operator
UAE	United Arab Emirates
UNFCCC	United Nations Framework Convention on Climate Change
UNGA	United Nations General Assembly
US	United States
USD	United States Dollar
VAT	value-added tax
VRE	variable renewable energy
WHO	World Health Organisation

Executive Summary

The global energy sector is in the midst of a profound energy transition. At the centre of this are the dual pillars of energy efficiency and renewable energy, both of which are rapidly expanding. Another key component of the energy transition is system-wide innovation, including the growing electrification of energy end uses and digitalisation.

Climate change mitigation, reducing local air pollution, improving energy security and socio-economic benefits are among the key drivers for energy transition worldwide. Many countries around the world provide clear examples of how a transition to a sustainable energy system can be achieved. Turkey has now joined in this effort by launching its own energy transition, scaling up investments both in local renewable energy sources as well as in energy efficiency. This transition is driven by Turkey's top policy priorities to reduce its current account deficit and ensure supply security to meet its rapidly growing energy demand.

Total demand for energy in Turkey is increasing by around 4% per year. In 2017, Turkey's total primary energy supply reached just below 150 million tonnes of oil equivalent (Mtoe) per year, a 50% increase compared to the level from one decade ago. Total demand for electricity is growing at an even faster pace, at around 5% per year. The projections for 2030 put the total demand between 440–550 billion kilowatt-hours (kWh) per year. In 2017, Turkey's total demand for electricity was just below 300 billion kWh per year.

Looking back at 2017, the growth of renewable energy capacity additions exceeded that of conventional fuels for a consecutive year, accounting for two-thirds of all additions. Many other promising developments have taken place in Turkey's renewable energy sector. In 2017, Turkey held its first round of capacity auctions for renewable energy[1], yielding extremely competitive prices for long-term power purchase contracts. The onshore wind auction was won with a price of 34.8 United States dollar (USD) per megawatt-hour (MWh) and solar PV auction with a price of 69.9 USD per MWh. Each auction had a size of 1,000 megawatt (MW). Following this success of auctions in 2017, the government of Turkey announced three new YEKA auctions in 2018. A second round of auctions for both onshore wind and solar PV technologies each with 1,000 MW, and one for offshore wind with a total capacity of 1,200 MW that will take place in 2019. Moreover, Ministry of Energy and Natural Resources (MENR) stated that Turkey plans to install an additional 10,000 MW solar PV and 10,000 MW wind capacity in the coming decade. One major factor behind Turkey's renewable energy transition is the declining costs of renewable energy technologies, particularly for wind and solar. If Turkey is to keep up this expansion of its renewable energy capacity, it has the potential to join international front-runners in the global renewable energy sector for wind and solar, following the global trends and using its own resources effectively.

The share of renewables in Turkey's electricity system is on the rise. By the end of 2017, renewables accounted for around 30% of all electricity output. This was split between 20% hydropower, 6.1% wind, 2% geothermal, 1% solar, and 1% bioenergy. Variable renewable energy sources represented only 7% of Turkey's total electricity demand. Although this share is still rather low compared to the country's significant

[1] This auction is different from the pre-licensing auctions for grid access, which are already being implemented.

resource potential, the recent growth in renewable energy (and variable renewables in particular) indicates that Turkey is clearly on the path toward the long-term transition of its power sector.

On 26 September 2018, Turkey's total electricity output was one of the highest throughout the year. On that same day, a new record was also made for wind power: its share in total electricity generation reached 16.8%, just below gas but surpassing resources like hydropower and lignite. This record revealed a crucial strength that Turkey possesses but does not use to its full extent: namely, the fact that its transmission and distribution grid can accommodate double-digit shares of variable renewables without experiencing disruptions in the system. This assertion is also supported by SHURA's recently released renewables grid integration study "Increasing the share of renewables in Turkey's power system". This study shows that Turkey has the potential to accommodate at least a 20% share of wind and solar power in its system by 2026 without any major operational issues and additional investments in grid infrastructure beyond what the Turkey's transmission system operator (TEİAŞ) has already planned.

The share of wind and solar power will increase as new capacity comes online; as a result, Turkey needs to start planning for this transformation in order to ensure the secure and reliable operation of its power system. Many countries have already achieved wind and solar shares above 15% or more without experiencing major problems. Some countries, such as Denmark, Germany, and Spain, provide close to or even more than one-quarter of all output from wind and solar power. Denmark and Germany have topped the charts for system reliability-in other words, experiencing the fewest power outages. In the process, countries have developed their own strategies to ensure a flexible power system to integrate higher shares of wind and solar. Strategies to better integrate high and growing shares of variable renewables include strong transmission grids, flexible generators, interconnector capacity that allows for electricity trade with neighbouring countries, demand-side management strategies, energy storage, and improved techniques for energy planning and forecasting. The ranking of the strategies in terms of their cost and ease of implementation will depend on country circumstances. SHURA's grid integration study outlines four flexibility strategies for Turkey: (i) locating more wind and solar capacity within proximity of load centres and strong grid areas, (ii) energy storage provided by batteries and pumped hydropower plants, (iii) demand response, and (iv) modernising thermal power plants.

To further drive energy transition regulations and market design will need to be improved, and innovative business models and financing structures will need to be developed. Achieving higher shares of wind and solar power requires current rates of technology uptake to be further increased over the coming years, combined with innovations for developing new technologies and enabling infrastructure such as energy storage, smart grids, and interconnectors. Technological efforts would need to be complemented with new approaches to ensure renewables' integration into the system. This calls for efforts extending beyond the development of new technology, notably a regulatory framework that is well adapted to rapidly evolving market developments. The goal of sound, future-oriented regulatory policy is to create a supportive environment for investments in innovation, new technologies, and new businesses.

As Turkey advances its energy transition, it can also learn from the useful lessons and experiences of other countries in order to accelerate progress in meeting its

national policy goals. National energy transition narratives around the world involve both successes and failures. However, they provide firm evidence that it is possible in all countries to build a system that is cleaner, more efficient, and more reliable by harnessing the local potential of wind and solar energy.

This paper is based on the review of ten countries selected from different regions around the world. Together they represent around three-quarters of the total installed wind and solar capacity worldwide. **It identifies four key areas that are crucial for energy transition, namely: (i) long-term energy planning, (ii) regulatory framework and renewable energy generation costs, (iii) system integration measures, and (iv) innovation in finance and business models.** The objective of this paper is to provide a brief review of the selected countries against these metrics and to discuss the commonalities of countries based on their best practices and experiences.

Based on the country assessments, three priority action areas emerge for Turkey:

- **Long-term energy planning:** Turkey has developed its renewables and energy efficiency strategy until 2023. While progress has been made towards achieving these targets, now it is suggested to start planning further ahead and establish a medium- and long-term strategy toward 2030 and ultimately toward 2050. This strategy is expected to progressively increase Turkey's ambitions in meeting its energy transition targets and it is advised to include all sectors of the energy system (electricity, heating and cooling, as well as transport and industrial energy use).
- **Policy design:** Renewable energy auctions have yielded successful results that were awarded with record prices for large-scale utility projects. Turkey is suggested to continue these efforts by considering its resource potential as well as encouraging project development to ease grid integration. As the costs of renewables go down, Turkey is suggested to continue implementing market-based policy mechanisms. In order to increase competition in the medium term, it might be beneficial to develop strategies for incentivising projects of different sizes, from large to medium commercial plants, as part of defining the framework after the expiry of the current feed-in tariff (FiT) system in 2020. These strategies are also suggested to include suitable policy frameworks for distributed generation, which has significant potential in Turkey and might yield strong benefits-both when it comes to reduced losses at the distribution and transmission systems and in terms of local and regional socio-economic value creation. It is suggested to complement these policies with similar instruments and financing for energy efficiency and widespread electrification in heating, cooling and transport sectors.
- **Grid integration and innovation:** As renewables' share increases in the electricity mix, this will require more system flexibility. Providing flexibility takes time and requires significant planning. As part of its energy system planning, Turkey is suggested to carefully analyse the costs and benefits of different flexibility measures, including strategies toward energy efficiency and coupling electricity generation with those sectors that consume the electricity. Setting adequate market frameworks is suggested to be emphasised, which would incentivise investment in flexibility, be it on the generation, demand, or storage side. Transmission and distribution system planning and operation is suggested to continue its pathway toward modernisation, thus facilitating smart and efficient integration. It is suggested to complement technological efforts toward renewables' grid integration with innovative approaches for new market design as well as new business models and new approaches to financing.

1. Introduction

The global energy transition

In 2015, United Nations General Assembly (UNGA) adopted The Sustainable Development Goals (SDGs). SDGs provide a powerful shared blueprint for achieving a sustainable future for the people and the planet through international cooperation. There are 17 SGDs, and SDG 7, namely “Affordable and clean energy”, is central to the success of Agenda 2030. This global goal on energy aims to “ensure access to affordable, reliable, sustainable and modern energy for all” (United Nations, n.d.).

The importance of reducing energy-related carbon dioxide (CO_2) emissions and mitigating climate change is at the heart of this transition. Energy sector CO_2 emissions account for about two-thirds of total global greenhouse gas (GHG) emissions. The global energy transition must be accelerated in the coming years to limit global temperature rise well below 2 degrees Celsius (2°C). This will require a complete transformation of the energy sector from fossil fuel-based energy systems to low- or zero-carbon alternatives by the second half of this century (IRENA and IEA, 2017).

A core part of achieving sustainable growth and limiting climate change in line with the goals of the Paris Agreement is transitioning the way we produce, distribute, and use energy. At the heart of this lies several key components:

- innovation
- the accelerated deployment of low-cost renewable energy,
- increased energy efficiency,
- electrification of heating, cooling, and transport and coupling these sectors with the power sector,
- and finally, digitalisation.

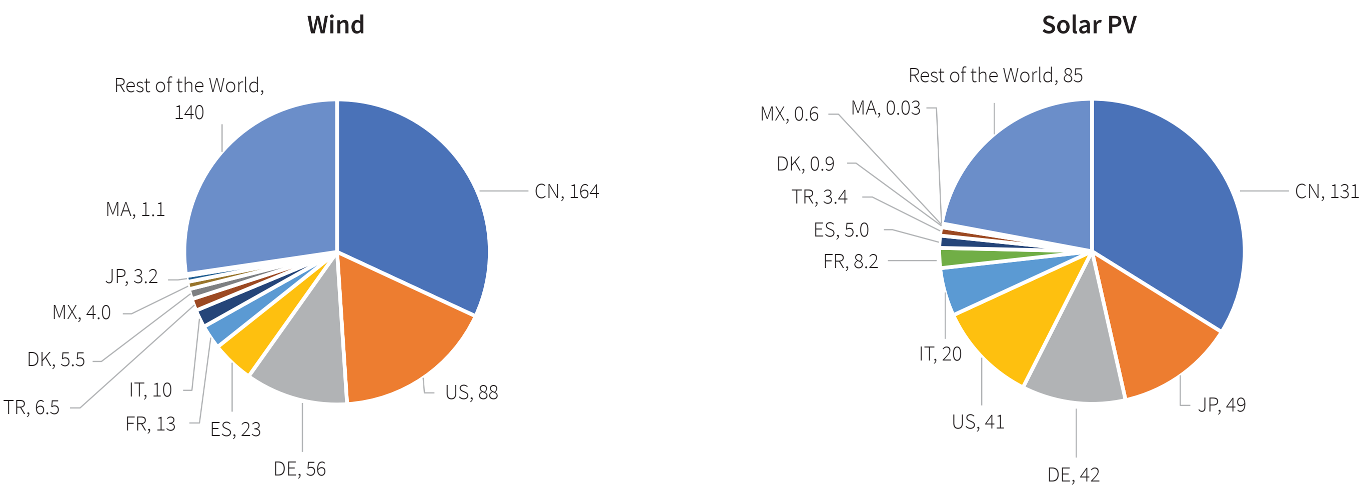
Climate change mitigation, improving energy security, and harnessing the socio-economic benefits of the energy transition are among the key drivers for scaling-up investments in low-carbon technologies worldwide. In addition, improving local air quality by limiting the combustion of fossil fuels is a main driver in many countries such as in China and in countries throughout Europe. Europe has shown global leadership in the energy transition by adopting some of the most ambitious energy and climate targets in the world.

The business case for scaling-up renewable energy in the power sector as well as for heating, cooling, and transportation continues to grow as costs come down and technologies become better adapted to the needs of consumers and the market. Solar photovoltaic (PV) module costs have decreased by 80% since 2009 thanks to technological learning and economies of scale. In the same period, wind power generation costs were halved, and other technologies such as offshore wind and storage continue to exceed market expectations in terms of price and performance. In 2017, onshore wind became one of the most cost-competitive ways of producing electricity with a global average cost of 70 USD per MWh (IRENA, 2018a).

The role of countries in the global energy transition

Many countries provide examples of how to transition to a sustainable energy system. One example is Denmark, which developed one of the first grid codes for interconnection requirements during the late 1980s in order to integrate the increasing number of wind and solar plants in its system. Thanks to hydropower imports from Norway and strong interconnections with other Nordic countries, Denmark has surpassed its 2015 world record to generate nearly 44% of its electricity from wind in 2017. Spain is another country that has shown how variable renewable energy (VRE) shares of around 25% can be accommodated. Unlike Denmark, Spain is a semi-islanded system with interconnector capacity below 10% of its total installed generation capacity (10% is the official European Union guideline) (Red Eléctrica de España, 2018). Spain has overcome this challenge by developing a real-time controlling system for all VRE units. Thanks to this unique approach, it is now generating more electricity from wind than any other source. Germany, with its flagship *Energiewende*-a leading example of energy transition and a standard-bearer for many countries-has been steadily transitioning its energy system since the 1990s. In 2017, renewable electricity generation hit a new record high, representing one-third of the total output, up from 29% in 2016. This increase was due to the rapid expansion of both onshore and offshore wind power in recent years.

Figure 1: *Breakdown of total installed wind and solar capacity in the countries selected for this analysis, 2017*



Source: (IRENA, 2018b)

China alone represents one-third of all installed solar and wind capacity worldwide. Ten countries, including China, make up three-quarters of the total global installed capacity.

Although the costs of renewable energy technologies continue to decline and are now broadly competitive with fossil fuels, experiences from different countries around the world make it clear that the global energy transition will not happen by itself. Governments play a critical role in creating policy frameworks that provide the necessary investment security and ensure a favourable fiscal and regulatory environment.

Germany's Energiewende is a long-term policy process dating back to the 1970s (Morris and Jungjohann, 2016). It is an advanced policy approach that builds on national consensus, applies both pillars of energy efficiency and renewable energy, and addresses all sectors of the energy system. Denmark has pursued its own energy transition by engaging all relevant stakeholders in its formulation, making its goals and objectives more credible and more predictable. As a global leader in innovation and research and development (R&D), the United States is implementing numerous federal-level initiatives on clean energy and enabling strategies and technologies such as smart grids and modernising grid reliability. Brazil has set the example of how long-term government and private sector cooperation can establish the world's biggest bioethanol industry and subsequently drive down its costs to make it fully competitive with fossil fuels.

Countries that are in the early stages of their energy transition have much to benefit from the good practices, experiences, and lessons from those that have been driving the global energy transition. These insights can help other countries around the world to accelerate their own energy transition, making it more cost-effective all while maximising socio-economic benefits.

Drivers of the energy transition in Turkey

Turkey is one of the fastest growing economies of the Group of Twenty (G20) and the Organisation for Economic Co-operation and Development (OECD). Turkey's total electricity generation has doubled in the past decade. Demand for gas, which represents one-third of the country's total primary energy supply (TPES), has more than doubled over the same period.

During the past decade, Turkey's energy system has seen considerable transformation driven by a high demand growth of 4-7% and high investments in the sector. Turkey's top policy priorities are to reduce its current account deficit and improve the overall security of its energy supply. In 2017, Turkey imported approximately three-quarters of its total energy supply (IEA, 2017a). By improving its supply security, Turkey is beginning to prioritise the use of local resources such as energy efficiency, solar power, and wind power. While transitioning its energy system, Turkey also aims to foster economic development and create new jobs. Turkey's renewable energy auction design includes at least a two-thirds share of locally manufactured equipment (a specific methodology that considers equipment, employment, etc., is used to determine the final share of the local content).

In many ways 2017 was a turning point for renewable power in Turkey. The end of the year saw the release of the National Energy Efficiency Action Plan, which provides 55 specific actions across six energy sectors to achieve 14% primary energy savings between 2018 and 2023 (ETKB, 2018). After decades of being considered too costly and not sufficiently scalable, economic arguments are starting to work in favour of solar and wind power (Saygin et al., 2018b):

- The latest YEKA auctions yielded long-term contract prices of 69.9 USD per MWh for solar PV projects and 34.8 USD per MWh for wind power.
- In addition to the favourable auction results, two-thirds of the net capacity additions were from renewables, of which three-quarters were represented by solar and wind. With these developments, renewable energy accounted for almost 30% of all power generation by the end of 2017.
- Solar and wind's share was at 7.1% out of a total generation of 18.8 TWh.
- More than 6.5 GW of wind power and 4.8 GW of solar power were installed by the end of September 2018. The government target is to install 20 GW of wind power and 5 GW of solar power by 2023.

Environmental problems are a growing concern in Turkey. The energy transition can improve both the quality of the environment as well as human health. The majority of the urban population in Turkey is exposed to particulate matter (PM) emissions higher than the limits set by the European Union (EU) and the World Health Organisation (WHO). Moreover, Turkey has ranked first in terms of GHG emissions growth among the Annex I countries since 2006. This makes Turkey a highly relevant country at a crossroads for global mitigation efforts (UNFCCC, 2018). Encouragingly, there is growing recognition of the importance of climate change in Turkey. Recent public surveys show that the share of the population that believes in climate change increased by 9 percentage points in 2017, or from 78% the year before to 87% (Ediger et al., 2018).

All of these developments suggest that Turkey is well positioned to launch into the next phase of its energy transition, building on its existing successes while drawing on experiences from other countries and states around the world.

Scope of the study and approach

Turkey has significant potential to exceed the targets it has set for itself by 2023. In the context of the electricity generation sector, the main question is how to integrate higher shares of renewables into the system and what this would entail in terms of additional costs. According to a recent study by SHURA (Godron et al., 2018), a doubling of the total wind and solar capacity to 40 GW compared to the current plans of the transmission system operator (TSO) by 2026 is realisable without any major additional transmission grid investments and impacts on the operation of the transmission grid. This would allow Turkey to supply more than 21% of its electricity from wind and solar only by the same year, tripling the current levels. More than 30% is possible if measures to enable system flexibility are enabled starting today.

Several countries have already achieved comparable shares of wind and solar energy, and many others are on the same path. Lessons from different countries around the world can provide valuable inputs to help with the transition of Turkey's power system to include higher shares of wind and solar. As such, the objective of this paper is to identify lessons and experiences from a selection of 10 countries that represent different regions of the world and different development pathways. Subsequently, the applicability of these findings to Turkey is qualitatively discussed. The findings of this paper complement the grid integration study recently published by SHURA (Godron et al., 2018). Figure 2 provides an overview of the countries selected for this analysis:

- Americas: Mexico (MX) and the United States (US)
- Asia: China (CN) and Japan (JP)
- Europe: Denmark (DK), France (FR), Germany (DE), Italy (IT), Spain (ES)
- North Africa: Morocco (MO)

The next section of this paper provides a brief assessment of each one of the 10 countries and presents the status of its energy transition based on several dimensions of its energy system (energy sector data refers to the year 2015, and any other information such as policies refers to the most recent year for which data is available). To ensure consistency between all countries compared, energy and CO_2 emission data is taken from the International Energy Agency (IEA, 2017a, 2017b) and installed renewable electricity generation capacity from the International Renewable Energy Agency (IRENA, 2018b). The US Department of Energy's Global Energy Storage

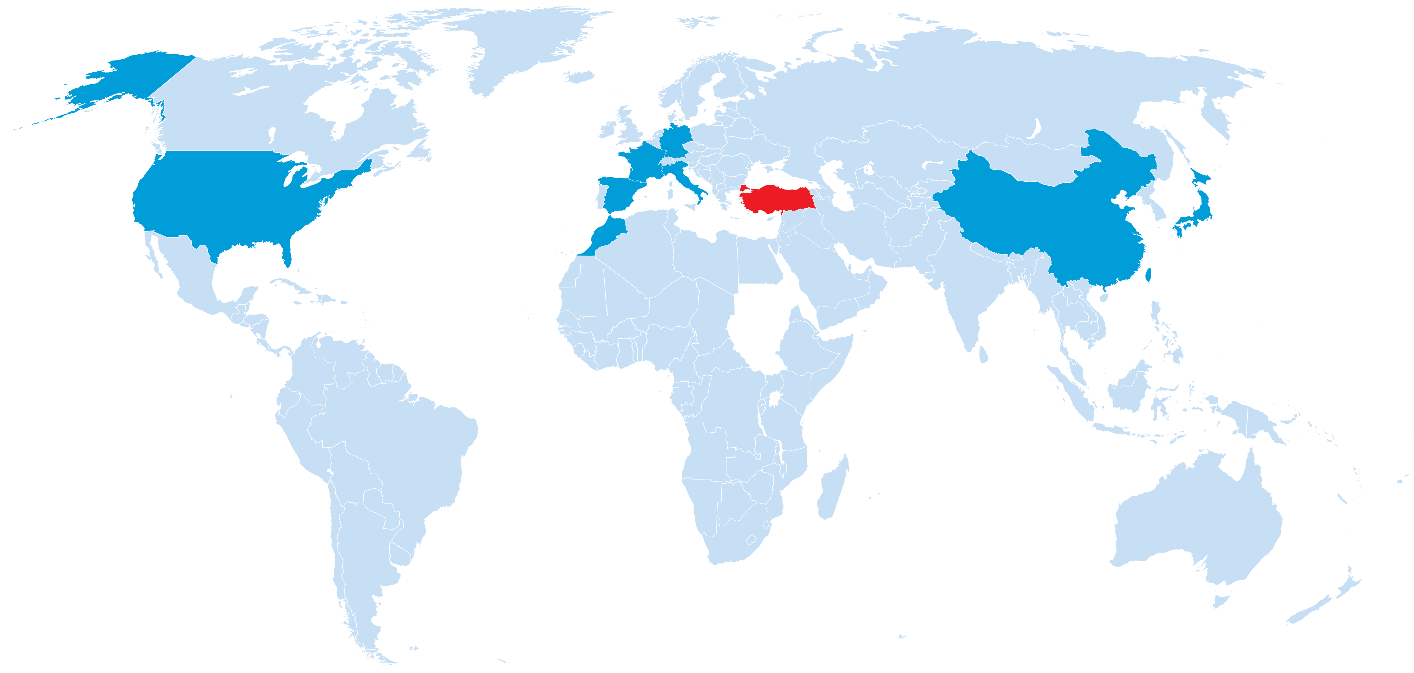
Database was used to estimate the electricity storage capacity (Sandia Corporation, 2018), and if available, national data sources were also used.[2] Policy information is collected from the latest Global Status Report of the REN21 (REN21, 2018) and national data sources.

With regard to the structure of each country analysis, the situation of each country has been broken down based on the following elements:

- Long-term energy planning and existing policy framework
- Existing policy instruments and costs of renewables
- System integration measures
- Innovation in business and finance models

Each country discussion ends with a summary table that shows the key areas that could be of interest to Turkey. The third and last section of the paper discusses the commonalities across the countries based on their best practices and experiences in achieving higher shares of solar and wind. Based on these commonalities, the paper concludes with suggestions for Turkey's energy planners and policy makers. The purpose of this paper is not to develop specific recommendations such as policies or models for Turkey based on country assessments, but rather provide an understanding of the emerging priority areas for action if Turkey aims to increase its renewable energy share through wind and solar energy.

Figure 2: *Selected countries for this analysis*



Turkey

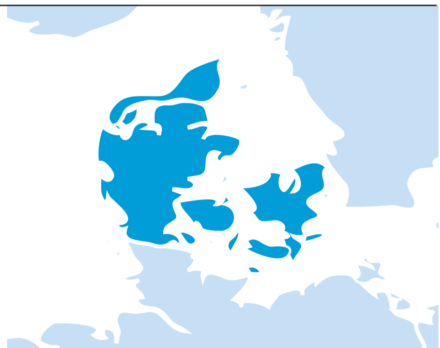
Countries selected for analysis

This analysis evaluates lessons from the 10 countries that make up around three-quarters of the total global installed solar PV and wind power capacity.

[2] The DoE database provides information on pumped hydro and battery storage systems. Units included in the database are classified as operational, contracted, announced, etc. For the purpose of this analysis, only the capacity that is operational is included.

2. Country Analyses

Denmark



Quick energy and climate facts		
Total primary energy supply	[Mtoe/yr]	16
Electricity generation	[TWh/yr]	29
Electricity consumption	[TWh/yr]	31
Per capita total primary energy supply	[toe/cap]	2.8
Per capita electricity consumption	[kWh/cap]	5,812
Per capita CO_2 emissions	[t CO_2/cap]	5.6

Renewable electricity generation		
Renewable electricity share in total generation	[%]	65.5
Variable renewable electricity share in total generation	[%]	50.9
Variable renewable elecricity capacity add. (2010-2015)	[%]	2.9
Total renewable electricity capacity	[MW]	7,106
Total variable renewable electricity capacity	[MW]	5,857

Power system		
Interconnector capacity with neighbours[2]	[MW]	6,452
Electricity storage capacity	[MW]	2.9
Electricity share in total final energy consumption	[%]	20.2

Renewable electricity targets
- 35% and 100% renewable energy share in total final energy consumption by 2020 and 2050, respectively
- 50% and 100% renewable electricity share in total generation by 2020 and 2050, respectively (50% wind by 2020)

Renewable electricity policies
- Renewable energy targets
- Contracts for difference (in addition to feed-in-tariff/premium payment)
- Net metering
- Tradable renewable energy certificates
- Tendering (for offshore wind)
- Investment or production tax credits
- Reductions in sales, energy, CO_2, VAT or other taxes
- Public investment loans, grants, capital subsidies, or rebates

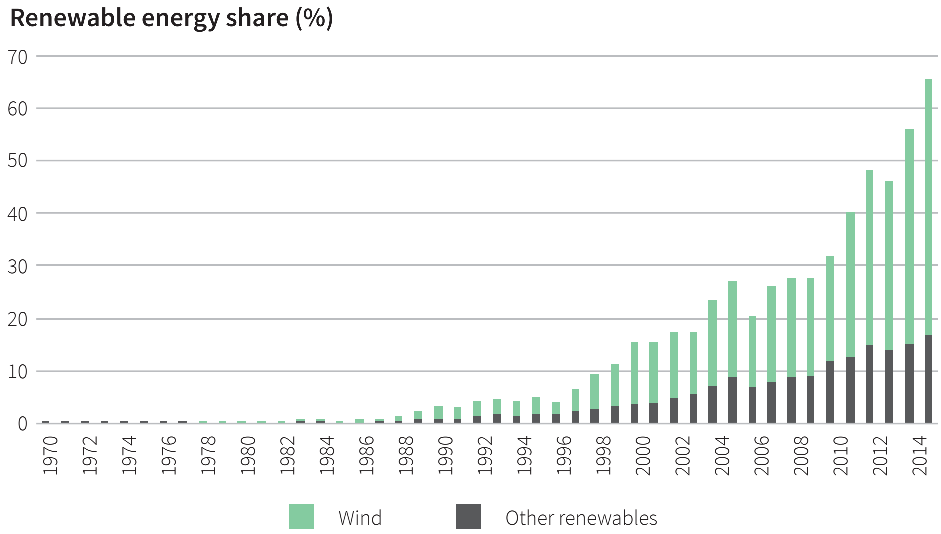
[1] Compared to the total generation capacity
[2] With Germany, Norway and Sweden

Sources: (Agora Energiewende, 2015a; IEA, 2017a, 2017b; IRENA, 2018b; REN21, 2018, p. 21; Sandia Corporation, 2018)

Denmark has been following a very ambitious and comprehensive energy strategy. In 2010, the government set a target of covering all Denmark's energy needs for electricity, heating, and transport with renewables by 2050. Today, the country holds the world record in terms of wind power penetration, representing more than half of all electricity generated (see Figure 3).

Figure 3: *Development of the renewable energy share in Denmark, 1970–2015*

Between 2001 and 2008, Denmark's renewable capacity growth stagnated, largely due to policy uncertainty. Since 2010, its renewable energy capacity has been rapidly increasing.



Source: (IEA, 2017a)

Long-term energy planning and existing policy framework

In the early 1970s, Denmark was strongly reliant on oil in its energy mix, which accounted for more than 90% of its total energy supply. The dual oil crises in the 1970s shifted Denmark's energy policy toward the use of non-oil products. This was the beginning of a seven-phase long-term energy strategy that has spanned from 1976 until today (IRENA and GWEC, 2013).

In 1980, large-scale thermal power plants (predominantly coal-based) were dominating the Danish electricity mix. Over the years, decentralised combined heat and power plants as well as wind turbines have been increasingly deployed, leading to a more distributed generation structure (Agora Energiewende, 2015b). Denmark was an early mover in wind power, with large numbers of small wind turbines installed in the 1980s and 1990s, as well as after 2008. This local market has created a local industry associated with it, generating important revenues for local municipalities as well as residents and farmers.

Despite the changes in government that have occasionally led to a decline in the pace of investment, as seen in the period 2001–2008, Denmark's broader energy strategy has remained focused on continuously improving energy efficiency and making maximum use of domestically available renewable energy resources, notably in both the electricity and heating sectors. Danish energy policy has been characterised by its *energiaftaler.* Energiaftaler can be described as political agreements, made between the government in power and other political parties represented in the Danish parliament, and have contributed considerably to continuity of Danish energy policy. These agreements establish the foundation for subsequent Danish energy sector regulations and policy initiatives. Additional energy objectives to this foundation are agreed upon by various governments over time. This mechanism has created a combination of long-term objectives with short-term goals and concrete initiatives. It has also helped to keep a flexible Danish energy sector strategy while ensuring stability, even during turbulent times and changing minority governments.

In 2011, "Energy Strategy 2050" was adopted. This comprehensive energy strategy has been an important milestone in energy transition in Denmark as well as the world, as it was globally the first of its kind. "Energy Strategy 2050" proposed several concrete initiatives for moving towards absolute independence from fossil fuels across all energy sectors. These initiatives included improved grid access and mitigation of market risk for investors (Agora Energiewende and DTU Management Engineering, 2015).

Existing policy instruments and costs of renewables

The country utilises a broad range of regulations, voluntary agreements, and planning and economic instruments, including financial support of various kinds. Generally, funding for the support of renewables is financed by means of a special Public Service Obligation (PSO), which takes the form of a surcharge included in consumer electricity bills. Over the years, Denmark has experimented with different forms of policy and regulatory instruments to bring its support into better alignment with the market and also to adapt to the rapid developments in renewable energy technologies. For some time in the early 2000s, for example, Denmark introduced fixed feed-in premiums (FiP) on top of market prices: developers would sell their power directly on the market and receive a fixed premium on top.

The two most important support instruments that Denmark has used to scale-up renewable energy technologies thus far have been feed-in premiums and fixed feed-in tariffs (FiT). The latter are provided as contracts for difference[3] determined in tendering procedures for offshore wind, providing stable revenues to investors.

Similar to other early movers, the support for wind power development required additional funding in the form of the above-mentioned PSO. The PSO increased from about 10 EUR per MWh to 30 EUR per MWh between 2011 and 2015, mainly driven by offshore wind and solar generation. It has increased household electricity bills by about 10%. For large industrial customers, which are exempt from value-added tax and electricity tax, costs increased nearly by 25% by 2015. This has sparked a debate on the cost of financing the energy transition, particularly for industrial consumers of electricity. As a result, the PSO for industry has been reduced, and part of the support bill has been shifted to the federal budget (Agora Energiewende and DTU Management Engineering, 2015). In addition, the government has recently announced increasing support to competition among all types of technologies to reduce necessary support levels and achieve better prices for its consumers in future renewable energy projects (Gyekye, 2018).

[3] Offshore wind parks sell their electricity on the spot market. A contract for difference is a private contract, where the wind park operator receives the difference between the spot market price and strike price, determined by the tender. A contract for difference is thus a support scheme which resembles the fixed feed-in tariff mechanism with a variable premium. The major difference between these mechanisms is that in contract for difference, the level of support for an individual offshore wind farm is determined through a tendering process.

System integration measures

For more than four decades Denmark has invested significant amounts of resources into technology, planning, policy design, and market development for higher renewable energy shares. The Danish energy transition has been characterised by several specific features: since 2000, Denmark belongs to the Nordic power market, which was the frontrunner of market liberalisation in the EU. As such, it focused early on improving the market integration of renewables. This includes the obligation to investors to sell power directly on the power exchange, in combination with linking the duration of support to full load hours, rather than providing fixed prices or premiums for all MWh produced over a specific period of time (e.g., 15 or 20 years). In other words, wind parks under this regime are eligible for determined feed-in prices or premiums for 22,000 to 25,000 hours only. As a result, Denmark's policy framework has enabled wind power development not only in the best locations with quality resources but also in regions all over the country.

In addition, all turbine owners are required to cover their balancing needs. They receive compensation of 3 EUR per MWh to account for the average costs of balancing, no matter what their actual balancing cost are-which is an incentive to minimise balancing needs (and maximise forecast accuracy) (Agora Energiewende, 2015b).

To synchronise network planning and wind power investments, the transmission system operator is taking a key role in developing and deploying a set of measures for power system balancing and high shares of wind integration based on short-, medium-, and long-term time horizons. To give just one example, both the geographical location and the specific size of the project (in MW) for which project developers can submit their bids are determined ex-ante by the Danish Energy Agency, based on grid capacity as identified by the TSO.

Denmark is one of the first countries in the world to develop and implement formal grid connection codes, having adopted their first grid codes in the 1980s. This ensured a reliable and secure power supply whilst allowing the sustainable growth of a distributed renewable energy industry predominantly made up of wind as well as small capacities of solar, biogas, and biomass. These codes were expanded to the national level in the early 1990s, and they have been expanded to cover offshore wind plants and other small generators (IRENA, 2016).

Finally, Denmark benefits from a high degree of interconnectivity with its neighbours Germany, Norway, and Sweden, featuring a total interconnection capacity that matches its peak load of 6 GW. The country also derives significant benefits from its integration within the Nordic power market, which features a complementary generation mix between the Nordic countries: while Denmark frequently exports wind power to its neighbours during times of high wind speeds, it imports hydropower from Norway and Sweden when it lacks supply.

An important factor for the rapid deployment of the wind sector and broad public acceptance is the emphasis Danish policymakers have put on making citizens and consumers part of the energy transition through different schemes of consumer participation contained in the Renewable Energy Act (Agora Energiewende, 2015b). This includes the support for local cooperatives that seek to invest in wind power plants as well as a regulation on local participation for any other wind investment:

citizens living up to 4.5 kilometres away from new wind turbines are eligible to participate financially in the ownership of local wind projects. As part of these regulations, wind project developers are required to announce the project in the local newspaper and to offer shares of at least 20% of the project's value to Danish residents.

Innovation in business and finance models

Denmark is also a frontrunner in terms of integrating the electricity and heating sectors, having developed several hundred decentralised combined heat and power generation facilities providing district heating to local homes and businesses. Many of these were traditionally fuelled by coal but are now being converted to rely on waste and biomass, which represent, after wind power, the second largest renewable sources of energy in Denmark's 2050 strategy. However, as many of these are "must run" facilities-their operation being dictated by the need for heating rather than for electricity per se-the flexibility needed to balance the large volumes of wind power being fed into the system is often lacking. This is one of the major challenges for the Danish system. The government seeks to resolve it by incentivising the use of heat pumps, which can be operated more flexibly.

Energy planning	Long-term planning based on broad party agreement Renewable energy targets broader than electricity sector Prioritising renewables as comparable and secure technologies Setting generation-based targets and increasing level of ambition over time
System integration and enabling technologies	Regional electricity market integration and liberalisation Support of biomass/biogas as flexible technologies
Policy instruments and costs of renewables	Support to address technology characteristics other than good resource locations only Policy of limiting support to specific number of full load hours, to incentivise market integration, limit support costs, and allow projects to be profitably developed in different geographic regions Evolving support mechanisms that account for the developments in wind turbine costs and energy market changes Incentives to create a local renewable energy industry to meet local demand and utilise the export potential in the region Creating local ownership Create local industry and exports
Innovation in business and finance models	Market-based approach, heat and power sector integration, grid codes

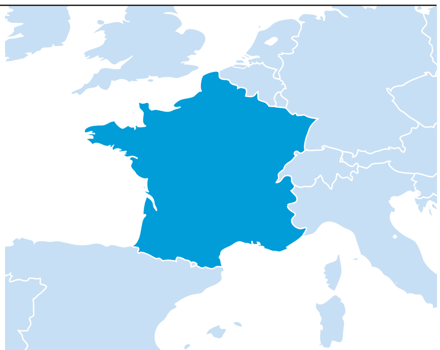
Box 1: Setting predictable, credible, and long-term targets and implementing support instruments: example of the European Union

In 2007, the leaders of the member states of the EU agreed on the "2020 climate & energy package". This included a 20% cut in GHG, 20% share of renewables in gross final energy consumption, and a 20% improvement in energy efficiency (EC, 2016a). Building on its 2020 targets, in October 2014, the European Council agreed on energy and climate targets for 2030 (EC, 2014a). This included a minimum target of a 27% share of renewable energy in gross final energy consumption and at least a 27% improvement in energy efficiency. In addition, a target to cut GHG emissions by 40% by 2030 compared to 1990 levels was included. The 2030 energy strategy was followed by the Energy Union framework strategy, which was released on February 2015. Under this strategy, the EU aims to become "the world leader in renewable energy." For the period between the two target years of 2020 and 2030, the European Commission released the "Clean Energy for All Europeans" package in November 2016. The package proposes a regulatory framework to support renewable energy deployment (EC, 2016b). Most recently, in June 2018, the Commission signed an agreement with the European Parliament and the Council of Europe to raise the binding renewable energy target for 2030 to 32%, up from 27% (EC, 2018). Currently, the Commission is discussing the revision of the GHG emission reduction targets for 2030 to 45%, up from 40% relative to the 1990 levels (Hook and Toplensky, 2018).

The developments that have taken place over the past decade show the EU's continuous approach to update targets and strengthen its policy framework over time to reflect market developments and technology maturity and to respond to the global challenge of climate change. Since the beginning of 2017, support has been provided through competitive bidding processes (EC, 2014b). As elsewhere in the world, renewable energy auctions have shown promising results in various EU countries, continuing the downward cost of wind and solar power. Auctions can increase competition and drive down prices; therefore, providing a framework that allows investors to attract cheap financing and ensure rapid project implementation is key (Berkhout et al., 2018). Prices have consistently fallen for solar and wind power. For example, in Germany, prices fell by almost 30% between 2015 and 2017; in Denmark, solar power was awarded at 19.19 USD per MWh premium over spot price. Denmark, Germany, and the Netherlands have achieved record low prices in offshore wind. In 2017, more electricity was generated from wind, solar, and biomass compared to coal for the first time (Agora Energiewende and Sandbag, 2018).

Against this backdrop, the EU's energy transition also faces challenges as the progress of some of the member states lags behind their targets. The EU has no credible sanctioning mechanisms if targets are unmet. Moreover, coal use and GHG emissions are on the rise in some states, and retroactive changes to policy frameworks have undermined investment and increased investment risk. Despite these developments, the EU has been pushing toward its targets, enabled by a comprehensive regulatory framework that includes Energy Union governance; a set of directives, such as Energy Efficiency, Renewable Energy, and Energy Performance of Buildings Performance; and a new electricity market design.

France



Quick energy and climate facts		
Total primary energy supply	[Mtoe/yr]	247
Electricity generation	[TWh/yr]	563
Electricity consumption	[TWh/yr]	425
Per capita total primary energy supply	[toe/cap]	3.7
Per capita electricity consumption	[kWh/cap]	7,043
Per capita CO_2 emissions	[t CO_2/cap]	4.4

Renewable electricity generation		
Renewable electricity share in total generation	[%]	15.9
Variable renewable electricity share in total generation	[%]	5.1
Variable renewable elecricity capacity add. (2010-2015)	[%]	1.6
Total renewable electricity capacity	[MW]	41,893
Total variable renewable electricity capacity	[MW]	16,973

Power system		
Interconnector capacity with neighbours[2]	[MW]	13,500
Electricity storage capacity	[MW]	5,831.1
Electricity share in total final energy consumption	[%]	27.2

Renewable electricity targets
- 23% and 32% renewable energy share in total final energy consumption by 2020 and 2030, respectively
- 27% and 40% renewable electricity share in total generation by 2020 and 2030, respectively
- 2018: 10.2 GW (solar PV)
- 2020: 380 MW (ocean), 19 GW (onshore wind)
- 2023: 21.8-26 GW (onshore wind), 3 GW (offshore wind), 18.2-20.2 (solar PV)
- 2023: 25.8-26.05 GW (hydro)

Renewable electricity policies
- Renewable energy targets
- Feed-in-tariff/premium payment
- Tendering (held in 2017)
- Tax reductions (e.g. on sales tax, energy tax, VAT), CO_2 tax
- Public investment loans, grants, capital subsidies, or rebates

[1] Compared to the total generation capacity
[2] Export capacity (import capacity 9.8 GW)

Sources: (CRE, 2016; IEA, 2017a, 2017b; IRENA, 2018b; REN21, 2018; Sandia Corporation, 2018)

France has made important commitments in favour of the energy and climate transition at the national, European, and international levels. France's key role in the adoption of the Paris climate agreement at the end of 2015 has been internationally recognised. The current president is pursuing this commitment to implement the agreement worldwide through active climate diplomacy.

Long-term energy planning and existing policy framework

The French law on energy transition and green growth, adopted in 2015, set ambitious mid-term and long-term national targets in terms of climate protection, renewable energy development, and energy efficiency. It aims at diversifying the French power mix by reducing the share of nuclear power from 71.6% (in 2017) to 50%.[4] The law pays special attention to building renovation, clean transportation modes, waste valorisation, nuclear safety, simplifying and clarifying energy efficiency procedures, and empowering citizens, companies, and territories. It introduces a carbon tax mechanism on fossil fuels in the heat and transport sectors, with a long-term trajectory (up to 100 billion EUR in 2030) to incentivise a shift towards low-carbon investments (Ministère de la Transition écologique et solidaire, n.d.). The French energy transition pursues a wide range of industrial policy objectives that favour green growth, new employment, and improved competitiveness.

French President Emmanuel Macron has reinforced climate ambitions. A set of new objectives and measures in favour of climate change mitigation were announced in 2017 and 2018: a complete phase-out of coal use in the power sector is scheduled by 2022, a ban on diesel and gasoline car sales by 2040, and a net zero emission target for 2050. At the EU level, France has committed to more ambitious energy and climate transition objectives and is pushing for the implementation of higher carbon prices on electricity generation (through a regional carbon price floor).

Key objectives of the "French Energy Transition Law" of 2015:

- Decrease final energy consumption by 50% less in 2050 compared to 2012
- Decrease fossil fuel consumption by 30% in 2030 compared to 2012
- Increase the share of renewable energy in total final energy consumption to 32%, and in electricity generation to 40% by 2030
- Increase diversification in electricity generation, and reduce nuclear energy's share in electricity generation to 50% by 2025
- Decrease landfill waste by 50% by 2025
- Decrease greenhouse gas emissions by 40% in 2030 compared to 1990

France benefits from comparably good performance when it comes to CO_2 emissions, especially in the electricity sector, considering its level of gross domestic product (GDP) and industrialisation. Nuclear power currently represents 71.6% of the country's electricity generation (Ministère de la Transition écologique et solidaire, 2018). Nuclear power plants, a significant share of which are already amortised and therefore only have to cover fuel and operating costs (while also putting funds away for future decommissioning), contribute to keeping electricity prices comparatively low for both households and industrial consumers and to making France the country with the second largest net electricity exports across the EU (after Germany) (ENTSO-E, 2017).

[4] Meeting these objectives was initially set for 2025. However, the new French government announced in November 2017 that it intends to postpone meeting the 50% target until 2030 or 2035 (de Clercq and Rose, 2017).

However, in the context of an aging nuclear fleet, important investment decisions would be needed to extend the lifespan of reactors beyond 40 years of operation. Renewable energy sources have been developed in the past few years (Bilan électrique, 2017). In 2017, France was Europe's third largest wind market (Wind Europe, 2018) and the fourth largest for solar PV (Solar Power Europe, 2018).

The French energy transition law set two important energy planning and monitoring instruments that are currently under revision: the *Stratégie nationale bas-carbone* (national low carbon strategy, SNBC) and the *Programmation pluriannuelle de l'énergie* (multiannual planning of energy, PPE). The new SNBC will break down the CO_2 budget allocated to each sector for a five-year period (2029–2033) to achieve net zero emissions by 2050.[5] The PPE will set the trajectory of the energy transition pathway up to 2028, defining the capacities for renewables and nuclear at this time horizon. It concentrates public and political attention on a development process including public consultations and a final adoption planned for the end of 2018.

France's political commitment in favour of the energy transition as well as recent legislation and regulation has improved the business case for renewable energy (Agora Energiewende and Sandbag, 2018). While these measures should help raise the share of wind, solar PV, and biomass power in the system, these renewable energy sources still only represent 8% of all electricity output (if hydropower is also included, the total rises to 19%), compared to an EU average of 21%. A few points still merit attention. The future remuneration of renewable energy projects will depend significantly on the share of nuclear energy in the power mix. If France, through major investments in extending the lifetime of nuclear power plants, keeps its share in the system very high, market prices are likely to stay low. As a consequence, there will be an increased risk of stranded assets for all other power plant investors. The required level of public support for renewables on top of low market prices will remain more pronounced, thereby pushing back the possibility of an exclusively market-based remuneration for renewables (Agora Energiewende and IDDRI, 2018). There is also local resistance against renewables from activists protecting the natural and built heritage in some regions of the country, making the construction of new projects costly and time-consuming. To address this problem and increase the local benefits of these projects, the 2017 tenders included a bonus for projects co-financed by local authorities and the local population, which accounted for one-third of the preselected projects (Ministère de la Transition écologique et solidaire, n.d.).

Existing policy instruments and costs of renewables

France has been funding renewable energy development through a consumer surcharge (*contribution au service public de l'électricité, CSPE*), which was initially used to help fund the surcharges from the country's FiT. However, fixed FiTs were replaced by a market premium in 2016. As of 2016, the surcharge for renewable energy stands at 22.5 EUR per MWh: at this level, the surcharge is expected to generate 5.4 billion EUR in 2018 (Commision de régulation de l'énergie, 2018). With the development of new renewable energy capacity, the total volume of the surcharge is estimated to reach about 6 billion EUR per year in 2022 (Commision de régulation de l'énergie, n.d.).

[5] This includes the following sectors: transport, residential and tertiary, manufacturing industry, energy industry, agriculture, and waste treatment.

The remuneration rates have been reduced considerably over the past years: the auction results in 2017 reached a new low of 55.5 EUR per MWh for ground-mounted solar PV and 65.4 EUR per MWh for onshore wind (Agora Energiewende and IDDRI, 2018). Offshore wind projects with a capacity of up to 3 GW were auctioned at remuneration rates of 180 to 200 EUR per MWh in 2011 and 2013, respectively. Two new offshore tenders are expected to be awarded in 2018 at a much lower price tag, benefiting from lessons from other EU countries (Ministère de la Transition écologique et solidaire, n.d.). Solar PV tender volumes should gradually increase from 1.5 GW to 2.5 GW per year (Ministère de la Transition écologique et solidaire, n.d.).

In April 2017, France implemented a new regulation on incentivising solar rooftop solar PV applications smaller than 100 kW. Under these new regulations, rooftop solar systems can follow either a 100% grid-export model (and receive a fixed FiT for their output ranging from 1.1 – 180 EUR per MWh depending on the project size), or a self-consumption model, according to which the solar panels can consume their own electricity onsite and receive a cash payment for their net excess generation. The payment offered for net excess generation ranges from 60 - 100 EUR per MWh. In addition, for projects engaging in self-consumption model, France offers an investment bonus (framed in EUR per year, spread over five years) that ranges from roughly 200 EUR per year (i.e., 1,000 EUR in total) for small projects of 3 kW and from 1,800 EUR per year (9,000 EUR in total) for projects of 100 kW (EDF ENR, 2017).

Generally, French renewable energy projects are slightly more expensive than in other mature markets like Germany or Denmark, despite better weather conditions. This is due to more restrictive regulatory conditions, as well as local opposition to projects that increase risks and prolong the development phase of projects. Regulatory changes are under discussion to simplify and speed up administrative procedures.

System integration measures

So far, France has not faced significant integration problems with renewable energy since penetration levels remain low. Furthermore, the French system benefits from several flexibility options, especially hydro, good grid infrastructure, even nuclear plants (some of which can be operated flexibly) as well as strong interconnections with several neighbouring countries, all of which help ease the integration challenge. Following the general trend in Europe, all large renewable energy generators have been responsible for their own balancing since 2016.

Innovation in business and finance models

The French government has positioned itself as a frontrunner in developing floating offshore wind power, a technology that would allow offshore wind power to be developed in many sea areas otherwise not suitable due to sea depth. The government has made a commitment to commission four pilot offshore wind farm projects in 2020 and 2021. Three of these projects will be in Mediterranean and one off the coast of Brittany, each with an installed capacity of 24 MW. These pilot projects are planned to pave the way for commercial deployment of floating offshore wind energy. The preparations for the first commercial floating offshore wind project tender have been in progress for some time (Foxwell, 2018).

French renewables tenders integrate industrial policy objectives with preconditions such as the development of innovative technologies, the creation of local employment opportunities as well as encouraging the use of products and technologies with a lower carbon footprint, generally favouring European companies. French corporations are adopting their business models accordingly: they are investing in renewables across the entire solar value chain, from manufacturing photovoltaic cells to developing utility-scale plants and installing solar home systems. For instance Total, traditionally a fossil fuel company, increased its positioning in electricity generation, distribution, and storage through acquiring Lampiris and Saft in 2016. It then acquired Direct Energie in 2018 for 1.4 billion EUR, which is the owner of 550 MW of renewable capacity with another 2 GW projects in the pipeline (Total, n.d.).

France's main energy company, EDF, in which the government continues to hold an 83.7% share, making it primarily state-owned, is also adapting its business model to expand its solar business to add 30 GW installed solar capacity in France by 2035 (EDF Group, 2017). The utility company Engie sold its coal and gas assets worth 15 billion USD over the period of 2016 and 2017 and will reinvest this amount in energy efficiency and renewable energy technologies (Engie, 2017). France is now home to several emerging data-driven business models to accelerate solar PV growth in built environments.[6] The French Overseas Territories also house innovative 100% renewables-based island solutions.

Energy planning	Has reversed energy transition strategy, which was initially focused on nuclear; strategy has subsequently been shifted to focus on renewables Covers both power and end-use sectors Prioritising citizens Integrated policy approach Broad consultation and rich democratic process
System integration and enabling technologies	Availability of flexible resources Regional electricity markets
Policy instruments and costs of renewables	Mix of FiTs with market premium and auctions Environmental and socio-economics benefits New policy for self-consumption
Innovation in business and finance models	Business models for rooftop solar PV

[6] Such as the BeeBryte and the SolarCoin (Dirand, 2017; Sonnet, 2017)

Box 2: The role of innovation for energy transition

Technological innovation has been one of the key drivers of the global energy transition. Combined with the economies of scale, innovation has helped to drive down the costs of renewables-notably solar and wind over the past decade. Since 2012 more than half of all capacity additions in the power sector are from renewables. In 2017, 67 GW of renewable energy capacity was installed, of which solar PV accounted for more than half of this capacity. With these developments, renewable energy provides around one-quarter of total electricity output worldwide (IRENA, 2018b). This share needs to increase in the coming years in order to put the power sector on track towards decarbonisation. As more solar and wind penetrate the power sector, it will be necessary to introduce measures to ensure they are integrated while maintaining the secure and reliable operation of the system. Hence, technological innovation must focus on development and cost reduction in order to enable technologies like storage, digitalisation of grid services, smart charging for electric vehicles (EVs), wider utilisation of mini-grids, and much more (IRENA, 2018c).

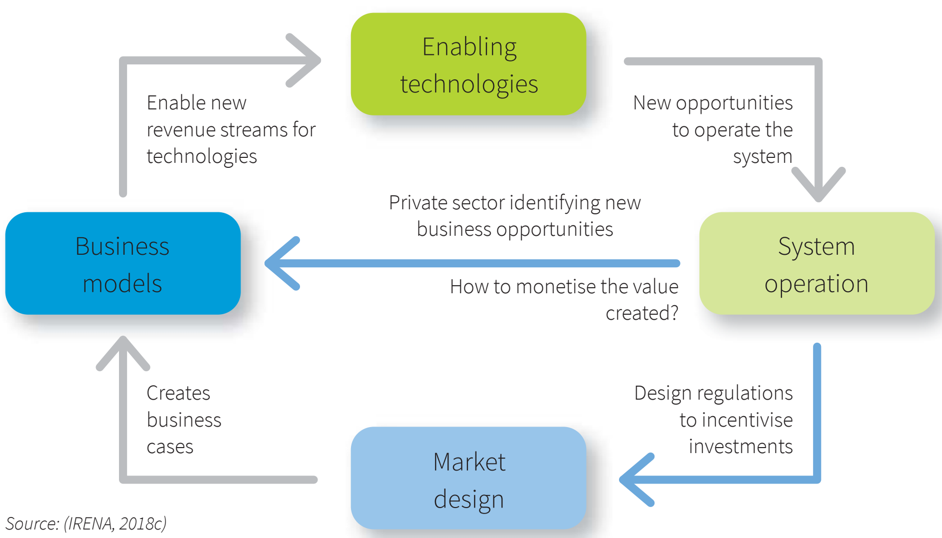
The efforts to decarbonise non-power sectors like heating, cooling, and transport are mixed. Modern renewable energy sources continue to play a small role in the manufacturing industry and buildings. The success of EVs continues. Liquid biofuel investments have stalled in recent years, but in view of market developments, production is expected to grow. Improvements in end-use energy efficiency have increased to an extent, but they are still far from the rates needed for a complete transition of the energy system. These sectors come with specific challenges that require the development of novel technologies to provide alternatives to incumbents in aviation, shipping, and freight transport as well as in high-temperature production processes such as iron, steel, chemicals, and cement. Technological innovation will play a key role in these sectors.

The future of the energy system will be more integrated, and it can no longer be assessed in isolation. The links and interdependencies will need to be explored, and synergies need to be utilised. For instance, coupling of electricity generation with sectors like cooling or transport will be essential to integrate higher shares of wind and solar. Utilising such synergies will also ensure electrified end-use energy applications like transport or heating are supplied with renewable power.

There is also a role for innovation beyond technology. This will require system-wide innovation that combines technological innovation with innovation in system operation such as consumer engagement, demand response and supply-side management, business models, processes, market design, financing, and regulation (see Figure 4) (IRENA, 2018c). SHURA's grid integration study shows the key role of innovation and technological development in increasing system flexibility to achieve higher wind and solar shares (Godron et al., 2018).

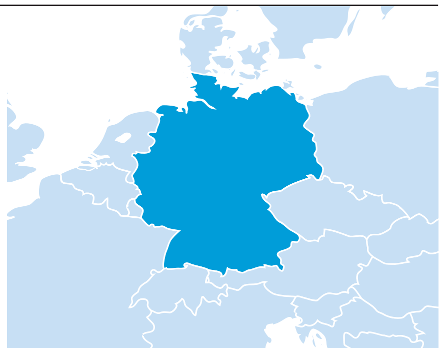
Figure 4: *Innovation priorities for an integrated energy system*

Systemic innovation is needed for an integrated renewable energy system.



Source: (IRENA, 2018c)

Germany



Quick energy and climate facts		
Total primary energy supply	[Mtoe/yr]	308
Electricity generation	[TWh/yr]	641
Electricity consumption	[TWh/yr]	515
Per capita total primary energy supply	[toe/cap]	3.8
Per capita electricity consumption	[kWh/cap]	7,015
Per capita CO_2 emissions	[t CO_2/cap]	8.9

Renewable electricity generation		
Renewable electricity share in total generation	[%]	29.2
Variable renewable electricity share in total generation	[%]	18.4
Variable renewable elecricity capacity add. (2010-2015)	[%]	4.4
Total renewable electricity capacity	[MW]	98,557
Total variable renewable electricity capacity	[MW]	84,456

Power system		
Interconnector capacity with neighbours	[MW]	21,300
Electricity storage capacity	[MW]	7,485.6
Electricity share in total final energy consumption	[%]	22.3

Renewable electricity targets
- 18%, 30%, 45% and 60% renewable energy share in total final energy consumption by 2020, 2030, 2040 and 2050 respectively
- 40-45% , 55%-60% and 80% renewable electricity share in total generation by 2025, 2035 and 2050, respectively
- Biomass: 100 MW added per year
- Onshore wind: 2.5 GW added per year
- Offshore wind: 6.5 GW added per year
- Solar PV: 2.5 GW added per year

Renewable electricity policies
- Renewable energy targets
- Feed-in-tariff/premium payment
- Tradeable renewable energy certificates
- Tendering (held in 2017)
- Reductions in sales, energy, CO_2, VAT or other taxes
- Public investment loans, grants, capital subsidies, or rebates

[1] *Compared to the total generation capacity*

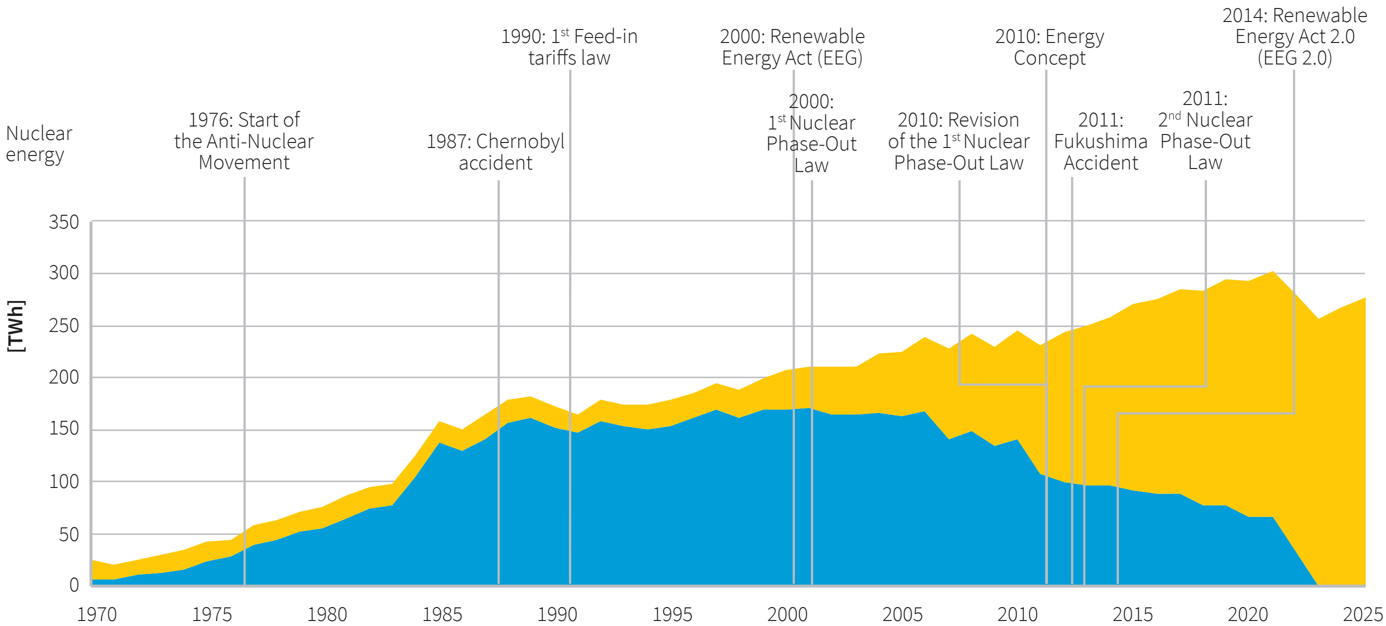
Sources: (Agora Energiewende, 2015b; IEA, 2017a, 2017b; IRENA, 2018b; REN21, 2018, p. 21; Sandia Corporation, 2018)

Germany achieved a fundamental transformation of its energy system through a long-term policy intervention, market design and citizen participation process. This fundamental transformation, which served as an example for several other countries in Europe and beyond, has been labelled as the *Energiewende.* The aim of Energiewende is to transform Germany's energy system based on renewable energy and energy efficiency. Future grid, markets, and system integration as well as support for energy sector R&D are Energiewende's other important focuses. The energy transition is also a programme to reduce Germany's need to import large amounts of fossil fuels. Fossil fuel import costs currently represent around 3% of Germany's gross national product, and would be even higher without the Energiewende.

In 2017, renewable electricity generation hit a new record high at 218 TWh, up from 38 TWh in 2000 (AG Energiebilanzen eV, 2018). This growth is based on Germany's attempt to harness the full spectrum of its domestically available renewable energy sources, instead of focusing on the cheapest technologies only. Renewable energy sources include solar, on- and offshore wind, biogas, biomass, hydro, and even geothermal. The objectives behind this approach are manifold, including encouraging further diversification of the energy mix, making better use of existing waste streams, developing knowledge in new areas of technology, and fostering job creation.

The most substantial increase of renewables came from the rapid expansion of wind farms and solar PV in the past 15 years, which now cover 36% of the total electricity consumption-a noteworthy achievement in the world's fourth largest economy (Reed, 2017). The projections for 2025 estimate that renewables-based electricity generation will exceed 250 TWh per year (see Figure 5), with future growth to come almost exclusively from on/offshore wind and solar PV.

Figure 5: *Nuclear and renewable electricity generation and major political events, 1970-2025*



Source: (Agora Energiewende, 2015c)

Electricity generation from renewables was on par with nuclear in 2010/2011 and since then has outpaced it.

Long-term energy planning and existing policy framework

Germany's energy transition emphasises governments' critical role in developing the secure, long-term policy frameworks that are necessary for private sector and civil society investment. Since the 1990s, various regulatory tools promoting the expansion of renewable energy in Germany are implemented. Most notable of these is the Erneuerbare Energien Gesetz (Renewable Energy Act, EEG), introduced in 2000. The EEG guarantees reliable investment conditions to renewable electricity producers.

A national consensus around both energy efficiency and renewable energy was built over the transition period, based on the ownership of energy transition by small and medium-sized enterprises (SMEs) and citizens. Feed-in-tariffs have driven small and large scale investments, such that over 1.65 million solar installations and 30,000 wind turbines are operating country-wide. Many of these investments are solar PV rooftop installations on privately owned houses, or wind farms developed an owned by local cooperatives (Appunn and Russell, 2015).

This rapid transformation of the energy sector was particularly boosted by hundreds of thousands of small "prosumers" emerging in the energy market. Prosumers both consume electricity from the grid and also feed electricity into the grid. This also meant major transmission hurdles for and new challenges introduced to the traditional grid, as it was designed to carry power from large plants to industries and consumers. In order to cope with these new dynamics the system should be updated, incorporating investment in smart meters, local substations, and better grid management software - a challenge countries that start with their energy transition should anticipate and plan for (Appunn and Russell, 2015). Germany also has far more favourable renewable energy conditions for wind power, which is the dominant source of renewables, in the north. In contrast to solar power, which is largely consumed near where it is produced, wind power often needs to be transported from the north of Germany to energy demand centres in the south. The challenge of strengthening the transmission capacity from the north to population and load centres in the west and south has resulted in fierce resistance against transmission system operators from local communities in densely populated regions of central Germany. Thus, this process has also tested the political and technical capacity of German federal and state governments (Appunn and Russell, 2015). As a result, making sure that the build-up of renewables is well aligned with the availability of sufficient grid capacity emerged as one of the key issues in Germany.

Another remarkable feature of the Energiewende is its success in attempting to harness the full spectrum of Germany's locally available renewable energy sources, including solar, wind, biomass, hydro, and even geothermal. Unlike many other countries that have focused on harnessing their best resources first, Germany took a comprehensive approach. The objectives behind this are manifold, such as energy supply diversification, better utilisation of waste streams, knowledge development in new technology areas, and job creation.

Despite the success in building up wind and solar, Germany is currently falling behind on its own 2020 and 2030 targets for GHG emission reductions. So far, the growth of renewables has mainly filled the gap that has resulted from phasing out nuclear power. Despite the share of coal having declined significantly since reunification in 1990, coal continues to represent approximately 40% of the country's electricity mix. The annual improvements in energy efficiency in buildings (i.e., energy renovation rates) are still half of the 2% target. Electric vehicle growth is falling short of government targets (1 million EVs by 2020), and the use of biofuels will continue to be limited for sustainability concerns. For the manufacturing industry, there is still no specific market framework in place to more steeply reduce the sector's emissions. With uneven distribution of taxes, surcharges, and levies among the power, heating, and transport sectors, there is limited incentive for the heating and transport sectors to shift appliances to the lower emissions power sector and effectively carry forward sector coupling (Reed, 2017).

As a step forward, the new governing coalition has committed to phasing out coal power, meeting emissions reduction goals in line with the Paris Agreement, and pledging action on transport and heating sectors (Amelang et al., 2018). This next phase of the energy transition will focus on the integration of sectoral policies in order to establish a consistent strategy for an efficient decarbonisation of the power, transport, and heating sectors. It will also focus on overcoming the mismatch in the various currently available sectoral incentives. (Agora Energiewende, 2017a).

Existing policy instruments and costs of renewables

For more than a decade FiTs and later FiPs provided an attractive environment for investment in renewables. Germany has been funding renewable energy development through a consumer surcharge. A consumer surcharge is based on the difference between the remuneration rate guaranteed to the project developer and the wholesale market prices.

This reliable policy framework, which focuses on taking away offtake risks from investors by providing a purchase guarantee and priority grid access, has been effective in bringing down the cost of wind and solar power by 50–90% in just a decade. Today, wind and solar power are the cheapest options for new electricity generation (Kost et al., 2018). Wholesale market prices have also been falling in recent years, partly due to thermal generation overcapacity and the rapid growth in renewables.

Since substantial exemptions are given to more than 2,300 electricity-intensive companies that compete internationally (they pay only about 2% of the surcharge although they use about 25% of Germany's electricity and therefore industrial energy prices remain one of the lowest in the EU), residential and small commercial customers pay the bulk of the support (IRENA, IEA, REN21, 2018). In 2017, the average power price on the exchange was 33 EUR per MWh, down from 54 EUR per MWh in 2011. The surcharge for private households rose to 68.8 EUR per MWh in 2017, but has gone down slightly to 67.9 EUR per MWh in 2018 (IRENA, IEA, REN21, 2018). German consumers will therefore continue to bear substantial surcharges for large numbers of wind, and especially solar PV projects that came online over the last 10–15 years, particularly when the FiTs offered were higher. Over the years, the EEG has been continuously modified. Each modification introduced a new set of rules stimulating innovation, aiming to accelerate technological development, speed up cost reduction, and improve the integration of electricity from renewables into grid and market (Agora Energiewende, 2017b). With the latest EEG rules, the mid- and long-term renewable energy targets are increased, most recently to cover 65% of power demand by 2030 (Amelang et al., 2018).

The FiTs, which are financed through consumer electricity bills, have put an extra burden on households, with residential electricity bills being almost twice as high as in France-40% above the EU average (Appunn and Russell, 2015). As an early adopter, Germany began developing renewables when they were still far more expensive than their conventional counterparts. In an attempt to keep up with technological cost reductions, the EEG was adjusted regularly to introduce annual, then quarterly, and eventually monthly adjustments to the FiT rates on offer. Despite these efforts, there were still time periods during which project developers were able to lock-in more generous FiTs before the scheduled reductions took place. This allowed investors during certain time periods to install cumulatively several GW of solar capacity at relatively high FiT levels.

After years of continuous increases in electricity prices for German households, these prices have been relatively stabilised since 2013. The primary reason for this stabilisation is the comparable costs of new renewable power plants and new conventional power plants, and the decreasing gap between FiT rates for renewables and real costs.

Since 2017, larger wind and solar power plant projects compete in auctions for grid access and long-term power purchase agreements, which has driven prices down to less than 50 EUR per MWh for solar PV and wind. In the first offshore wind auction in 2017, three of the four winning projects (1,380 MW out of the total 1,490 MW) offered a strike price of 0 EUR per MWh for projects to be delivered in 2024. These remarkable bids are a testament to how technology cost reductions have outstripped even the most optimistic market forecasts.

System integration measures

Germany's power system operators have been able to integrate more than 20% of variable solar and wind power while maintaining security of supply at world record levels (BNetzA, 2017).[7] Successful grid integration has been facilitated by a legacy of high-quality grid infrastructure and strong interconnections with neighbouring countries. It was further enabled through the development and deployment of numerous innovative technological and operational options as well as the adaptation of market designs and business models.

The market design has been developed to allow for short-term intraday trading very close to real time, thereby reducing imbalances as well as the burden to system operators. Many thermal power plants, mainly hard coal and lignite, have been overhauled, increasing their flexibility to be able to meet steeper ramp rates when solar or wind generation rapidly change. Germany's pioneering approach to developing specific grid code requirements and largely improved forecasting systems for both wind and solar energy generators have also helped operators to ensure system reliability.

Germany is ambitious about increasing the share of renewable energy further in its overall energy mix. In view of this target, its energy policy will focus on enabling flexibility measures like smart grids/metering; local coupling of electricity, heating, and transport sectors; and improving cross-border exchange and balancing of supply and demand.

[7] Unplanned power interruptions of Germany are 13–15 minutes annually, compared to 50 to 70 minutes in the United Kingdom, France, and Sweden.

Innovation in business and finance models

The Energiewende has driven an investment boom, encouraging growth and innovation in new low-carbon sectors, such as renewable energy, energy efficiency, new energy services, and alternative transport modes. Total renewable energy investment across all sectors, between 2000 and 2015, is estimated at 235 billion EUR. This corresponds to an average of 16 billion EUR annual investment. Investment in renewable energy has not only supported economic growth in Germany, but has also increased country's competitiveness in low-carbon technologies. Moreover, the Energiewende has had an essential impact on the employment structure in energy sector. In 2017, the renewable industry alone accounted for approximately 332,000 jobs, accounting for twice as many as in 2004 and roughly ten times more than in coal (Agora Energiewende, 2017c; Appunn, 2017; IRENA, 2018d).

Some sub-sectors of the electricity-intensive industry sectors are flexible in their production processes, thereby offering demand response potential. With widespread electrification of industrial processes and the increased use of renewables-based hydrogen, demand response will become a more prominent flexibility option (Energie Agentur NRW, 2016). An innovative company in Germany is focusing on the production of steel from renewable hydrogen that will also involve hydrogen storage in the process, which can provide services to the grid (HYBRIT, 2018).

Virtual power plants are integrating distributed generation units, storage plants, and energy consuming industrial plants to operate and provide grid balancing and other ancillary services similar to large-scale conventional power plants. An aluminium smelter in Germany used as a virtual battery delivers up to 1.12 GWh of flexible capacity (Deign, 2017). Similar designs on digital platforms are being developed to convert market players in various sizes to become utilities (Lumenaza, 2017).

Not only its positive outcomes, but also the challenges of the Energiewende are equally helpful for Turkey in developing its renewable energy policies: these include the relatively high cost burden of inflexible FiTs on consumers in the past, the shortcomings of CO_2 pricing policies such as oversupply of emission allowances that have resulted in only symbolic prices for many years (an issue which was present in other EU member states as well), insufficient grid capacity for transmitting wind produced in the north to the consumers in the south, and difficulties in implementing renewable energy and energy efficiency measures in sectors outside of electricity generation, such as transport and buildings.

Energy planning	Long-term energy/climate strategy planning
System integration and enabling technologies	Transmission planning, ensuring a strong grid Grid operation improvements (grid codes, forecasting, direct control of renewable energy plants) Sector coupling and other strategies to integrate higher shares of wind and solar
Policy instruments and costs of renewables	Shift towards market-based mechanisms to support renewables Electricity market design Large share of private individuals, farmers, project firms, and other small participants owning renewable power capacity Environmental and socio-economic benefits
Innovation in business and finance models	Various business models to integrate distributed generation to the system in a more efficient and affordable way Policies that stimulate technological innovation by taking into account price developments

Italy

Quick energy and climate facts		
Total primary energy supply	[Mtoe/yr]	153
Electricity generation	[TWh/yr]	282
Electricity consumption	[TWh/yr]	288
Per capita total primary energy supply	[toe/cap]	2.5
Per capita electricity consumption	[kWh/cap]	5,099
Per capita CO_2 emissions	[t CO_2/cap]	5.5

Renewable electricity generation		
Renewable electricity share in total generation	[%]	38.7
Variable renewable electricity share in total generation	[%]	13.3
Variable renewable elecricity capacity add. (2010-2015)	[%]	3.1
Total renewable electricity capacity	[MW]	50,408
Total variable renewable electricity capacity	[MW]	28,035

Power system		
Interconnector capacity with neighbours	[MW]	9,925
Electricity storage capacity	[MW]	7,133.2
Electricity share in total final energy consumption	[%]	22.0

Renewable electricity targets
- 17% renewable energy share in total final energy consumption by 2020
- 26% renewable electricity share in total generation by 2020
- Bio-power: 19,780 GWh/year from 2.8 GW by 2020
- Geothermal power: 6,759 GWh/year from 920 MW by 2020
- Hydropower: 42,000 GWh/year from 17.8 GW by 2020
- Solar PV: 23 GW in 2017
- Onshore wind: 18,000 GWh/year from 12 GW by 2020
- Offshore wind: 2,000 GWh/year from 680 MW by 2020

Renewable electricity policies
- Renewable energy targets
- Feed-in-tariff/premium payment
- Net metering
- Tendering
- Investment or production tax credits
- Reductions in sales, energy, CO_2, VAT or other taxes
- Public investment loans, grants, capital subsidies, or rebates

[1] Compared to the total generation capacity

Sources: (ENTSO-E, 2016; IEA, 2017a, 2017b; IRENA, 2018c; Ministero Dello Sviluppo Economico and Ministero Dell'ambiente, 2018; REN21, 2018, p. 21; Sandia Corporation, 2018)

Italy is the EU's second largest industrial producer after Germany and the fourth largest energy consumer following Germany, France, and the United Kingdom. It is a leading country in renewables and energy efficiency although its progress has not drawn nearly as much attention as its European partners to the north.

Italy has already reached its 2020 renewable energy targets and stands as the second largest producer of renewables in the EU after Germany (EC, 2017). This is partly the result of a strong historical hydropower and geothermal basis: already in 1990, Italy had 19 GW of hydropower capacity (Terna, 2017a). The main reason, however, is the dramatic growth of renewables during the last decade, from around a 16% share in the years 2005–2007 to 34% of consumption by 2015–2016 (GSE, 2018a). From 1990 to 2018, hydropower capacity grew moderately from 19 GW to 22 GW (Terna, 2017a) (Terna, 2018a). In the same timeframe, geothermal capacity nearly doubled to 6.2 GW in 2015 (Terna, 2017a). Solar PV and wind capacities grew from a very low base to 20 GW and 10 GW, respectively (Terna, 2018a). In 2016, total electricity demand was supplied from 14% hydro, 7% solar PV, 5.6% bioenergy, 5.5% wind, and nearly 2% geothermal (Qualenergia, 2018). In April 2018, solar PV alone covered 10% of the total power demand (Bellini, 2018a). In the heating sector, renewables' share grew from 10% in 2006 to 19% in the years 2014–2016. In the transport sector, it grew from 1% in the years 2005–2007 to 7% in 2016 (GSE, 2018a).

In the ACEEE's International Energy Efficiency Scorecard 2018, Italy tied for first place with Germany. This publication by an US-based non-governmental organisation (NGO) "examines the efficiency policies and performance of 25 of the world's top energy-consuming countries" considering the level of national policy efforts in three main sectors: buildings, industry, and transport. Turkey ranked 16th in this study, just behind Poland and India but ahead of Indonesia and Australia (ACEE, 2018). Italy's energy efficiency success is partly a result of dedicated policies such as the White Certificate scheme and high end consumer energy prices, mainly due to high levels of taxes and levies.

Italy's energy mix is very dependent on gas, most of which comes from unstable regions in North Africa, especially Libya, and from Russia, with a historical background of tensions with the EU. Italy was the first country in the world that phased out its (small) active nuclear power fleet, following a referendum in 1987. Within the first decade of the 21st century, the government adopted a plan to reintroduce nuclear, with a massive investment plan for 10 GW by 2025. However, a second referendum in June 2011 resulted in a 95% majority against nuclear. Nuclear is no longer on the agenda.

The main drivers for the energy transition in Italy are its very high dependency on fossil fuel imports, high energy prices for end users, and a constant commitment to climate change mitigation and environmental protection.

The broad awareness of climate risks is also linked to Italy's specific vulnerability to climate change, including increasingly frequent floods and droughts, a widespread risk of landslides, extended coastal areas endangered by rising sea levels, and the recent spreading of tropical diseases. Moreover, there are growing concerns about the human health impacts of urban air pollution. The strong tourism industry appreciates high environmental quality and can be particularly affected by climate change.

For all these reasons, the broad support for climate policies has withstood several changes in government, though with different levels of commitment. The country has already shown how it can utilise its renewable resources with strong technological and innovative capabilities across manufacturing, agri-food, electric, and co-generation technologies.

Long-term energy planning and existing policy framework

In May 2017, Italy released its new National Energy Strategy (NES) for 2030, which followed its 2013 predecessor. It includes a phase out of the remaining 8 GW of coal generation capacity by 2025. The renewable share in total energy consumption should grow from 17.5% in 2015 to 28% in 2030, while business as usual (BAU) would lead to a share of only 22%. In the electricity sector, renewables' share should grow from 34% in 2016 to 55% in 2030 (BAU: 38%). Total energy consumption should be 9% lower than BAU. The NES also announced an investment plan of 175 billion EUR. This is split into 110 billion EUR in energy efficiency, 35 billion EUR in renewables, and 30 billion EUR in energy infrastructure, including electrical grids, gas and LNG infrastructure, and some district heating (Ministero Dello Sviluppo Economico, 201; ArgusMedia, 2017; Ministero Dello Sviluppo Economico and Ministero Dell'ambiente, 2018). Another high priority is diversifying gas access through new gas pipelines through the Mediterranean.

Among the largest electricity utilities worldwide, independent observers consider Enel-Italy's largest electricity company, which remains 25% government-owned-to be a global pioneer in renewables (IEEFA, 2017a). Within a decade Enel transformed itself from a formerly state-owned, largely nuclear and fossil fuel-focused company to one of the leading global renewable energy companies. Its early adoption of the energy transition not only helped Enel outperform other major European utilities, it also strongly contributed to opening the debate about the country's energy future. Enel operates 36 GW of renewable energy capacity worldwide and it plans to cut fossil fuel-based generation capacity by 39% by 2019 in a campaign to reduce stranded-asset risk (IEEFA, 2017a). In March 2015, Enel committed to phase out coal and become a carbon neutral company by 2050 (Littlecout, 2017). Enel is the owner of seven of the 11 last coal power plants in Italy. It endorses Italy's coal phase out by 2025.

Existing policy instruments and costs of renewables

Within the EU's power market regulatory framework, Italy has unbundled generation, grid operation, and retail. Since 2015, Italy's competitive wholesale spot electricity market is coupled with France, Austria, and Slovenia and thus part of the Multi-Regional Coupling covering 19 European countries (EPEX SPOT, 2018). Italy also has physical connections with Switzerland, Greece, and Malta. The retail market is liberalised, with a level of concentration slightly higher than the European average (CEER, 2018a). The average electricity price for household consumers in 2017 was 210 EUR per MWh, slightly above the EU average (Eurostat, 2018), and down from 240 EUR per MWh in the years 2014-2016 (Statista, 2018). The electricity prices for non-household consumers in Italy are close to the EU average before tax. However, after levies and taxes it is the second highest in Europe after Germany (Eurostat 2018). Like in Germany, Italy's heavy electricity consumers benefit from several tax exemptions (Selectra, 2018).

In this fairly stable overall context, the framework for renewable electricity deployment in Italy underwent several major changes during the last decade. There has been a complex interaction between the rapid developments of the policy instruments, ongoing declines in the investment costs for renewable energy technologies, as well as substantial changes in market conditions (such as costs of capital, permitting procedures, social acceptance, and power grid constraints in certain regions).

More than 15 of the 20 GW of solar PV in operation in Italy in 2018 (Terna 2018) have been installed in less than three years, between 2010 and 2012 (GSE, 2016). To a large extent these were installed in the form of large-scale ground mounted plants. At this time, solar PV in Italy was supported by an overly generous, uncapped FiT system. Similar to the case of Germany in those years, the demand for solar PV in Italy gave a decisive impulse for the creation of large-scale PV manufacturing capacities at the global level, which triggered the economies of scale leading to massive cost reductions during the following years. However, energy policy makers in Italy reacted too slowly to the new conditions. For a short but intense period, very high profit margins could be earned on the Italian PV market. This put further upward pressure on electricity bills, although it is noteworthy that the total cost of renewables support started decreasing recently.

For medium- and large-scale solar PV systems, the FiT system was phased out in 2013 for several reasons. First, the excessive costs paid by Italian consumers under the previous regime were untenable. Second, the impact of the economic crisis had significantly reduced power consumption as well as the preparedness of voters to invest in renewable energy. Finally, time was needed to adapt the transmission and the distribution grids as well as the power market design to the massive increase of variable renewable generation.

After the phase out of the FiT, the Italian solar PV market shrank, with only 1.1 GW newly installed between 2013 and 2016. This has started changing again recently, as investors announced a pipeline of 500 MW of unsubsidised large-scale PV projects (Bellini, 2018a), of which at least 116 MW have already been fully refinanced, according to the developer (PV Magazine, 2018). The trend towards large-scale unsubsidised PV is favoured by the strong decrease of the costs of PV equipment, by the currently extremely low capital costs, by an increasing demand for power purchase agreements based on emission-free electricity, and by the positive prospects of reselling the developed projects to generating companies (Energieoltre, 2018). Nevertheless, currently the main driver of the Italian PV market remains the rooftop sector in residential and commercial buildings, which is driven in part by rising retail prices, the country's net metering policy, along with continued reductions in solar PV technology costs (Bellini, 2018b).

Although less extreme, the wind sector was also characterised by strong growth from 2006 (1.9 GW capacity in operation) to 2012 (8.1 GW), followed by much slower growth afterwards, leading to 9.4 GW capacity in operation in 2016. Nearly 90% of the wind capacities in operation in May 2017 were installed before 2013 under the previous tradable certificates support scheme, which was replaced by an auction system with a law approved in 2012. Unclear rules concerning the amounts to be auctioned led to legal actions and uncertainty at the beginning of the first phase. A new law was approved in 2016 (GSE, 2017)

Table 1: *Results of onshore wind auctions in Italy*

	Available	Bids	Awarded	Operating	Developing	Excluded	Strike price
	In MW			In MW (as of 30 June 2017)			EUR/MWh
Auction 2012	500	442	442	324	30	64	124
Auction 2013	465	1086	465	400	65	0	115
Auction 2014	368	1261	368	311	47	10	93
Auction 2016	800	1972	800	10	790	0	66

Source: (GSE, 2017)

All these auctions had a pay-as-bid system. The price indicated in Table 1 is the highest of those awarded. Most bids were awarded a (much) lower feed-in premium. In the last auction, all awarded projects bid the minimum price allowed by the auction, 66 EUR per MWh.

Notwithstanding the strong price decreases, the clearing prices of onshore wind auctions in Italy are still significantly higher than in many other countries (IRENA, 2017a). There are several reasons for this. First, the prevailing wind capacity factors in Italy (GSE, 2017) are significantly lower than in many European countries, even more if compared with the best wind resources in other continents (IRENA, 2017a). Large parts of the country, especially in the north, have virtually no usable wind resources, and most of the good resources are concentrated in mountain areas or coastal regions with high standards of environmental and landscape protection, thus making it difficult to obtain permits. In addition, many areas of Italy are subject to a high risk of landslides and earthquake (BWE, 2014). Moreover, the costs for land as well as the costs and uncertainties linked to permitting procedure increase the costs in comparison with some other countries.

Last but not least, the cost of capital is a crucial cost factor for both wind and solar energy projects. Due to higher perceived country risks the capital costs in Italy are significantly higher than, for instance, in Germany. A recent analysis undertaken for financing costs across the EU shows a weighted average cost of capital for wind power projects in Italy between 7–9%, while the range in Germany is between 3.5–4.5% (DiaCore, 2016). These higher risks are related, for instance, to the lengthy and complex permitting procedures, extremely slow justice systems, political instability, and in the case of PV, to the frequency of theft (Codegoni, 2016; Montrella, 2017), which led some insurance companies to refuse insuring of ground-mounted solar PV systems in Italy (for instance, see (SolarWatt, 2018)), while other companies increased their premiums.

In recent years, there has been a considerable boom of small wind energy plants in Italy. Of the 8.76 GW in operation in June 2017, around 4% (350 MW) are systems below 1 MW, half of which are below 200 kW. These systems are not supported by auctions but by a FiT (system up to 200 kW) or FiP (up to 10 MW) with prices defined by the government. In this case, the costs of support are higher than the European average (GSE, 2017).

All of the above refers to onshore wind only. The Italian offshore wind resources are much smaller and economically less favourable than those in the North Sea or the

Baltic Sea. In 2016, a separate auction dedicated only to offshore wind resulted in a 30 MW project winning with a bid price of 169.8 USD per MWh. However, based on recent offshore wind results in the North Sea and elsewhere, which have seen prices fall by more than half, it is likely that offshore projects in Italy will become competitive in the years ahead (offshoreWIND.biz, 2018).

For the period 2018–2020, the government has announced combined wind and solar auctions for a total of 4.8 GW with ceiling prices ranging between 70 EUR and 110 EUR per MWh depending on project size (Bellini, 2018c).

System integration measures

In 2017, variable renewables reached a combined share of 13.3% of the total electricity demand in Italy (Qualenergia, 2018). In 2016, Italy had the seventh highest share of variable generation globally. During the years of strong variable renewables growth, Italy could slightly improve its performance in terms of the unplanned System Average Interruption Duration Index (SAIDI). According to this benchmark, Italy is currently ranked 7th of the 28 European countries monitored by the Council of European Energy Regulators (CEER, 2018b).

This is particularly remarkable, as the wind resources and capacities are concentrated almost exclusively in southern Italy, far away from the main centres of demand in the north, where most hydropower capacities are located. While solar PV capacities are more geographically dispersed than wind, they remain regionally concentrated: 20% of total PV capacities are concentrated in two of Italy's 20 regions, Apulia and Sicily (GSE, 2018b). The rise of variable renewables has created new challenges for the transmission grid, especially in the connection between the south and the north and between the east and the west coast of the peninsula (Terna, 2015). The transmission grid operator Terna reacted with an ambitious grid development plan, including the strengthening of cross-border capacities and an additional undersea connection with the western Balkans via Montenegro.

The system integration of variable renewables has been facilitated by the fact that the Italian wholesale electricity market is divided in six price zones. Smaller price zones enable flexibility sources to react according to the needs of the grid region where they are located, reducing the costs of redispatch in comparison with countries with single price zones, like Germany. For instance, consider one hour of high wind and solar generation in Southern Italy: the transmission lines might be congested and therefore unable to transport all power to the demand centres in the north. In this case, the wholesale electricity price in the southern price zones decreases, triggering less production from flexible (gas) power plants and/or an increased demand from responsive demand in the south, thereby helping to manage the transmission bottleneck. In the northern price zones on the other side of the bottleneck, the wholesale price increases, triggering additional generation or reduced demand from responsive loads. In the long term, smaller price zones provide incentives to place new generation or flexibility sources in the regions where they are needed more. If Italy would have a single price zone like Germany, it would need more frequent redispatching, leading to significant high integration costs.

In view of managing the grid congestions caused by the rapidly increasing variable renewable generation peaks, the Italian transmission grid operator Terna has been a pioneer in the deployment of large-scale power storage projects dedicated to grid management and is further developing this field (Terna, 2018b).

Innovation in business and finance models

Since Luigi Galvani and Alessandro Volta's foundation work on electric science in the 18th and early 19th century and the opening of the first power plant in continental Europe in Milan in 1883, Italy has been driving innovation in the electric sector.

Italy's TSO Terna recently accelerated its R&D efforts to meet the challenges and opportunities created by the energy transition. The focus is on transmission technologies, innovative technologies for the management of the electricity system, and the interactions between a TSO with smart grid and storage (Terna, 2018c). For example, some of the pilot projects pursued by Terna focus on enabling the participation of additional demand and generation resources in the balancing markets; testing the aggregation of electricity storage, demand response, and flexible generation for the purpose of redispatching; and testing forms of remuneration of ancillary services that were so far remunerated only implicitly, with the purpose of a more granular procurement of ancillary services to support the participation of variable renewables in this market (Terna, 2017b).

Enel is also heavily investing in innovation. Some of their flagship projects are Enel Green Power's high efficiency bifacial PV modules; the Wind Big Data Boost Project, which is applying the most advanced data analysis to more than 4,000 wind turbines at the global level; applying artificial intelligence tools to improve wind energy production forecasts; testing advanced IT solutions to operate the 828 MW PV plant Villanueva in Mexico (the largest PV plant in the Americas, to start operation in late 2018), which includes over 380,000 automated trackers tilting the panels as they follow the sun's path to maximize their efficiency. Enel also runs R&D programmes on-among others-ocean energy, advanced biofuels, big data for hydropower, and the use of drones to monitor wind, solar, and hydro power plants (Enel Green Power, 2018).

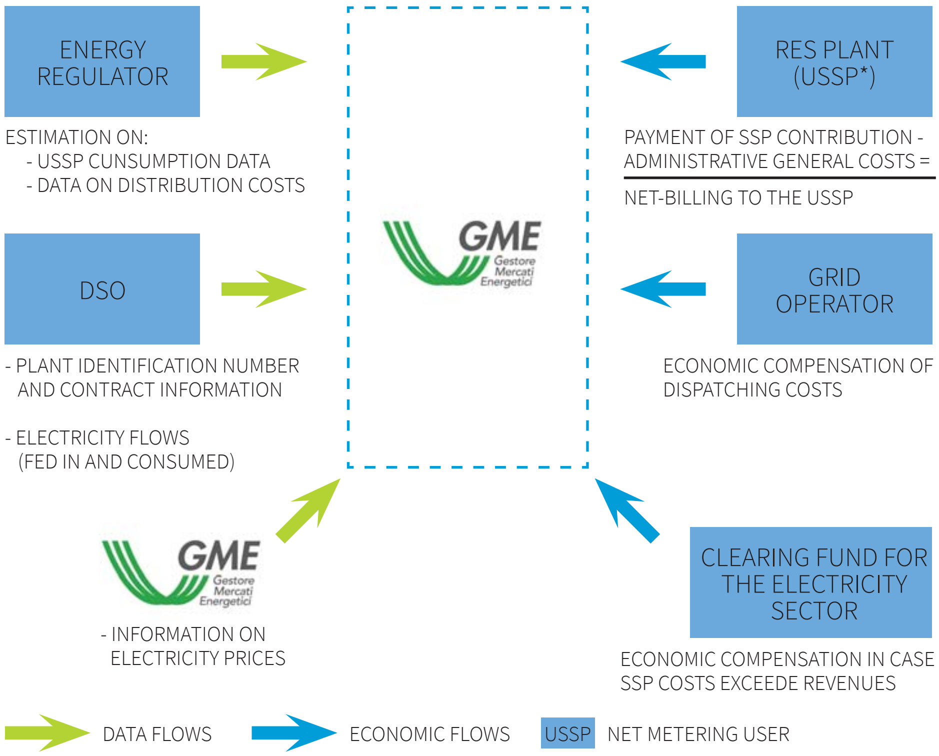
Prysmian Group, which works on energy and telecom cables, spends circa 100 million USD annually in R&D. The firm is constantly developing new technologies to improve the performance and reduce the costs of production and installing onshore and subsea high voltage AC and DC cables, as well as for a range of other products, many of which are related to the energy transition such as inter-array cable systems for offshore wind farms.

At a smaller industrial scale, some of Italy's strong electric and mechanical medium-sized industries are catching up on the national delay on wind energy manufacturing. Recently, some Italian companies such as Leitner-a global leader in ropeways and ski transport-and Tozzi Nord have developed innovative small and (<200 kW) and medium (200 kW to 1 MW) wind turbines products with potential for global deployment. Moreover, Italy has unique regulatory experience with smart meters, which has been ongoing for more than fifteen years. Nearly all consumers have smart meters installed that provide benefits across the entire power sector value chain, including new actors: securing revenues (including reducing electricity theft), raising efficiency, enabling a switch to new tariff mechanisms by coupling energy measurements with time information, allowing pro-competitive features, and making loads and generators more flexible (Piti et al., 2016). Building on this experience, Enel alone is planning to replace 16 million meters with second generation ones in order to improve the application of time-of-use tariffs, activate more demand-side options, and facilitate network planning and operation (Gallo, 2017).

Figure 6 below provides an overview of Italy's net metering scheme, in particular how different actors are involved and how customers (top right) are compensated for their net excess generation by the Gestore dei Servizi Energetici (GSE) fund. The GSE fund itself manages ten different incentives schemes for renewable energy and energy efficiency, allocating approximately 15 billion EUR per year to qualifying projects, including rooftop solar projects (GSE, n.d.).

Italy's net-metering scheme functions as a service for virtual energy storage. Customers can use the grid as a battery and be compensated for the net excess generation they provide.

Figure 6: *Main actors involved in Italy's net-metering scheme*



Source: (Toxiri, 2014)

Energy planning	NES foresees coal phase out by 2025, 55% renewables share on power demand by 2030, and 28% renewables on total energy demand by 2030 Main electricity company committed to phasing out coal and shifting to renewables
System integration and enabling technologies	Global frontrunner in system integration of variable renewables; steep increase of wind and solar generation managed without impact on the high standards of supply security Distribution and transmission grids expanded within the country as well as on its borders; market design and grid operation adapted
Policy instruments and costs of renewables	FiT, FiP, and auctions Current auctions for large-scale and FiP with net-metering scheme for rooftop systems Wind energy costs higher than in other countries Solar PV costs high in past; current support scheme much less generous, with large-scale unsubsidised solar PV systems in the pipeline
Innovation in business and finance models	Innovation and manufacturing strength Net-metering scheme

Spain

Quick energy and climate facts		
Total primary energy supply	[Mtoe/yr]	119
Electricity generation	[TWh/yr]	278
Electricity consumption	[TWh/yr]	232
Per capita total primary energy supply	[toe/cap]	2.6
Per capita electricity consumption	[kWh/cap]	5,481
Per capita CO_2 emissions	[t CO_2/cap]	5.3

Renewable electricity generation		
Renewable electricity share in total generation	[%]	34.9
Variable renewable electricity share in total generation	[%]	20,7
Variable renewable elecricity capacity add. (2010-2015)	[%]	0.8
Total renewable electricity capacity	[MW]	47,890
Total variable renewable electricity capacity	[MW]	30,099

Power system		
Interconnector capacity with neighbours	[MW]	5,300
Electricity storage capacity	[MW]	8,126.8
Electricity share in total final energy consumption	[%]	26.4

Renewable electricity targets
- 20.8% renewable energy share in total final energy consumption by 2020
- 38.1% of enewable electricity share in total generation by 2020
- Bioenergy: 0.1% of final energy by 2020
- Geothermal, ocean, heat pumps: 5.8% of final energy by 2020
- Hydropower: 2.9% of final energy by 2020
- Solar PV: 3% of final energy by 2020
- Wind: 6.3% of final energy by 2020
- 38.1% renewable electricity share in total generation by 2020
- Bio-power: 2 GW, geothermal: 50 MW, hydro: 13.9 GW, pumped storage: 8.8 GW, ocean: 100 MW, solar PV: 7.3 GW, CSP: 4.8 GW, onshore wind: 35 GW, offshore wind 750 MW by 2020

Renewable electricity policies
- Renewable energy targets
- Tradable renewable energy certificates
- Tendering (held in 2017)
- Investment or production tax credits
- Energy production payment
- Public investment loans, grants, capital subsidies, or rebates

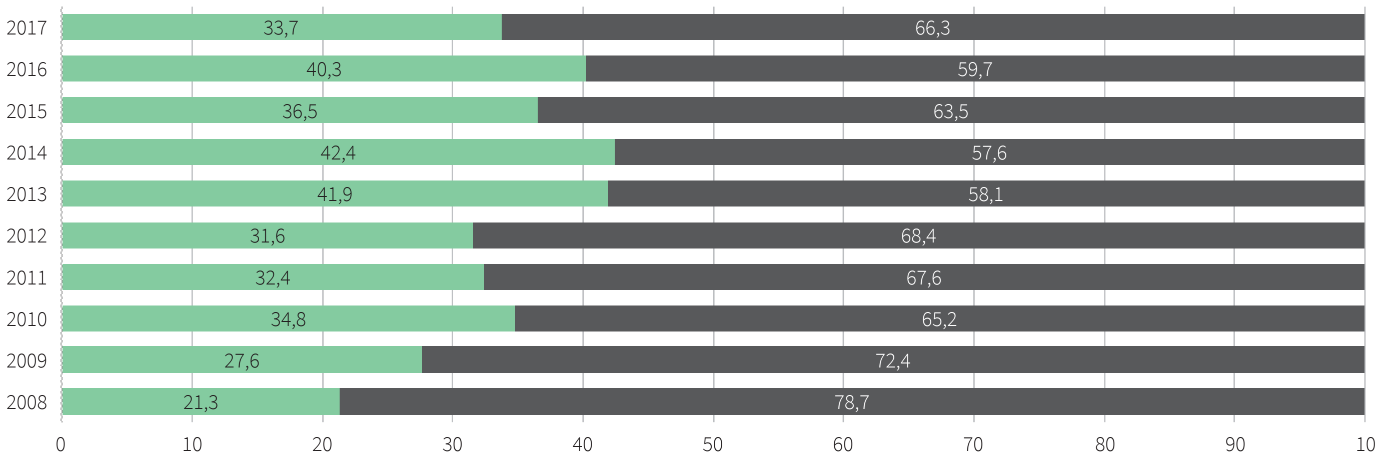
[1] *Compared to the total generation capacity*

Sources: (IEA, 2017a, 2017b; IRENA, 2018b; Red Eléctrica de España, 2017; REN21, 2018, p. 21; Sandia Corporation, 2018)

Spain is the world's leader in concentrated solar power (CSP) installed capacity and the fourth largest country worldwide with respect to wind electricity generation. Spain is a pioneer in advancing the development of renewable energy. The share of variable renewable energy in Spain's total electricity generation reached 20.5% in 2017. This included 18% wind and 2% solar PV. When 3% CSP is also included this share increases to 23.5%.

The share of renewables, including from sources other than sun and wind, is steadily increasing. In 2014, renewable energy sources generated 42.4% of the total annual electricity demand. In March 2018, 56.6% of the country's electricity was generated from renewable energy sources. On 25 March 2015, Spain's wind energy supply peaked at 46.9% of the power consumed on that day. The success of this growth can be attributed to a comprehensive set of support scheme mechanisms that were implemented at the right time and adapted to the rapidly changing conditions of the renewable energy markets. However, despite this success, Spain's policies towards renewables have also slowed its efforts. Spain attracted much international attention in 2012 following changes in its renewable energy policy, which subsequently stopped all project developments. While recently three auctions have taken place, it is still too early to assess the effects of the latest stop-and-go policy approach implemented in Spain.

Figure 7: *Annual share of electricity from renewables in Spain, 2008–2017*



Renewables: hydro, wind, solar photovoltaic, solar thermal, other renewables and renewable waste.

Non-renewables: pumped-storage hydro, nuclear, coal, fuel/gas, combined cycle, cogeneration and non-renewable waste.

Source: (RED, 2017)

Long-term energy planning and existing policy framework

Spain's power system has one of the world's highest shares of wind power and solar power, representing about one-quarter of the total electricity output.

A long-term planning strategy document for the whole energy sector is, to some extent, absent. The main planning instrument for renewable energy is the Renewable Energy Plan (REP) 2011–2020 (IDAE, 2011) approved in November 2011. It seeks to incorporate the provisions of the European Directive, with the objectives indicated in the REP 2011–2020 demanding a 20.8% share of energy generated from renewable sources in gross final energy consumption. For each sector, there are also specific, indicative targets for renewables' energy share: 39% of electricity gross consumption; 18.9% of heat consumption; 11.3% of energy for transport demand. It must be noted that the REP is the third National Renewable Energy Plan after those adopted in 1999 (IDAE, 2009) and 2005 (IDAE, 2005), both with the horizon 2010.

The Spanish Government has also already approved four National Action Plans for the promotion of energy efficiency, with the plans for the periods 2005–2007 and 2008–2012 already concluded. At present, the government is enforcing the National Energy Saving Action Plan 2017–2020, which is an updated version of the previous 2011–2020 plan, to accommodate all mandatory requirements from European legislation (Gobierno de España, 2017). Spain has also enacted a national strategy to develop electric mobility (MINCETUR, 2010) as well as a five-year electricity transmission development plan. One of the six key principles of the electric mobility plan is to improve the integration of variable renewable energy sources (MINCETUR, 2015).

For the future, to ensure full compliance with the EU's 2030 energy and climate targets, national objectives and policies need to be aligned with EU goals; at the same time countries should maintain the flexibility to adapt to local conditions and needs. This requires countries to develop Integrated National Energy and Climate Plans for the period 2021 to 2030. Detailed plans are due by the end of 2018. The government has expressed its willingness to approve the Law on Climate Change and Energy Transition before 2020.

Existing policy frameworks and costs of renewables

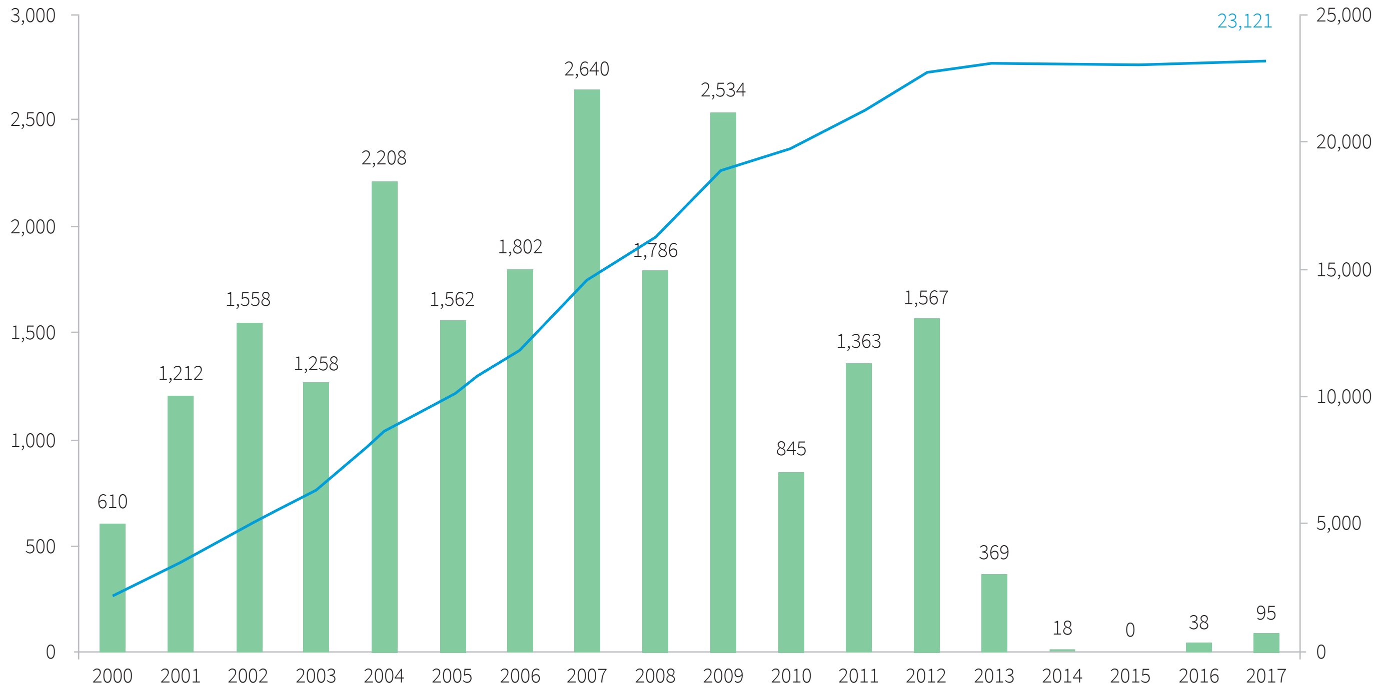
As a green energy pioneer, renewables support schemes in Spain have evolved alongside the degree of deployment of renewable energy markets, from higher and more secure support at the time of the sector's infancy to the current use of market mechanisms in its maturity.

The Royal Decree (RD) 2818/1998 proposed a fixed FiT for each renewable energy technology. In addition, it guaranteed access to the grid and priority dispatching. The RD 436/2004 forced renewables to integrate into the electricity market, changing the remuneration scheme: a premium on top of the incomes from selling the electricity to the wholesale market. To reflect the reduction of costs and to avoid windfall profits, the RD 661/2007 capped the remuneration (pool price + premium) establishing ceiling tariffs. Notably, this regulatory practice is very progressive in terms of the integration of renewables into the grid and the market and has introduced mandatory forecasting and the application of penalties in case of deviation (for projects over 10 MW).
The cost reduction of solar PV technology has been particularly drastic. This forced policy makers to implement a dynamic FiT system for solar PV in 2008. The RD 1578/2008 established the so-called capacity corridors. Each time a pre-approved amount of new solar PV capacity was reached, the tariff for the next projects was automatically reduced.

The latest support scheme adopted is fully market-oriented: renewable energy auctions. Since the first feed-in tariff decree, the right to connect has always been guaranteed for renewable energy projects. At present, renewable energy is granted with priority of dispatch over high efficiency combined heat and power or conventional generation, but only if it implies the same costs to solve congestions or keep the system in balance for the final consumers.

The tariff deficit is the difference between the cost of supplying the electricity and the incomes from the tariffs. The amount paid for electricity generated from renewables, compared with the average electricity price in the wholesale market, is one of the factors that increases the deficit of the tariff. This deficit is recovered by increasing the retail tariffs in subsequent years. It is estimated that the deficit of the tariff had reached 23 070 billion EUR at the end of 2016 (CNMC, 2017). The government, pursuing the main objective of reducing the deficit of the tariff, approved three regulations: RDL 1/2012 Premiums moratorium on new installations; Law 15/2012 Creation of new taxes to electricity generation; and finally, the Royal Decree Law (RDL) 9/2013 on urgent measures to guarantee financial stability in the electricity system, and its further legislative development, the RD 413/2014, which recalculates the FiT for all existing plants. These measures have almost led to a complete stop of the deployment of renewable energy in Spain in the last five years.

Figure 8: *Annual and cumulative installed wind capacity (in MW), 2000–2017*



Source: (APPA, 2017).

Annual wind capacity installations stopped in the past five years.

With the main objective of meeting the 2020 target, the government started a new support scheme based on auctions and annulled the moratorium. The inaugural auction round in 2016 requested 700 MW of capacity. 500 MW of this capacity was allocated towards wind and 200 MW towards biomass. Round two of the auctions (May 2017) was technology neutral (but limited to renewables). This round of auctions offered 3,000 MW capacity. Round three (July 2017) had specific demand for solar PV and onshore wind. It initial requested 3,000 MW but eventually awarded more than 5,000 MW. In general in Spanish auctions, the bid placed is for a wholesale electricity market price floor. It is estimated that the price floors have effectively been set by the rates achieved in the second (40 EUR per MWh) and third (28–32 EUR per MWh) auctions.

Another regulation was passed in 2015, the RD 900/2015, which established the conditions for distributed generation. This regulation mandates that any systems with an installed capacity over 100 kW will pay a fee to the distribution companies even if they may not feed electricity into their grid. This new fee for distributed generation increased the payback period for the system and makes it unattractive in most cases. This regulation has in fact served to limit the deployment of distributed generation in Spain. At present the Spanish government supports heating from renewable energy with grants and loans and through Energy Service Companies (ESCOs). The government supports these with technical assistance and marketing.

System integration measures

On the Iberian Peninsula, Spain and Portugal are well connected and operate under a combined market. However, the Iberian Peninsula has a low level of interconnection with the rest of Europe, and the peninsula's grid system can be considered as an isolated semi-island grid. Spain, and the transmission system operator Red Eléctrica de España (REE), is a pioneer in implementing solutions to integrate high shares of generation from variable renewable energy sources.

In the medium term, the main strategy to integrate variable renewables is to consider their benefit for new or reinforced transmission infrastructure in the five-year electricity transmission development plan.

Since 2006, all wind turbines, old and new, have been asked to comply with new technical operational procedures. Following this regulation, wind turbines must continue operations under grid disturbances, as a measure toward increasing stability. Since 2007, all renewable energy facilities larger than 10 MW in Spain must be connected to a control centre. The REE officially inaugurated the Control Centre for Renewables (CECRE) to supervise and communicate with all intermediate control centres in 2007.

Accurate forecasts are essential to adequately anticipate and provide daily reserves and to ensure demand coverage. Since 2007, all projects over 10 MW in size are mandated to forecast their generation and communicate it to the REE. REE relies on its own prediction software SIPREOLICO and contrasts it with the producers' programs used to forecast wind production.

The grid simulation program called GEMAS and used at REE can provide real-time stability assessment, simulating the possible failure of the system every 20 minutes and allowing the program to safely expand variable generation.

Spain's latest pioneering measure has been participation of renewable energy sources in balancing markets. Any facility that wishes to participate must pass the same prequalification tests designed for all technologies, without the need to have the ability to provide its full capacity at any time. Participation of variable renewable generation is currently significant in the tertiary reserve upward and downward market, with more than 6,700 MW of wind generation prequalified to participate and compete with conventional technologies (De la Torre, 2017).

Innovation in business and finance models

The adoption of renewables in Spain has followed the principles of technology push and market pull. Innovative market deployment policies have been complemented by continuous R&D efforts. Among the many initiatives, it is worth mentioning the creation of two centres of excellence, the Plataforma Solar de Almería (PSA) and the Centro Nacional de Energías Renovables (CENER).

The PSA emerged as a collaborative project of several countries in response to the oil crisis of the 1970s. The countries initially participating in the project were Germany, Austria, Belgium, the United States, Greece, Spain, Italy, Switzerland, and Sweden. The signing of the agreement took place in 1980. At present, PSA is a Public Research Centre, and it was formally considered as a European Large Scientific Installation by the European Commission. PSA is also the largest and most comprehensive R&D centre in the world which is dedicated to solar thermal concentrating systems. Its R&D activities focus on potential industrial applications of concentrating solar thermal energy and storage, and solar photochemistry. Currently, PSA has a large variety of experimental installations and laboratories for R&D activities related to solar thermal concentrating systems.

CENER develops applied research in renewable energy. Moreover it provides technological support to companies and energy institutions in six areas: wind, solar thermal and photovoltaic solar energy, biomass, smart and efficient buildings and districts, and grid integration of energy. CENER's activities cover the entire renewable energy generation process: resource assessment, simulation and design tools, generation technology, definition and performance of tests on complete systems and components, technological risk assessment, feasibility studies, and regulatory aspects.

Energy planning	Renewable energy and energy efficiency plans Renewable energy targets broader than the electricity sector Prioritising renewables Electric vehicle national strategy
System integration and enabling technologies	State of the art grid management Limited interconnection capacity Full integration of renewable energy in the market Renewable energy participating in the ancillary service market
Policy instruments and costs of renewables	Support schemes adapted to evolution of renewable energy from FiT to large auctions
Innovation in business and finance models	Excellence centres for R&D and renewable energy technology support.

Mexico

Quick energy and climate facts		
Total primary energy supply	[Mtoe/yr]	187
Electricity generation	[TWh/yr]	311
Electricity consumption	[TWh/yr]	257
Per capita total primary energy supply	[toe/cap]	1.6
Per capita electricity consumption	[kWh/cap]	2,230
Per capita CO_2 emissions	[t CO_2/cap]	3.7

Renewable electricity generation		
Renewable electricity share in total generation	[%]	15.4
Variable renewable electricity share in total generation	[%]	2.9
Variable renewable elecricity capacity add. (2010-2015)	[%]	0.8
Total renewable electricity capacity	[MW]	17,255
Total variable renewable electricity capacity	[MW]	3,444

Power system		
Interconnector capacity with neighbours	[MW]	901
Electricity storage capacity	[MW]	0.0
Electricity share in total final energy consumption	[%]	19.3

Renewable electricity targets
- 35% , 37.7% and 50% renewable energy share in total generation by 2024, 2030 and 2050, respectevily
- Renewable electricity generation capacity of 20 GW by 2030 of which 10 GW related to wind

Renewable electricity policies
- Renewable energy targets
- Net metering
- Tendering
- Investment or production tax credits
- Public investment loans, grants, capital subsidies, or rebates

[1] Compared to the total generation capacity

Source: (IEA, 2017a, 2017b; IRENA, 2018b; IRENA and SENER, 2015; REN21, 2018, p. 21; Sandia Corporation, 2018)

Mexico is a large country with significant resource potential for solar, wind, and geothermal. Currently, renewables represent 15% of its total electricity output. Much of this comes from hydropower and geothermal. The share of wind and solar PV is still low but is developing rapidly, increasing from 3.3% of the generation mix in 2016 to 4.6% in 2017 (Arcos, 2018; Fernandez, 2017). The government target is 35% electricity from "clean sources" by 2024 (Government of Mexico, 2017), which underlines that renewables will play a larger role in Mexico's energy mix in the coming decade. Mexico has already launched three successful rounds of competitive auctions, achieving close to record-low prices for solar PV and wind.

Long-term energy planning and existing policy framework

In recent years, Mexico has initiated a comprehensive reform of its three main energy sectors: oil, gas, and electricity. The objective of the reform was to end state-owned monopolies, Petróleos Mexicanos (PEMEX) in the hydrocarbon industry and the Federal Energy Commission (CFE) in the power sector, with the aim of modernising the energy sector through increased efficiency and productivity (IRENA and SENER, 2015). As part of these reforms, the Electricity Industry Law (LTE) was released in August 2014. The law provides a framework for clean energy, energy efficiency, and GHG emissions reductions. Moreover, it guarantees grid access and fair competition to all power market participants (except for a specific regime for nuclear), opening up competition in generation and supply to large customers. The wholesale electricity market became operative in 2016 with the newly established National Center for Energy Control (CENACE) overseeing market operation.

The primary objective of Mexico's 2016 "Transition Strategy to Promote the Use of Cleaner Technologies and Fuels", which followed the LTE, is to significantly increase the share of clean energy sources (including renewables, nuclear, and efficient cogeneration) in the power generation mix. The law sets a 35% clean energy target for 2024 (up from 20% in 2016). The 2018 edition of the main planning document, the Program for the Development of the National Electricity System (PRODESEN), foresees a scenario in which 14.8 GW of wind and 11.4 GW of solar PV capacity are to be added by 2032, representing almost 40% of a total of 66 GW to be additionally installed by that year (SENER, 2018). These clean energy generation goals are complemented by ambitious energy intensity improvement targets of 1.9% per year for until 2030 and 3.7% between 2030 and 2050 (Arcos, 2018).

Existing policy instruments and costs of renewables

The rapid transformation of the electricity sector is supported by various policy instruments, mainly highly competitive medium- and long-term auctions and clean energy certificates as an obligatory quota for retail suppliers and large consumers, to promote the development of clean energy sources for electricity generation. In addition to utility-scale clean energy generation, the strategy focuses on improving energy efficiency by strengthening the existing National Program for the Sustainable Use of Energy (PRONASE) and fostering the large-scale deployment of clean distributed generation.

In 2015, Mexico announced the call for projects in its first long-term power auction as an instrument to procure three distinct products: clean energy, firm capacity, and clean energy certificates. For energy and capacity 15-year contracts are awarded, while the clean energy certificate contracts are valid for 20 years (Diario Oficial de la Federación, 2015). In order to provide stable market development, the law foresees annual auctions. Three long-term power auctions have been held so far, in 2015, 2016, and 2017. They are expected to trigger investments of 9 billion USD and give rise to an aggregate installed clean energy capacity of 8.9 GW (by the end of 2017, 73 GW capacity was installed). The government forecasts that the development of 50 projects with corresponding infrastructure will have a positive economic impact on 19 Mexican federal states (Pages, 2018).

The average bid price was rather low from the start and dropped 57% between the first and the third long-term power auction. In the first auction, wind projects were awarded at a minimum price of 42.85 USD per MWh and solar PV at 35.46 USD per MWh, while in the third auction the lowest successful bid for wind stood at 17 USD per MWh and for solar PV at 19 USD per MWh. This decrease can be explained by increased investor confidence considering the solid legal and regulatory framework, changes in auction design (ceiling price was reduced from 51 USD to 40 USD per MWh), and selection criteria. The most successful bidders were highly experienced international companies, since project sizes favoured economies of scale with capacity size of 100 MW and above (Secretaría de Energía, 2018).

The winning auction is determined based on a complex mechanism that includes regional and hourly adjustment factors considering market value and system integration. One remarkable change in the auction design was the location-specific component. The first auctions included locational adjustments according to the local grid integration capacity. Projects in the northwest regions of Mexico, for instance, were not contracted because of negative adjustment factors for offers there. In this part of the country, the transmission grid system is weak despite significant resource availability. In the second auction phase, these adjustments were reduced significantly, favouring projects in high resource areas.

The first compliance period of clean energy certificates (CEL) starts in 2018, and all clean energy generators developed after August 2014 receive 1 CEL per MWh generated. Penalties for non-compliance are between 30 USD and 250 USD per MWh. Up to 6 million certificates were awarded in the first auction, another 10 million in the following one (IRENA, 2017a). For 2018 and 2019, the Ministry of Energy (SENER) set a minimum purchase requirement of 5% and 5.8% of the total electricity demand to retail suppliers and large consumers. In light of very successful solar PV and wind auctions, however, it is currently being debated whether the clean energy certificate mechanism provides any additional incentive in contracting the most cost-efficient renewable energy projects (Lucas, 2018).

In addition to mechanisms that focus on clean energy, there are other mechanisms in place that indirectly support the use of clean energy resources. In 2014, Mexico introduced a carbon tax on fossil fuels use at 3.5 USD per tonne CO_2 (IRENA, IEA, REN21, 2018). However, the rates are below the lower end of the range for social costs of carbon, and they do not fully reflect the differences in the carbon content of different types of fuels (in addition, gas is exempt from the tax) (OECD, 2017). In 2016, the Ministry of the Environment and Natural Resources (SEMARNAT), the Mexican Stock Exchange, and the Mexican Platform for CO_2 (MEXICO2) agreed on developing a pilot for an emissions trading system (ETS) that is designed to be in alignment with the country's GHG emission reduction commitment in the Paris Agreement. The first pilot phase of the emissions trading scheme is planned to be launched in 2019. Before transitioning to an ETS, the pilot phase will run for three years. SEMARNAT anticipates the regulatory framework for the ETS to be fully operational by 2022 (ICAP, 2018).

System integration measures

Despite having held a series of successful renewable energy auctions, Mexico still has a fairly low share of variable renewables in its power mix (roughly 3%). As the share of variable renewables is expected to increase, planners are looking to learn from international best practices. For example, the tender system tends to favour developers who choose to build projects in under-supplied regions while disadvantaging those who go where supply is already abundant, thus facilitating grid integration. Furthermore, the Mexican Energy Secretariat (SENER) and CFE have initiated cooperation activities with national and international institutions. This cooperation aims to explore the role that pumped storage hydropower might play for the integration of variable renewable energy into the Mexican grid (ESMAP, 2016).

Interconnector capacity will also be particularly important in regions with good wind and solar resources. While grid capacity remains weak in the northern regions of Mexico such as Baja California, the national grid is largely interconnected. There is also a small interconnection capacity with Belize and Guatemala in the south and larger capacities with California and Texas to the north.

Innovation in business and finance models

One additional specific feature of Mexico's energy transition story is the special emphasis it places on innovation. Mexico is establishing national energy research centres, the so-called Mexican Energy Innovation Centres, which will carry out research on specific technologies like solar, wind, pumped hydro, and geothermal. Between 2013 and 2016, Mexico invested 150 million USD in the creation of these centres (Government of Mexico, 2017).

In sum, particularly for clean energy, the current regime can be considered as quite effective, mainly due to long-term power auctions. Therefore, the energy transition in Mexico has been progressing at an impressive pace so far. The wide range of applied policy and support instruments makes it interesting to look at and to closely monitor in the coming years.

Energy planning	Long-term policy setting Policy framework that encompasses various types of renewable energy and clean technologies Policy environment
System integration and enabling technologies	Spending on flexibility measures
Policy instruments and costs of renewables	Policy tools: periodic auctions to gain confidence, changing design, etc. Auction design and market-based mechanisms
Innovation in business and finance models	Creation of innovation centres and development of locally manufactured capacity

Box 3: The key elements in designing renewable energy auctions

As the costs of electricity generation from renewables have become more cost competitive, countries have turned to market-based mechanisms over support schemes like FiTs. One such mechanism is renewable energy auctions, which are now commonly applied in many countries.

An auction is designed based on certain rules, and project developers are invited to bid at a price at which they think they can realise a project. The decision-making authority evaluates the offers and signs a purchase agreement with the successful developer based on rules of execution. Many countries prefer auctions because they are flexible in terms of their design structure, contribute to real price discovery, help in greater price certainty, and are capable of guaranteeing commitments and transparency.

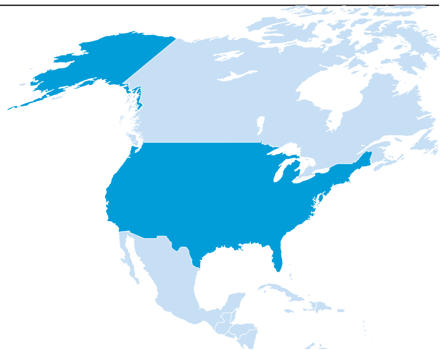
The four main categories of auction design elements are defined as: (i) auction demand, referring to the choice of the auctioned volume and the way this volume is divided between different technologies and project sizes, (ii) qualification requirements that determine who is eligible to participate, (iii) winner selection process, and (iv) sellers' obligations.

Technology-neutral auctions could reduce undercontracting risks, since typically more developers participate in the bidding process. Therefore, they can seek the most cost-competitive technology with high flexibility. Technology-specific auctions offer the advantage of reducing technology prices further, and they are simpler in nature. Auction volumes and the number of rounds also influence the competition. It is important to reduce entry barriers for potential bidders and their perceived risks. This will help increase the number of bidders and spur competition. These barriers can be overcome by setting requirements for qualification and compliance rules, reducing administrative procedures and costs, and providing timely and clear information to bidders. Meeting the demand-side responsibilities, mitigating financial risks, and creating better auction schedules can help reduce risks. Finally, it is also important that collusion and price manipulation are prevented.

While it is important to ensure broad participation in the auctions, it is also key to limit participation to bidders that can successfully meet the objectives of the auction. This can be ensured by introducing prequalification requirements, compliance rules, technological and project size requirements, location constraints, and grid access requirements. In addition, requirements for socio-economic development can also be introduced (IRENA and CEM, 2015).

As there is no single formula for the design of a successful auction, different elements need to be combined in a way that is tailored in line with national circumstances and country priorities. For the specific case of Turkey, SHURA's new studies on the role of system-friendly locations of renewable power plants and auctions discusses how the existing design can be improved for a more cost-effective transformation of the power system to higher shares of wind and solar (Sarı et al., forthcoming; Saygin et al., 2018b).

United States



Quick energy and climate facts		
Total primary energy supply	[Mtoe/yr]	2,188
Electricity generation	[TWh/yr]	4,297
Electricity consumption	[TWh/yr]	3,782
Per capita total primary energy supply	[toe/cap]	6.8
Per capita electricity consumption	[kWh/cap]	12,833
Per capita CO_2 emissions	[t CO_2/cap]	15.5

Renewable electricity generation		
Renewable electricity share in total generation	[%]	13.2
Variable renewable electricity share in total generation	[%]	5.2
Variable renewable elecricity capacity add. (2010-2015)	[%]	0.9
Total renewable electricity capacity	[MW]	194,922
Total variable renewable electricity capacity	[MW]	94,257

Power system		
Interconnector capacity with neighbours[2]	[TWh/yr]	73
Electricity storage capacity	[MW]	25,398.5
Electricity share in total final energy consumption	[%]	23.3

Renewable electricity targets
No national targets

Renewable electricity policies
- Renewable energy targets (renewable portfolio standart)
- Retail choice (community choice aggregators)
- Transmission expansion
- CO_2 cap and trade (and auctions for large emitters)
- Net metering, net billing, avoided cost-based feed-in tariffs
- Renewable energy auctions

[1] Compared to the total generation capacity
[2] Total of exports from Canada (65 TWh) and imports to Mexico (7.5 TWh)

Sources: (CEC, 2017a; IEA, 2017a, 2017b; IRENA, 2018b; NRCAN, 2018; REN21, 2018, p. 21; Sandia Corporation, 2018; US EIA, 2017)

The United States' electricity system has 50 state-level regulated energy markets with distinct policy priorities, seven federally regulated competitive wholesale power markets, and over 3,300 electric utilities under distinct regulatory, ownership, and investment paradigms-thus, it offers a highly heterogeneous set of experiences of the energy transition. Through a combination of strong state and local-level policy and regulation, declining renewable energy costs, and federal support via renewable energy tax credits, federal air emissions regulations (which, along with cheap natural gas prices, have helped accelerate the phase-out of coal in a number of US states), and significant R&D funding, renewable power has seen strong growth in the United States in the past years.

As of 2017, the country ranked second in terms of total installed wind capacity (GWEC, 2018) and solar capacity (IEA, 2018a), with 89 GW and 51 GW of installed capacity, respectively. As of 2017, clean sources (including large-scale hydro) contributed to 17% of its total electricity output (EIA, 2018a). However, as pointed out above, the disparities between different states are enormous: while some states like California (CEC, 2017b) and South Dakota (EIA, 2018b) have gone beyond a 30% share of renewables in total electricity output, other US states like Louisiana and Wyoming remain below 2% (DOE, 2018) renewable electricity in their power mix.

Long-term energy planning and existing policy framework

Given the highly heterogeneous US governance structure for electricity, state-level policymakers and regulators tend to drive policy decisions around renewable energy, energy efficiency, and power system modernisation more broadly-though the federal government also influences the energy transition in several notable ways. There is no existing national "plan" for the energy sector, and most states rely on some combination of utility-led resource planning, regional planning activities (if they participate in a multi-state wholesale power market), and specific policy and regulatory actions to influence long-term energy plans.

Today, thirty-nine states have their own set of explicit renewable energy policies or programmes, with California and Texas leading the change in terms of total capacity installation. The main policy instrument through which states pursue their renewable energy ambitions is called Renewable Portfolio Standards (RPS) (IRENA, 2015), which are established in 29 states and Washington, DC and apply to load serving entities (i.e., utilities) representing approximately 56% of total electricity sales. The RPS mechanism mandates that companies that distribute electricity must provide a specified share of their electricity to retail customers from renewable energy (Clean Energy State Alliance, 2012). It is estimated that half of all growth in renewable energy installations since 2000 is associated with state RPS requirements (Barbose, 2018), with many renewable energy projects in the US moving forward due to favourable economics and other power market conditions.

With respect to energy efficiency, many states have also established Energy Efficiency Resource Standards (EERSs), which establish specific long-term targets for customer energy savings. As of January 2017, 26 states have EERSs, and most states without EERS nevertheless allow utility-led energy efficiency programmes for retail customers (ACEEE, 2018) (NREL, 2014a).

The US federal government has also influenced the energy transition in several notable ways. First, it offers renewable energy developers a choice of a 30% investment tax credit (ITC) or 19 USD per MWh production-based tax credit (PTC) for renewable energy projects-with wind developers uniformly opting for the PTC and solar developers the ITC. The ITC and PTC have been periodically renewed since the 1990s and, following a renewal in late 2015, began a gradual ramp down of their value. The US Environment Protection Agency (EPA) has also issued power plant air emissions rules over the last decade regulating certain toxic air emissions (see e.g.,(EPA, 2018a;b)) and CO_2 (see e.g., (EPA, 2017a;b)), which have discouraged the utilisation of coal-fired power plants and accelerated the clean energy transition. While various legal challenges have been mounted, as well as forthcoming changes by the Trump Administration to weaken carbon emissions rules (EPA, 2018c), the spectre of these regulations, in combination with an aging coal fleet and low-cost natural gas and renewables, has led to significant early retirements of coal.

Existing policy instruments and costs of renewables

This section focuses on two US states: California and Texas.

California

California, the world's sixth largest economy (State of California, 2018), has long been seen as the state-level pioneer in environmental issues related to global warming. It has also shown leadership in this area over the last four years. In 2017, renewable energy accounted for 27% of the state's total generation, with wind and solar representing 6.81% and 9.98%, respectively (California Energy Commission, 2018). Progress in California has been enabled by a range of policies starting in the late 1990s that aimed at creating a market for renewable energy and promoting conservation and energy efficiency.

In 2002, the California State Legislature enacted the state's RPS. The law was subsequently amended to require electricity utilities in California to procure the equivalent of 33% of their retail sales from renewables by 2020 and 50% by the year 2030, maintaining this standard afterward. The programme has been so successful that in 2017 the California Public Utilities Commission (CPUC) announced that its large investor-owned utilities (IOUs) had reached their 2020 goal, with the target being amended, and was likely to meet the 50% goal by 2020 (CPUC, 2017). A 2003 Energy Action Plan established a "loading order" for energy planning processes, mandating that energy efficiency and conservation be considered a "first resource" during utility integrated resources planning processes (State of California, 2003). This policy has helped to contain retail electricity rate increases associated with the cost of California's first-mover energy transition.

In 2015, California became the first state in the nation to mandate energy storage deployment targets for their utilities, mandating that IOUs must procure a total of 1,325 MW of storage by 2024 (CPUC, 2013); in 2016, a law was also passed mandating an additional 500 MW of behind-the-meter storage be deployed (State of California, 2016). This policy has helped launch a budding energy storage market, and several other states have since taken up or are considering energy storage targets (see, e.g., AZCC, 2018; NYSERDA, 2018). Finally, California has the largest market in the US for distributed solar, with over 7 GW of capacity installed as of June 2018 (California Distributed Generation Statistics, 2018). The state has used a wide range of policy instruments to govern this development, including a net energy metering policy, direct financial incentives that have declined in value as deployment increased, innovative retail rate design to support utility cost recovery, a progressive policy for interconnection of small-scale resources, and periodic programme evaluations to carefully monitor financial impacts to utilities and ratepayers. Recently, the state issued a mandate requiring all newly constructed homes in California to have solar systems (CEC, 2018).

Texas

Texas, the second largest state in the US by both size and population, is the largest state in the US in terms of power generation (US EIA, 2018). Texas has long been associated with fossil fuels since the boom commonly referred to as the "gusher age" in the early 1900s as well as its more recent boom of unconventional oil and gas. However, the state has more recently been undergoing a new energy transformation, rapidly scaling wind power. From 2000 to 2017 Texas saw an increase in its installed capacity from 116 MW to 21,450 MW of wind capacity, making it the world's sixth largest wind market (AWEA, 2017). Like the state of California, Texas made use of the RPS to mandate the increase in wind power ("Energy Policy Case Study - Texas: Wind, markets, and Grid Modernisation," 2016). The bill, which was initially signed into law in 1999, originally mandated that 2,000 MWs of renewable energy be installed by 2009, with subsequent bills increasing the threshold. In 2005, a bill was introduced requiring 10 GW of total installed capacity by 2025, which was achieved ten years early in 2015.

Such a vast overachievement of targets can be explained by a range of factors in Texas, including its high quality wind power resources and the establishment of its competitive renewable energy zones (CREZ). Under this state-led process, specific renewable energy "zones"-typically wind-rich in nature with no or limited transmission access-are identified. Thereafter, new ratepayer-financed transmission projects are built to connect these areas, and developers are granted access to the lines on a competitive, first-come, first-served basis. This approach has led to a significant and systematic de-risking of the Texas wind energy investment environment. Furthermore, it has reduced network congestion and helped to support a cost-effective grid integration of wind resources.

Texas' electricity market, Electric Reliability Council of Texas (ERCOT), is almost entirely isolated from the rest of the US power system. Its interconnector capacity with its neighbours remains a mere 1.3 GW out of the power system, with a total peak summer demand of roughly 70 GW (IEA-RETD, 2015). As a result of its isolation, ERCOT is not subject to federal regulatory oversight and is largely in control of its own regulatory policy decisions.

In 2016, wind power in Texas supplied a record 48% of total electricity demand in the ERCOT region (Woodfin, 2016). Partly as a result of its tremendous success in developing wind power, Texas has also emerged as a leader on power system flexibility and boasts one of the most advanced wholesale power markets in the world, including a complex system of nodal pricing with thousands of different load and pricing nodes. In order to promote system flexibility, ERCOT has introduced a wide range of policy, regulatory, and system planning measures:

- Texas has a day-ahead, intraday market (closing one hour before operation) as well as a real-time dispatch market with five-minute intervals. This market sophistication enables more rapid responses from generators and from other market participants and helps improve overall system integration.

- In 2014, ERCOT introduced a reliability price adder to energy and reserve products, which increases in value as available operating reserves decrease. The value of this price adder is administratively predetermined to reduce uncertainty for developers and plant owners and helps to ensure that the system value of reliability is better reflected in energy and reserve prices while promoting new investment in flexible capacity.
- ERCOT has adopted a special forecasting mechanism requiring rolling forecasts to be submitted to the operator every hour.
- Texas launched an Emergency Reserve Service that enables the operator to tap into ten-minute ramping capabilities from different loads on the system.
- Texas introduced a Large Ramp Alert System (LRAS) to notify the market operator of a high risk of rapid wind power ramping events occurring in the next six hours. This is intended to help the system operator deal with large surges in wind power production.
- Since 2012, wind power projects were required to provide primary frequency response to help stabilize the system.
- The state has developed a Fast Regulation Reserve Service pilot project focusing on projects capable of providing both up- and down-ramping capacity.
- Texas has adopted a special grid code for variable renewable energy technologies, including specific requirements for reactive power, fault ride-through, and frequency response.

Taken collectively, these policies have helped significantly improve power system flexibility. Texas also benefits from having a large share of natural gas plants representing approximately half of its total power generation: these gas plants make Texas' power system as a whole more flexible than other states in the US, with higher shares of baseload, inflexible generation.

System integration measures

US states offer a range of experiences on system integration approaches. At the national level, the federal government has historically supported research on national and regional grid integration studies, which are conducted with significant input from utilities, system operators, state regulators, and other industry stakeholders. Such studies look systematically at the various technical pathways, and cost implications thereof, of integrating increasing penetrations of renewable energy on the US grid. For example, a recent federally funded study by the US National Renewable Energy Laboratory used state-of-the-art grid modelling techniques to characterise what would be required for the eastern interconnection of the US to achieve 30% renewable energy penetration, identifying specific changes to policy, regulation, market design, and operating procedures (Bloom et al., 2016).

At the state level, experiences with system integration are vastly different. Changes to electric utility resource planning practices are in many ways the bedrock of system integration in the US (Kahrl et al., 2016), as well as strong state and regional coordination. In settings with competitive markets, price mechanisms to support system integration are already in place. For instance, many traditional baseload plants operating in competitive markets are experiencing reduced operating hours and the need to operate more flexibly-in response, some are undergoing retrofits to gain more operational flexibility (e.g., higher ramp rates, lower minimum generation levels) and support system integration. Some utilities are beginning to utilise renewable energy resources themselves to support system integration- for example, Xcel Energy in the state of Colorado was among the first in the world to utilise wind turbines to provide system services (IEA-RETD, 2016). Efforts to support innovative system integration measures are numerous-California and several other states have begun to enrol customers in demand response programmes and procure large volumes of battery energy storage. In addition, advanced renewable energy forecasting techniques have also played a significant role in promoting system integration in the US, including states like Texas and Iowa as well as the Northeastern US.

Innovation in business and finance models

The US experience emphasizes the role that policies must play to encourage the creation of innovation networks and technological development in the renewable energy space. Such policies can lead to large cost reductions in renewable technology and provide a competitive advantage to domestic companies and the country as a whole. Between 1992 and 2012, the US federal government spent 3.4 billion USD and 1.2 billion USD in R&D funding for solar and wind, respectively (in real USD in 2011) (Mazucatto, 2015).

The Sunshot Initiative is a federal programme that was launched in 2011 targeting a 75% reduction in the price of solar by 2020, characterising it as grid-parity (Mazzucato, 2015). The initiative had a significant focus on reducing soft costs (i.e., non-hardware costs) for solar installations. It was so successful that in 2017 it announced that it had already reached its goal and was now focusing on grid reliability issues. While the private sector has taken the lead in many technological developments, they have had help and direction from the federal government; between 2008 and 2016 the Department of Energy increased its annual spending on renewable energy R&D from 1.2 billion USD per year to 2.1 billion USD per year. Likewise, R&D for solar and wind increased from 215 million USD to 337 million USD over the same period, with spending on research into energy efficiency in vehicles, buildings, and manufacturing rising from 379 million USD to 739 million USD (Simon and Hayes, 2017).

Among the most notable federal innovation programmes is the Advanced Research Projects Agency – Energy (ARPA-E) initiative, which provides funding and support to the US private sector to advance high potential, high-impact energy technologies that are too early for private sector investment (ARPA-E, 2018). Initiatives for grid modernisation, smart grid technology, and electric vehicle deployment also enjoy strong federal support.

The US solar industry in particular has benefited from the emergence of new business models in both the energy efficiency sector (e.g., ESCOs) as well as in the solar sector, especially for solar leasing companies. With regard to the solar sector, such new business models have played a major role in driving residential and commercial adoption of solar by reducing the costs and time of investing in solar for end users. Under these new business models, a third-party company (e.g., SunRun, Sungevity, Solar City) typically takes care of much of the paperwork, the financing, the installation, as well as the project maintenance. In turn, different contracting structures exist that allow customers to consume their power themselves and benefit immediately through reduced utility bills. Most of these new business models have emerged to capitalize on US tax policies, though they have been supported by rising retail prices, declining solar costs, and perhaps most critically, the existence of state-level net-metering policies. With regard to ESCOs, the US has emerged as a world leader with a booming energy efficiency services market. ESCOs typically make use of an "Energy Performance Contract," which provides the legal framework for a private third-party company to invest in a series of agreed-upon upgrades and energy savings measures with the building owner (or tenant). The energy savings generated by these energy efficiency investments lead to lower energy bills for the tenant or building owner, savings that the building owner or tenant may not be able to capitalize upon themselves due to a lack of time, expertise, or access to finance.

Some US-based ESCO companies are branches of original equipment manufacturers (OEMs) like Johnson Controls, while others are technology-neutral energy efficiency service providers like Clark Energy or Metrus Energy. Some of these ESCO companies are starting to expand internationally, including in Europe, the Middle East, and the Asia Pacific region. Recent analysis by Navigant Research indicates that the global ESCO market is projected to grow from approximately 15 billion USD in 2017 to over 30 billion USD in 2026 (Navigant, 2017). There is significant potential for countries like Turkey to expand the market for ESCO companies, which can yield a wide range of benefits in terms of reduced energy costs, greater energy security, reduced emissions, and local job creation.

Energy planning	Distributed, state-driven processes Integrated planning practices for utilities
System integration and enabling technologies	Advanced utility planning, strong state and regional coordination, advanced forecasting, demand response, energy storage, EVs
Policy instruments and costs of renewables	RPS, EERS, renewable energy zones, storage deployment mandates, RD&D funding
Innovation in business and finance models	Innovation initiatives at the federal level Rigorous focus on reducing soft costs Funding for high-risk/high-reward technologies

Box 4: Policy, business and finance options for developing a distributed generation market

Renewable electricity has reached cost-competitiveness in many countries. Many interesting developments have taken place in countries like Germany or the US, where rooftop solar PV systems have reached socket parity, meaning the cost of self-generated electricity is equal to or lower than the retail price of electricity purchased from the grid-the price on which electricity consumers base their decisions (IRENA, 2017b). More onsite generation of electricity from renewables increases self-consumption and enhances self-sufficiency. This has multiple benefits and puts the consumers in the power markets as active participants. The higher share of such systems could also reduce energy transition costs by reducing infrastructure investments and providing system flexibility like demand response or, if available, as energy storage.

A successful deployment of distributed generation requires well-designed tariff structures. This is essential since not all self-generated electricity will be self-consumed, either because there is no demand or since the investment is only financially available if some portion of the electricity is sold back to the grid. Several options exist. For any option, it is essential to understand electricity demand patterns, retail electricity tariffs, actual installation, operation and maintenance costs, as well as any tax liabilities and grid charges that apply (Dunlop and Roesch, 2016; EC, 2015; IRENA, 2017c):

- Under FiTs, distributed generators have typically been paid a fixed tariff for a renewable energy project's gross output (i.e., 100% of their production). This is the case under Germany's FiT, for instance, and it allowed citizens and businesses to finance individual solar PV systems without any self-consumption. In recent years, a growing number of users are beginning to start to self-consume their own power as the FiTs on offer have been reduced, and the incentive to erase one's own consumption has increased as electricity prices have gone up.
- In other cases, such as in Australia, a fixed FiT is only offered for a customer's net excess generation (after they consumed any power provided by the system onsite): this is called a NET-FiT, because the FiT only applies for the net excess generation and not the entire (or gross) output of the system.
- Some countries have moved away from fixed FiTs altogether and have introduced FiPs that offer a fixed or floating premium on top of the wholesale market price.
- In contrast to FiTs, FIPs, and NET-FiTs, net metering does not involve the direct sale of electricity. Customers that install onsite generation and connect to the distribution grid are simply credited for their net excess generation at the retail rate. Net metering is generally applied to systems with a certain capacity (e.g., up to 2 MW), and the billing period can range from hours to months. Net metering is commonly applied across many countries in the world, including EU member states, the US, and Malaysia. While it brings advantages to consumers, from a system perspective it raises questions since remuneration is done based on the retail price, which may well exceed the levelised cost of generation from rooftop solar systems as well as the actual value of that generation to the grid. As a consequence, advanced methodologies have been developed to assess in detail the costs and benefits of decentralised small-scale generation to power systems, for example, in the US (NREL, 2014b).
- Some countries and states have moved toward net billing, which was introduced in the Philippines and Italy. Under net billing, the surplus electricity exported to the grid is credited at a rate that is different from the retail rate that customers pay. In the case of Italy, the surplus electricity can be exported to the grid by crediting at the market price. In some cases, jurisdictions allow customers to actually be paid for the net excess generation, receiving either the wholesale market price or the avoided cost price for any surplus generation exported to the grid over a given time period. This is the case in California's new distributed generation rules. In cases where there is an actual purchase of net excess generation, the policy is called a "NET-FIT", as seen above.
- A further nuance that is emerging is exposing prosumers to time-of-use pricing signals, either by requiring them to sell their net excess generation directly on the spot market (as seen above) or by establishing separate time-of-use rate structures within the retail rate itself. Under time-of-use rate structures, a prosumer would benefit on two levels: first, they are compensated more for their net excess generation exported to the grid during peak hours, and second, they are able to avoid peak prices by self-consuming during those hours. A variation on this approach is used in Italy for large-scale solar PV systems owned by commercial customers. However, settling small amounts of excess generation on a real-time basis may be challenging in a setting with numerous small installers, notably due to the need for costlier metering infrastructure. In this case, aggregators can help by offering a bundled service to a large number of different prosumers. A further variation is applied in Portugal, where only 90% of the market price is paid to surplus electricity sellers.

In creating a sustainable distributed generation market, determining tariffs that reflect the costs will be key. For this regulators in various countries have followed different approaches to abandon purely volumetric charges, expose prosumers to time-dependent tariffs, decouple feed-in compensation from retail tariffs, and introduce more advanced tariff designs as a driver for demand response and energy storage (IRENA, 2017c). Financing scheme and business models are arguably as important as remuneration policies in helping make investments in distributed generation bankable. Various financing schemes exist such as self-funding, debt, equity, mezzanine financing, leasing, or crowdfunding. These different schemes are applied depending on the choice of the solar PV segment (e.g., single family residential houses, public and educational buildings, industrial buildings, etc). Examples from countries and applications to financing are available in the literature (Dunlop and Roesch, 2016; IEA, 2014a). The few examples provided here illustrate how sophisticated the market for distributed generation is becoming as solar PV costs continue to decline.

China

Quick energy and climate facts		
Total primary energy supply	[Mtoe/yr]	2,987
Electricity generation	[TWh/yr]	5,882
Electricity consumption	[TWh/yr]	4,922
Per capita total primary energy supply	[toe/cap]	2.2
Per capita electricity consumption	[kWh/cap]	4,047
Per capita CO_2 emissions	[t CO_2/cap]	6.6

Renewable electricity generation		
Renewable electricity share in total generation	[%]	23.6
Variable renewable electricity share in total generation	[%]	3.9
Variable renewable elecricity capacity add. (2010-2015)	[%]	2.3
Total renewable electricity capacity	[MW]	479,108
Total variable renewable electricity capacity	[MW]	174,600

Power system		
Interconnector capacity with neighbours[2]	[MW]	Not available
Electricity storage capacity	[MW]	6,123.9
Electricity share in total final energy consumption	[%]	24.1

Renewable electricity targets
- 700 GW non-fossil fuel generation, 380 GW hydropower, 110 GW solar PV, 210 GW wind by 2020

Renewable electricity policies
- Renewable energy targets
- Net metering
- Tendering
- Investment or production tax credits
- Public investment loans, grants, capital subsidies, or rebates

[1] Compared to the total generation capacity

Sources: (IEA, 2017a, 2017b; IRENA, 2018b; REN21, 2018, p. 21; Sandia Corporation, 2018)

Due to its size, ongoing growth, and being the largest emitter of CO_2 from the power sector, China's role in the energy transition is crucial. With increasing demand for energy and pressure to tackle air pollution while upholding economic growth, China has turned to renewables. However, the Chinese coal sector remains strong and it is expected to grow in the upcoming years before peaking, along with CO_2 emissions, before 2030.

From 2011 to 2016 China experienced an increase in renewable energy capacity characterised by an average annual growth of around 25% for wind and 86% for solar PV, achieving at an installed capacity of 148 GW of wind and 77 GW of solar PV (China Energy Portal, 2018; IRENA, 2018b). In 2017 alone, China added 53 GW of new solar PV capacity, more than half of the total additions worldwide and more than all of Germany's currently installed PV capacity, which is estimated at around 44 GW. This has increased total solar PV capacity to 129 GW. Wind additions were 18 GW in the same year, totalling 163 GW (China Energy Portal, 2018).

In 2017, China consumed 6,363 TWh of electricity, of which 1,693 TWh were renewables including hydropower, wind, solar, and biomass. The share of renewables generation from wind and solar PV accounted for 4.7% for wind and 1.8% for solar PV. The remainder was split between 248 TWh nuclear and 4,476 TWh thermal power generation, mainly coal (China Energy Portal, 2018).

Long-term energy planning and existing policy framework

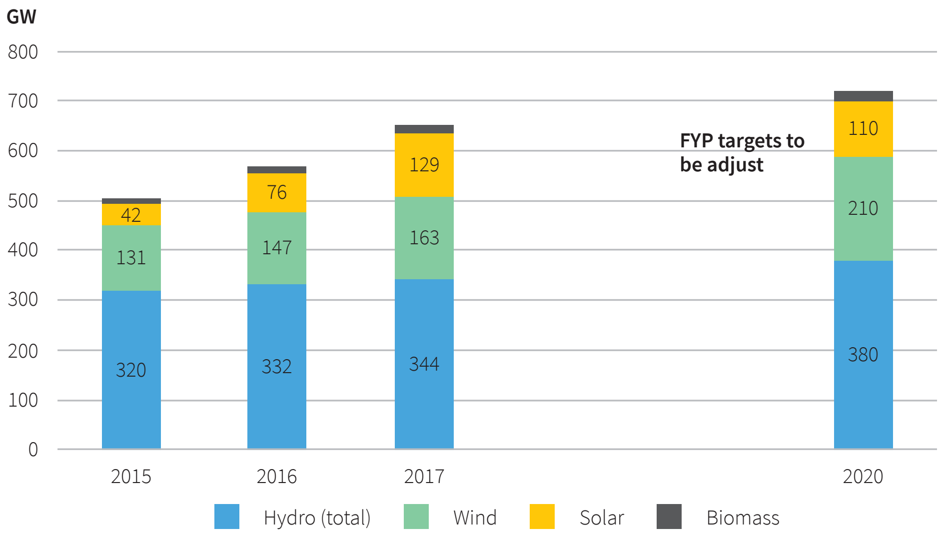
China's 13th Five-Year Plan includes targets for the energy sector until 2020. Maintaining economic growth while combating air pollution and committing to climate protection have been the main pillars of China's strategy to advance toward a greener economy. To meet demand, the plan projects a total electricity consumption of 6,800–7,200 TWh by 2020 with a total generation capacity of 2,000 GW and a 27% share of electricity in total final energy consumption. Approximately 15% of the electricity consumption must be delivered from non-fossil resources, with a 39% share of the total installed capacity. The installed capacity of coal-fired power generation is limited to 1,100 GW. In 2017, China's installed power generation capacity amounted to 1,777 GW, which slightly exceeds the 13th Five-Year Plan's expectation of 1,700 GW for the same year. This accounted for 38.3% non-fossil capacity, almost reaching the 2020 target (China Energy Portal, 2016).

The plan also includes renewable energy targets for 2020: 210 GW of wind power (2017: 163 GW) and 110 GW of solar PV, though this was already surpassed in 2017 (129 GW) (see Figure 9). Recent policies hint at a reduction of the current pace of additions (China Energy Portal, 2016). In 2017, China represented two-thirds of the total global solar PV additions worldwide, which are estimated at 92 GW according to IRENA (IRENA, 2018e). In 2018, it is expected that China's new additions will drop as the government reduces subsidies by limiting them to a pre-defined quota (Hook and Hornby, 2018). On one hand, this is expected to strip solar of its 2017 world record. On the other, it will drive down solar PV prices even lower both in China and around the world due to excess solar PV module production.

As China has ratified the Paris Agreement, 2030 targets are subsequently defined in China's Nationally Determined Contribution (NDC). China has committed to peak its CO_2 emissions by 2030 or earlier, increase the share of non-fossil energy sources in the total primary energy supply to 20% by 2030, and lower its carbon emissions by 60-65% compared to 2005 levels.

China aims to provide 20% of its total primary energy supply from non-fossil energy resources by 2030, with renewables playing a major role in achieving that.

Figure 9: *Development of total installed grid connected renewables capacity and the 13th Five-Year Plan targets to be adjusted, 2015–2020*



Source: Own illustration based on (China Energy Portal, 2018) (China Energy Portal, 2016)

Existing policy instruments and costs of renewables

Remuneration of renewables is organised through the FiT programme China established in 2006. International experiences drove the development of the FiT scheme. While having used auctions at several occasions in the past, China's renewables expansion up to now mostly relies on FiTs, which have also been designed to offer differentiated support levels for projects in different regions of the country with different resource endowments. The FiT is paid by the Ministry of Finance and financed via surcharges on household electricity prices. The level of the FiTs is periodically adjusted to match decreasing technology costs in order to minimise the impact on consumers. Surcharges also depend on the resource category (i.e., which technology is used), as well as the quality of renewable resource in a particular location. An overview of the 2018 FiT level in 2018 is provided in Table 2.

Table 2: *Overview of the FiT level in 2018*

	Onshore wind	Offshore wind	Solar PV (utility size)
Effective 2017	400 to 570 RMB/MWh	750 to 850 RMB/MWh	650 to 1050 RMB/MWh
Effective 2018			550 to 1050 RMB/MWh

Note: In August 2018, 1 USD was equivalent to 6.85 RMB.
Source: (NDRC, 2016)(NDRC, 2017)

Currently, China is struggling to pay remuneration to producers of renewable energy while trying to maintain affordable electricity prices for households. Consequently, in May 2018, the government initiated fundamental changes to wind and solar support policies. It issued a guideline document that requires auction-based pricing for new utility-level wind projects after 2018, differing from the previous FiT system. Yet, how this fundamental change of renewable support policy will be implemented in detail is still to be communicated. Also in May 2018, the government announced a halt to supporting large-scale solar projects for the rest of the year and a 10 GW cap to distributed small-scale PV projects, as well as underlining the intention to phase out financial support in the near future (NDRC, 2018).

China started to employ voluntary green electricity certificates in April 2016, releasing a report titled "Guiding Opinions on Establishing Renewable Energy Portfolio Standards" (RPS). Each grid operator is required to meet the targets for renewable energy generation (Cheng, 2016; NEA, 2016). In summer 2017, a "green certificate" scheme was launched that credits companies with the environmental benefits of renewable electricity generation. The initial stage of the system focused on onshore wind and utility-scale solar PV projects, which resulted in the issuance of certificates equivalent to a total electricity volume of 8 TWh until the end of October 2017. There are plans to make the RPS a mandatory regime. The scheme is also part of China's efforts to reform subsidies for renewable energy development (Hong et al., 2017). Corporate renewable energy targets are also met through various platforms that allow the trading of certificates. One example is the Renewable Energy Buyers Alliance (REBA, 2018).

Additionally, China announced in December 2017 that it will go forward in setting up a national emissions trading scheme that will initially cover the entire national power sector. By covering 3 Gt CO_2 emissions it will be largest carbon market in the world. This move forward comes as China's emissions increased in 2017 (Climate Home News, 2018) and the first quarter of 2018 (Hornby and Hook, 2018).

System integration measures

China considers several additional measures for integrating higher shares of solar and wind. These include a mix of technologies and strategies, including battery storage services provided by EVs, pumped hydro and batteries heat storage like power-to-heat, modernisation of conventional thermal technologies to increase their ramp rates, and digitalisation.

China is also planning for grid expansion and prioritising the construction of significant interprovincial transmission capacity. However, the construction of these lines has lagged behind the growth of renewables capacity: an estimated 70% of China's renewable energy capacity has been installed in resource rich areas of China, in some cases exceeding the available transmission capacity. This has been the main reason behind the relatively high level of curtailment of both solar and wind in recent years. In 2016, total curtailment of all wind generated in China was more than 15% of all electricity generated (Ye et al., 2018). In 2012, it declined to 12%. In certain regions, the rates are higher than the national average. For instance, in Northwestern China (Xinjiang, Qinghai, Gansu), wind curtailment approached 40% in 2015/16 (Yuanyuan, 2016).

One method that is being explored to reduce curtailment is to allow the direct trading of electricity between users, particularly larger commercial and industrial power users. In addition, end-use sector electrification in areas with high renewable energy shares is prioritised to utilise renewable energy resources. Demand-side management programmes, including dynamic pricing for load shaving, are also being considered. Due to these and other measures as well as to the ongoing expansion of transmission infrastructure, curtailment already decreased significantly in 2017 and during the first quarter of 2018.

Critical to China's success in the energy transition is whether China will succeed in limiting coal power production, increase its efforts in terms of energy efficiency, and continue to increase and integrate renewable energy technologies.

As part of the ongoing power market reform in China, the government is developing a market-based mechanism with the aim of coordinating the dispatch of power plants by splitting the wholesale market into two, where one part will be supplied by nuclear and renewables and will be dispatched and priced by regulators while the other part (which is largely supplied by coal) will be traded. Although existing coal-fired power generation will be awarded fixed full-load hours, these allocations will be lowered each year. In its 13th Five-Year Plan, China has committed to retrofitting 133 GW combined heat and power and 86 GW condensing coal-fired plants by 2020, with the purpose of boosting their operational flexibility and environmental performance. This commitment represents about one-fifth of the total installed coal-fired capacity in China (Zhou and Lou, 2017).

Innovation in business and finance models

China has followed a unique strategy for creating a domestic wind and solar industry through R&D programmes, financial support schemes, and local content requirements. This was complemented by a strong export strategy, which has helped to reduce the costs of solar PV technology globally and has created a large local manufacturing base. As China's renewable manufacturing sector grew, the costs of renewable energy technologies decreased dramatically. Innovation and new business models helped reducing the costs, but its main driver has been market expansion. In 2015, China became the world's largest solar PV manufacturer with 43 GW of total installed capacity. Between 2005 and 2014, production of solar cells in China expanded 100-fold (Mathews and Tan, 2014).

Together with the US, China has been driving innovation in EVs. It leads the world in electric vehicle sales by a considerable distance, with 579,000 sold in 2017. EVs have a 2.2% market share in China, which is more than EVs can boast in the US (1.2%) (IEA, 2018b). This is no coincidence. At the national and local levels, China has implemented policies and incentives to increase EV deployment attempting to solve its pollution crisis, reduce GHG emissions, and support its domestic automotive industry (Wang et al., 2017). In the past, the surge of EVs has been driven by a mix of subsidies to manufacturers and consumers and the offer of free license plates in some cities-a big incentive at times when reducing license plate issuance is a major policy lever being used to limit the growth of private car use and encourage alternative modes of transport.

In an effort to reduce the volume of subsidies for EVs, the Chinese government is attempting to shift costs from the public sector to consumers and manufacturers through portfolio standards and trading. In September 2017, the government set a minimum size for the electric car market by 2020, with flexibility through a cap-and-trade mechanism (Ministry of Industry and Information Technology of the People's Republic of China, 2018). On top of this, support is tied more closely to innovation in battery range. This could lead to a market share of 3% to 6% by 2020. In parallel, subsidies will be phased out until 2020.[8] The rapid growth of sales of electric buses is

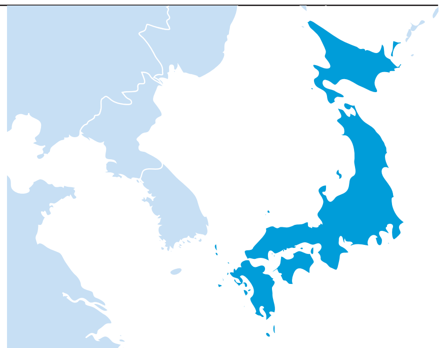
[8] However, in the short term they have been increased for vehicles with ranges over 400 km and reduced for vehicles with ranges under 300 km. Fleet average fuel economy standards are being tightened in parallel.

almost entirely driven by China, which accounts for 99% of the 370,000 units on the road globally (IEA, 2018c). Due to Chinese subsidy policies at national, regional, and city levels, the purchase price of a BEV bus is now close to that of a conventional diesel bus. By the end of 2017, the city of Shenzhen completely replaced its urban bus fleet with EVs and is now targeting its taxi fleet.

Innovation potential in the EV market is still high. Some of the largest venture capital transactions in the last two years have involved Chinese EV start-ups, such as the 1.5 billion USD series A investment by Tencent in WM Motors, an electric car start-up. They bear witness to the fact that China will play a leading role in the development of new technologies in the EV market (IEA, 2018c). Supported by the aspiration of continuing rapid growth in demand for EV batteries, China hosts almost 75% of global capacity total investment in new EV-suitable battery capacity (IEA, 2018c). In addition, China has a number of government policies that favour Chinese-produced batteries as well as targets for battery factories that require them to produce at least 8 GWh per year. Collectively, these policies are helping turn China into a battery and EV powerhouse.

<table>
<tr><td>Energy planning</td><td>Long-term energy and power system planning</td></tr>
<tr><td rowspan="5">System integration and enabling technologies</td><td>Various types of storage</td></tr>
<tr><td>Transport electrification</td></tr>
<tr><td>Demand response</td></tr>
<tr><td>Interconnector capacities</td></tr>
<tr><td>Market reform</td></tr>
<tr><td rowspan="3">Policy instruments and costs of renewables</td><td>Complementary policies, auction, RPS, FiT, ETS</td></tr>
<tr><td>Market design</td></tr>
<tr><td>Energy pricing</td></tr>
<tr><td rowspan="2">Innovation in business and finance models</td><td>Manufacturing hub</td></tr>
<tr><td>Investing in storage and transport electrification</td></tr>
</table>

Japan



Quick energy and climate facts		
Total primary energy supply	[Mtoe/yr]	430
Electricity generation	[TWh/yr]	1,035
Electricity consumption	[TWh/yr]	949
Per capita total primary energy supply	[toe/cap]	3.4
Per capita electricity consumption	[kWh/cap]	7,865
Per capita CO_2 emissions	[t CO_2/cap]	9.0

Renewable electricity generation		
Renewable electricity share in total generation	[%]	16.0
Variable renewable electricity share in total generation	[%]	4.0
Variable renewable elecricity capacity add. (2010-2015)	[%]	1.7
Total renewable electricity capacity	[MW]	66.612
Total variable renewable electricity capacity	[MW]	36,108

Power system		
Interconnector capacity with neighbours	[MW]	0
Electricity storage capacity	[MW]	28,465.7
Electricity share in total final energy consumption	[%]	32.4

Renewable electricity targets
- %14 renewable energy share in total primary energy supply by 2030
- 22-24% renewable electricity share in total generation by 2030
- Bio-power: 3.7-4.6%, Geothermal: 1-1.1%, Hydro: 8.8-9.2%, solar PV: 7%, wind: 1.7% by 2030
- Ocean power (wave and tidial): 1.5 GW by 2030

Renewable electricity policies
- Renewable energy targets
- Feed in tariff/premium payment
- Tradable renewable energy certificates
- Tendering
- Reductions in sales, energy, CO_2, VAT or other taxes
- Public investment loans, grants, capital subsidies, or rebates

[1] *Compared to the total generation capacity*

Sources: (IEA, 2017a, 2017b; IRENA, 2018b; Lund, 2016; REN21, 2018; Sandia Corporation, 2018)

The Great East Japan Earthquake and the subsequent accident at the Fukushima nuclear power plant in 2011 put Japan in the spotlight, not least with regard to how it would respond to the sudden disruption of its energy supply. The earthquake resulted in the loss of about 30 GW of electricity generation capacity. The affected fossil fuel and hydroelectric power stations were quickly restored, but approximately one-third of Japan's nuclear power stations were shut down immediately. Nuclear electricity generation dropped from approximately 300 TWh in 2010 to 100 TWh in 2011. Over the years, the remaining reactors stopped operating, thus decreasing nuclear electricity generation further to 9.5 TWh (Zissler, 2018). The Fukushima incident has not only had a major impact on Japan's energy mix but also led several other countries to turn away from nuclear energy towards renewables.

Japan's renewable energy generation (excluding hydropower) increased from 64 TWh in 2010 to 120 TWh in 2017, mainly driven by solar PV investments. Japan recently surpassed Germany to become the world's second largest solar PV market, with total installed solar PV capacity of nearly 50 GW. Japan's share of solar PV generation has grown rapidly in recent years as it has scaled-up the development of its domestic renewable energy resources since Fukushima in 2011 (IRENA, 2018f).

In addition to renewable energy, Japan's strategy includes a wide range of energy efficiency measures. Japan is one of the major exporters of energy-sector capital equipment and has a strong energy R&D programme that significantly contributes to advancing energy efficiency. Through its technological innovations and incentive policies, Japan has been able to control industry energy consumption for the past 30 years and achieve the world's highest level of energy efficiency (JICA, 2013).

Long-term energy planning and existing policy framework

The basic concepts of Japan's energy policy are energy security, economic efficiency, environment, and safety-referred as *3E+S*. This is formulated in the "Strategic Energy Plan 2014". Japan's long-term energy planning focused on setting targets and developing consistent national policies to manage the complexity and various dimensions of energy security. It was accompanied by a reorganisation of the government's attitude toward energy security and a nationwide effort to reduce energy consumption (IEA, 2016; 2017c).

In response to the shortfall of supply from the nuclear power plant shutdown in 2011, the government regulated the energy supply and implemented mandatory energy efficiency targets for large end consumers. These measures successfully avoided blackouts during the summer peak time and saved 15% of electricity consumption from 2011 to 2012. After 2012, emergency measures were gradually relaxed (not governed by mandatory numerical targets) and supported by other long-term measures, for example, incentives for large end consumers to shift peak demand time (IEA, 2017d)

Due to the conservation measures, electricity demand fell by 6% in 2011 and has not bounced back to pre-earthquake levels. As the emergency measures ended in 2016, it was observed that the targeted policy measures also caused behavioural change among consumers, which resulted in sustainable energy savings. Demand reduction was the single largest factor (39%) in balancing the loss of nuclear power generation, while the remaining deficit was covered by an increase in gas (30%), renewables

(13%), and coal (12%); nuclear was only generating 6% of its pre-Fukushima levels (Zissler, 2018). Energy efficiency measures also reduced Japan's dependency on fuel imports: Japan was able to save 20% of oil imports and 23% of gas imports in 2016 (IEA, 2017c). Japan's energy intensity was 21% below the global average in 2010, and it has made significant progress since then. Thus, as a frontrunner in energy efficiency, Japan can serve as a role model for other countries. However, despite the tremendous improvements in energy efficiency that have taken place in Japan, there is significant potential for improvement. Policy action in the building sector, which is still far behind Europe, has just started, for example.

Existing policy instruments and costs of renewables

After the nuclear shutdown in 2011, renewable energy development became one of the strategies for reducing the vulnerability of Japan's energy system. Japan strongly promoted renewable development through the FiT Act (2012), superseding the previous green power RPS. The Ministry of Economy, Trade, and Industry (METI) set higher purchase tariffs for three years (from 2012 to 2015) and gave incentives to early entrants (IEA, 2017e).

During five years of the FiT, the renewable energy sector in Japan grew rapidly. Solar PV installation constituted more than 75% of the annual installed renewable energy capacity. In this five-year period, solar PV capacity increased by a factor of 12. Geothermal increased more than seven-fold, while medium and small-scale hydropower (below 30 MW) increased more than three-fold, bioenergy almost doubled, and wind power increased by 80% (Kimura, 2017). The declining costs combined with economies of scale drove solar PV generation tariffs down by 38%. This is still a rather small decline if compared to other countries, which can usually be explained by the limited cost pressure exercised by high FiT levels. Onshore wind power tariffs declined by 29% and biomass by 16% during the same period. In 2017, the Japanese government moved towards the use of auctions for large-scale installations and introduced a pilot auction for solar PV (500 MW) where the ceiling price was set at 178 USD per MWh. The lowest bid was received stood at 145 USD per MWh. The halving of the 2012–2014 FiT presents opportunities of further cost reduction as Japanese solar projects, based on a high FiT, have some of the highest generation costs compared to other regions.

Including residential solar PV in the power purchase programme also shifted the general perception of electricity generation being a business that is strictly for large companies building big power plants. After the enforcement of FiT, residential solar PV increased steadily. Comprehensive policy between renewable energy and energy efficiency, including Japan's Zero Energy Home target, will be a major element driving higher residential solar PV adoption. It is likely to lead to homebuilders installing rooftop solar as a default feature in new housing developments.

Currently, Japan still has one of the highest generation costs in the region. This is influenced by high land and labour costs and the strong industrial policy that prioritises domestic manufacturers. In enabling renewable energy development, the gap between expenditure for renewable energy and procurement costs for conventional electricity is filled by the surcharge from electricity consumers. From 2011 to 2016, the surcharge increased from 0.1 to 18 USD per MWh (Kimura, 2017). The cumulative surcharges for 20 years are projected to be equivalent to a price increase of

11% for residential and 16% for industrial sectors (IEEJ, 2017). In the long run, the price increase could contribute to decreasing the public acceptance of renewables.

The government forecasts that the use of nuclear energy is necessary to alleviate Japan's current energy supply strains, alongside the high energy prices country's industries and end users face. Despite the current trends in solar PV development, Japan's government still aims for nuclear to provide 20–22% of the electricity generation mix. However, the cost competitiveness of nuclear is deteriorating against the decreasing costs of solar PV, wind, and battery systems, in particular because of the costly safety upgrades that will be necessary ahead of any nuclear restart. Gaining social acceptance for re-opening nuclear plants after the Fukushima accident will also be challenging. Driving down the cost of renewables in parallel with the comprehensive market design reform will therefore be of paramount importance.

The share of wind energy is expected to grow more modestly than solar power, reaching 1.7% (20 TWh) by 2030. However, recently, growth has been hampered by a number of factors. During the first year of FiT enforcement, there was only 125 MW onshore wind installed as compared to 1,296 MW solar PV installation. Wind energy generation only accounts for 4–5 TWh of annual generation. This is quite unusual since in many countries wind and solar have grown in lockstep with one another, with wind having been historically more favourable due to its lower cost. The slower development of wind power in Japan has been influenced by regulatory factors, in particular by the environmental impact assessment (EIA) process, which is stricter than that applied to thermal power plants. Wind energy development in Japan requires an EIA, while solar PV projects do not. Many of the good wind locations are in forested areas, where development is strictly prohibited. The coexistence of nature conservation and renewable energy development in Japan underscores the importance of holistic energy system planning.

System integration measures

Installed solar PV capacity in Japan is expected to rise from 48 GW in 2017 to 100 GW by 2030. Reaching this target means high penetration of variable renewables, which will require flexible grid and balancing capacity. So far, Japan relies mostly on pumped storage of hydro and gas to balance demand and supply. In addition to energy storage development, Japan is determined to scale its demand response market to increase grid stability, particularly during peak demand periods. Demand response measures will be included in the auctions for flexible power generation capacity, and electricity balancing and capacity market are planned to be established by 2020 (IEA, 2017d).

As an island nation, grid-related challenges have been considered one of the largest bottlenecks in Japan. Japan has two large synchronous grids that run at different frequencies: where the southwestern half of Japan uses 60 hertz (Hz) and the northeastern half uses 50 Hz. Japan has only three frequency converter facilities that can allow transmission between the two networks, with a capacity of 1.2 GW (IEEFA, 2017b). There is limited sharing of resources between regional system operators due to regional monopolies and the absence of interconnections to neighbouring countries.

In addition, the power system as a whole is rather inflexible due to a high penetration of base load power plants. The power system operators still give priority to conventional generation and require un-adapted (i.e., baseload) nuclear output. Under the FiT, grid operators can enforce renewable energy curtailment without compensation up to 30 days per year and even more than 30 days in cases of newly connected generation facilities (Kimura, 2017). This presents a major risk for investors and contributes to increasing financing costs, while providing another justification for the higher than average FiT rates. Developing greater interregional grid connections and undertaking a reform of the energy market will be two of the key issues to address in moving forward the energy transition.

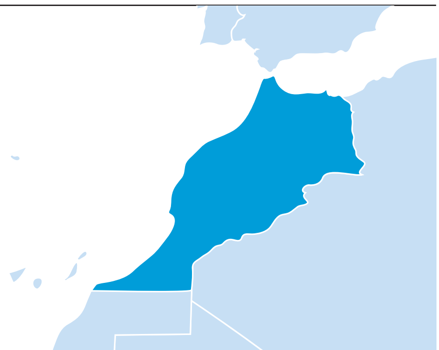
Innovation in business and finance models

The Japan Strategic Energy Plan also formulates a roadmap for intensive R&D in energy-related technologies that are needed for the implementation of a multi-layered, diversified, and flexible energy supply and demand structure. The national R&D budget from 2015 to 2020 is 65 billion EUR for renewable energy and 138.2 billion EUR for energy savings. This includes investment in battery-storage technology, lighter manufacturing technology, and high-tech products (SETIS, 2016).

Given the geographical constraints that Japan faces as an island nation and the scarcity of domestic fossil fuel resources, Japan has had to invest heavily in industrial technology innovation in order to ensure its energy security and reliability. The integration between the sectors plays a key role in the country. As one of the largest electric vehicle markets worldwide, Japan has a high concentration of charging stations (including high-speed charging stations) and is well-positioned to provide leadership in the electrification of the transport sector.

Energy planning	Energy Security, Economic Efficiency, Environment, and Safety
System integration and enabling technologies	Demand response Energy efficiency Sector integration (transport electrification) Energy Storage
Policy instruments and costs of renewables	FiT, auction (this includes residential sector as prosumer) Zero Home Target
Innovation in business and finance models	Intensive R&D for tech innovation Electrification of heating Energy efficiency in end-use sectors

Morocco



Quick energy and climate facts		
Total primary energy supply	[Mtoe/yr]	19
Electricity generation	[TWh/yr]	31
Electricity consumption	[TWh/yr]	30
Per capita total primary energy supply	[toe/cap]	0.6
Per capita electricity consumption	[kWh/cap]	892
Per capita CO_2 emissions	[t CO_2/cap]	1.6

Renewable electricity generation		
Renewable electricity share in total generation	[%]	14.3
Variable renewable electricity share in total generation	[%]	8.2
Variable renewable elecricity capacity add. (2010-2015)	[%]	2.1
Total renewable electricity capacity	[MW]	2,341
Total variable renewable electricity capacity	[MW]	1,034

Power system		
Interconnector capacity with neighbours[2]	[MW]	3,800
Electricity storage capacity	[MW]	625.7
Electricity share in total final energy consumption	[%]	17.8

Renewable electricity targets
52% and 100% renewable electricity share in total generation by 2030 and 2050, respectively
- Hydropower: 2 GW, solar PV and CSP: 2 GW, wind: 2 GW by 2020

Renewable electricity policies
- Renewable energy targets
- Net metering
- Tendering
- Public investment loans, grants, capital subsidies, or rebates

[1] *Compared to the total generation capacity*
[2] *With Spain and Algeria*

Sources: (IEA, 2017a, 2017b; IRENA, 2018b; Office National de l'Electricité et de l'Eau Potable, 2014; REN21, 2018; Sandia Corporation, 2018)

Morocco's demand for energy is growing rapidly. Growth in electricity demand averaged 6.5% per year between 2002 and 2015, driven mainly by economic growth and the country's rising population (IEA, 2014b; Leidreiter and Boselli, 2015). Morocco must provide energy services to its rapidly growing economy and population. However, in contrast to neighbouring Algeria, it has no domestic fossil fuel reserves. Its energy import dependency is more than 95% (this includes electricity imports from Spain, which represent nearly one-fifth of all power consumed in the country).

Morocco has positioned itself as a frontrunner of the energy transition in Africa since adopting its 2009 National Energy Strategy, including ambitious renewable energy and energy efficiency targets. The North African country is blessed with ample resources for solar and wind power (Nfaoui, 2018).

Renewables represented more than 14% of the country's total electricity output in 2015. Around 8% of the total was from wind, and the remaining 6% was from hydropower. In the meantime, the first 160 MW CSP project has become operational, as well as additional wind and PV plants. With over 800 MW of renewable energy projects in operation at the end of 2017, Morocco has the second largest installed capacity (excluding hydropower) in the Middle East and North Africa (MENA) Region after Egypt (866 MW) (IRENA, IEA, REN21, 2018).

Long-term energy planning and existing policy framework

Reducing import dependency, providing affordable access to electricity, and reducing its carbon footprint are the main drivers behind Morocco's energy transition. Building on the original 40% renewables target, the government, at the 21st Conference of the Parties (COP 21), committed to supply more than half of its electricity needs from renewables by 2030 (20% solar, 20% wind, and 12% hydro). In addition, Morocco set a goal to increase energy efficiency by 20% by 2030. In 2009, Morocco established the Moroccan Agency of Sustainable Energy (formerly known as Moroccan Agency for Solar Agency) to promote renewables and integration with neighbouring regions: Europe, sub-Saharan Africa, and other Arab countries. Morocco is also one of the signatories of the Sustainable Electricity Trade that was signed together with the governments of France, Germany, Portugal, and Spain during the COP22 that took place in Marrakech.

Existing policy instruments and costs of renewables

State-owned ONEE is the sole off-taker for power projects developed in Morocco, fulfilling the role of a single buyer. Since 2010, Morocco has focused its renewables policy on competitive bidding processes for independent power producer (IPP) projects. Some of these, in particular early wind and large-scale CSP projects, have relied on highly concessional conditions and have benefitted from considerable support from European and other partners (IRENA, RCREEE, LAS, 2016).

Most recent tenders for wind projects resulted in exceptionally low prices. In 2016, Morocco achieved a record low price of 30 USD per MWh for an installed capacity of 850 MW, three times lower than what Morocco achieved in its 2011 auction at 90 USD per MWh. The consortium that won the project will build five projects under a 20-year build, own, operate, and transfer (BOOT) contract. A 170 MW solar PV project was also recently awarded at an auction price of 60 USD per MWh at the Nour-Ouarzazate solar complex (IRENA, 2017a). At the time, this was the record low price in North African markets. At this same site, 510 MW of CSP capacity was awarded in past auctions.

Morocco's Ouarzazate CSP project under the MENA CSP initiative is a 500 MW public-private partnership (PPP) and is one of the largest solar IPPs in the world. The first phase of the project, with a total installed capacity of 160 MW, started operations in 2016. The project had the objectives to provide secure and affordable electricity generated from CSP and provide employment benefits.

System integration measures

Morocco has been successful in attracting broad interest for medium- to large-scale wind and solar projects, which were awarded in auctions organised by the government and supported in part by international concessional financing. Morocco's unique regulatory and financing conditions have helped increase investor confidence and have contributed to bringing costs down, boosting ambitions to increase renewable energy shares by 2030.

In contrast, the country has been somewhat less successful in terms of improving the market integration of renewable energy and boosting energy efficiency. With a single-buyer market and long-term contracts for conventional and renewable generation, flexibility in power system operation is low and may cause challenges as the share of wind and solar power grows. Plans to liberalise access to medium and low voltage networks for smaller-scale investors are still awaiting implementation. In addition, energy efficiency programmes have not matched the original level of ambition, leading to a reduction of the 2020 target from 12% to 5%; in order to fulfil the 2030 target of a 20% increase in energy efficiency, a new entity has been put in place, the Moroccan Agency for Energy Efficiency (AMEE), which is charged with streamlining policy measures according to the example of the renewable energy agency Moroccan Agency for Sustainable Energy (MASEN) (Le Vert, 2016).

Energy planning	Long-term energy planning
System integration and enabling technologies	Interconnector capacity
Policy instruments and costs of renewables	Large-scale tenders Public-private partnerships

3. Action areas for Turkey based on international experiences

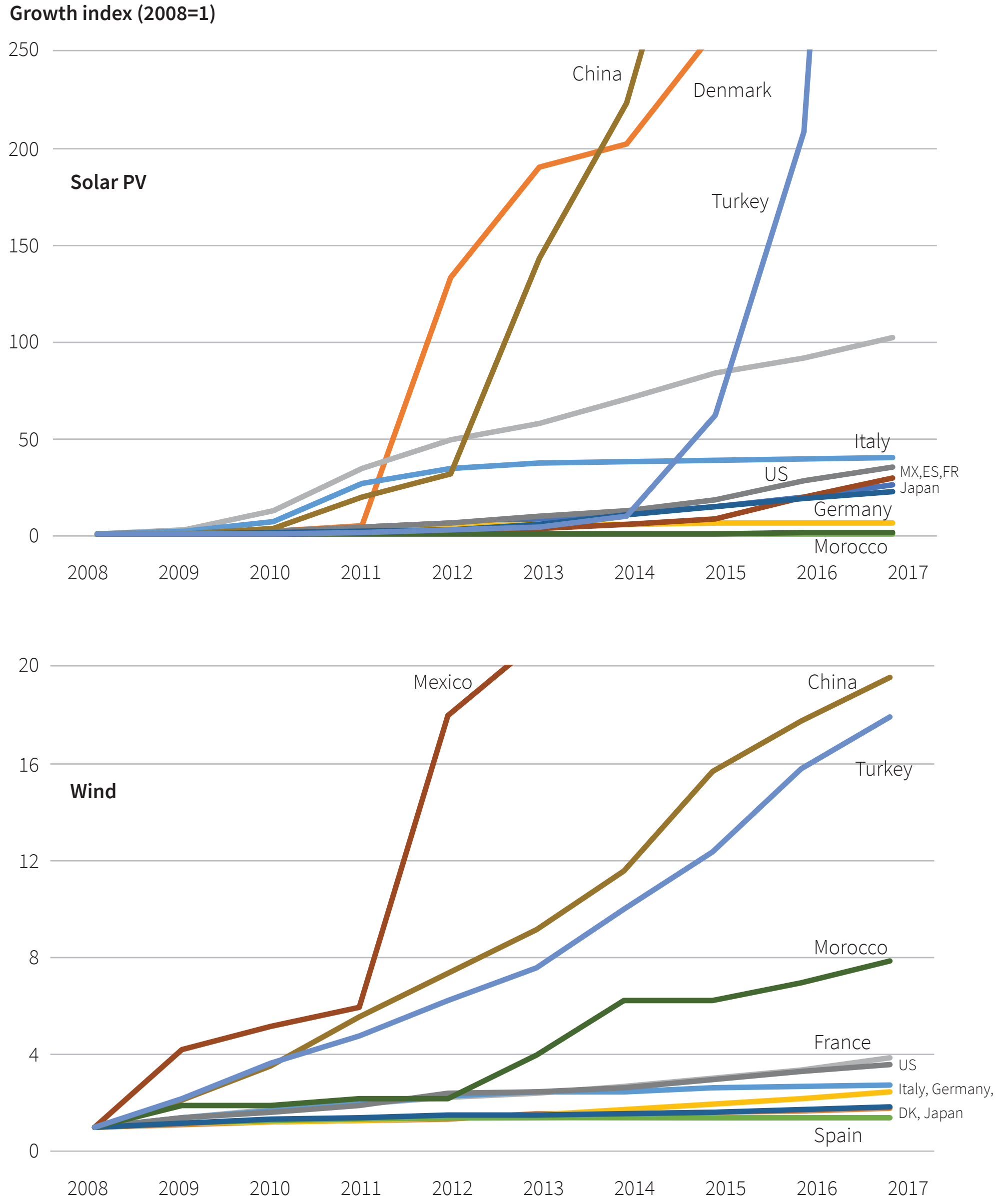
This section provides insights from the recent developments in Turkey on each of the issues that were discussed for all ten countries. For each issue, the most relevant lessons from these countries' best practices and experiences are identified. This provides the framework for suggestions that are provided at the end on how Turkey can efficiently increase its share of wind and solar in the power system.

Long-term energy planning

2017 was an unprecedented year for Turkey's energy transition. Approximately twothirds of all new electricity generation capacity added to the Turkish power system came from renewables. Two different auctions, each for 1 GW of new renewable power capacity, took place, yielding prices of 34.8 USD per MWh for wind and 69.9 USD per MWh for solar PV, about half of the FiT. Following this success of auctions in 2017, the government of Turkey announced three new YEKA auctions in 2018. In 2018, a second round of auctions for both onshore wind and solar PV technologies is announced and they will take place in early 2019. Each auction has a size of 1 GW (4x250 MW for onshore wind and 500 MW, 300 MW and 200 MW for solar PV). Also, another auction for offshore wind with a total capacity of 1.2 GW was initially planned to take place and was recently postponed to 2019. Ministry of Energy and Natural Resources (MENR) recently stated that Turkey plans to install an additional 10 GW solar PV and 10 GW wind capacity in the coming decade. By September 2018, Turkey achieved total installed capacities of more than 6.5 GW and 4.8 GW for wind and solar PV, respectively. Taken together the output from solar and wind power represented over 7% of total electricity generation. When generation from other renewables are also included, this share rises to nearly 30%. Still, Turkey can do much more to accelerate its transition to a more secure, affordable, clean, and sustainable energy system whilst meeting its energy and climate goals.

For each technology, a capacity target has been set for 2023: 34 GW for hydropower, 20 GW for wind, 5 GW for solar PV, 1 GW for biomass, and 1 GW for geothermal. Historically, Turkey invested earlier in wind power than in solar PV. Turkey crossed the 100 MW threshold for solar in 2015, significantly later than many other countries that started harnessing their solar potential a decade ago or even earlier. With the capacity additions in 2016 and 2017, solar PV has grown rapidly in the past two years, reaching rates that were once only seen in Germany, Spain, or Italy. Wind has been growing gradually, averaging 500 MW per year in capacity installations between 2009 and 2013. Recent capacity installations ramped up the compound annual growth rate, which is now four times the global average and following the trends of China and Mexico (see Figure 10).

Figure 10: *Growth in annual solar and wind installations, 2008–2017*



New entrants to the global solar and wind market like Mexico, Morocco, and Turkey are showing impressive growth in solar and wind capacity additions.

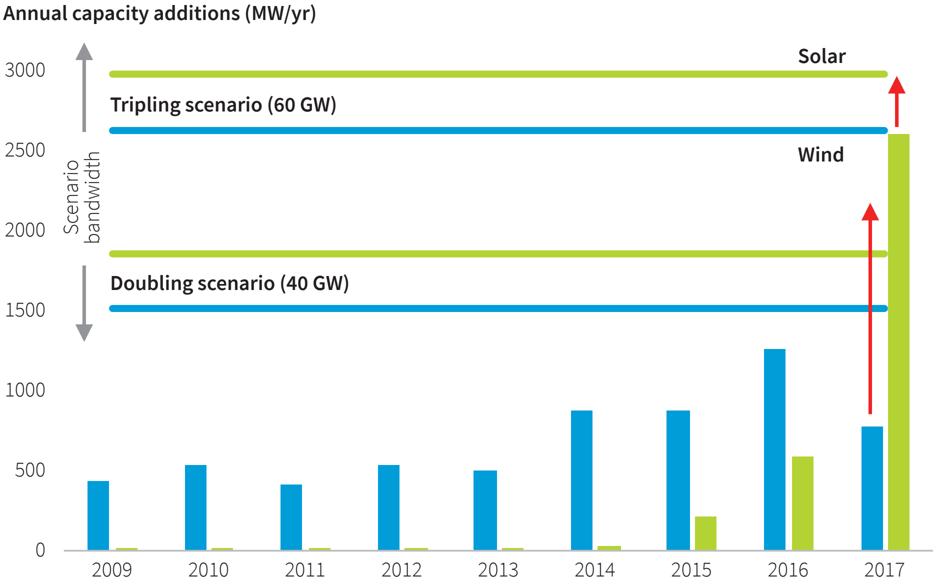
A recent study by SHURA shows the benefits of renewable energy for Turkey, if the country continues this direction. The renewable energy industry is establishing itself and is already offering important socio-economic benefits to the country. In addition, there is appetite for more investments. Renewable energy has emerged as Turkey's main strategy to ensure an affordable and secure supply of energy for its citizens (Saygin et al., 2018b). However, since the beginning of 2018, the slow down in the economy of Turkey and a change in regulation regarding small-scale solar PV have resulted in a fewer investments.

According to the study, without any major operational difficulties and additional investments in its grid, Turkey can supply more than 20% of its total electricity demand with wind and solar power by 2026. A 30% share is technically and economically feasible, as well; however, in order to limit the need for additional grid investments and ensure grid security and reliability, the system will need to become more flexible. Achieving a 20% share means installing 40 GW of total capacity split equally between solar and wind by 2026 (Doubling scenario).

Similarly, a 30% share requires 60 GW of solar and wind power (Tripling scenario). Annual capacity additions would need to double from the 2017 level if Turkey aims to achieve a target of 20 GW of total installed wind capacity by 2026. Achieving 30 GW solar PV by 2026 would only require a 25% increase from 2017 solar PV investments of 2.5 GW. Ramping up capacity additions would create significant investment opportunities in Turkey. Cumulative investments between 2018 and 2026 could reach up to 50 billion EUR. On average this is equivalent to 5.6 billion EUR per year during the same period (see Figure 12) (Saygin et al., 2018a).

Turkey needs to considerably upgrade annual investments in order to supply more electricity from renewable energy sources and improve its energy security. The challenge is significant both for solar and wind in particular.

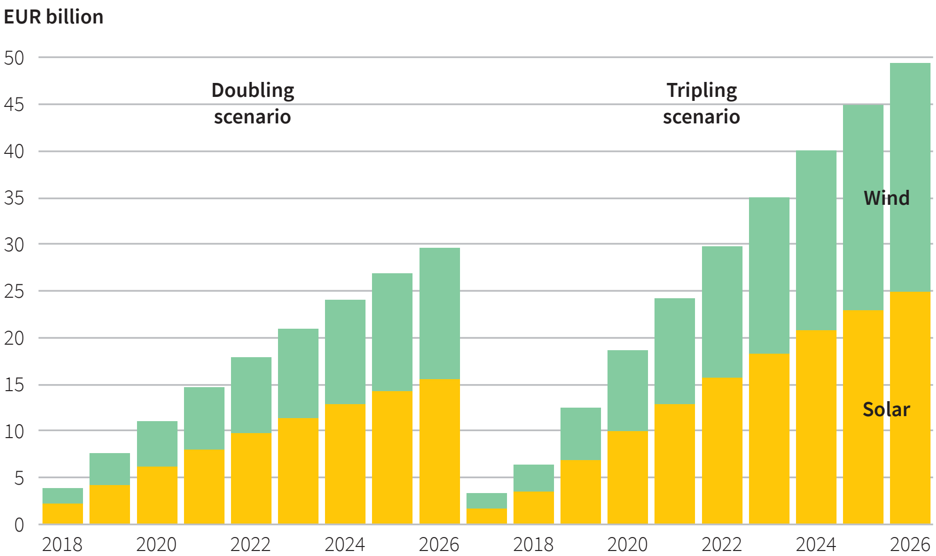
Figure 11: *Annual solar and wind capacity additions needed to reach the Doubling and Tripling scenarios, 2009–2026*



Source: (Godron et al., 2018)

Figure 12: *Cumulative investment potential in Turkey's wind and solar sector, 2018–2026*

Realising a share of 20-30% wind and solar in Turkey's electricity mix would require annual investments between 3.3¬ and 5.6 billion EUR per year on average between now and 2026, depending on electricity demand growth, capacity development, and capital costs of technologies.



Source: (Godron et al., 2018)

Turkey has already surpassed its geothermal target, and it will most likely achieve its solar PV, biomass, and hydropower targets as well. However, if current trends continue, it will most likely fall short from reaching its wind targets. In this respect, it is important to note that Turkey's current solar PV target (5 GW) is quite low when compared to the capacity additions that came online in 2018 alone, as well as in light of its considerable solar resources. The main reason for this is that its solar targets were set at a time when technology cost were much higher-something that can be observed in other countries as well. Turkey would benefit from increasing its solar PV target in the near future in order to tap into a local, more cost-effective supply of electricity.

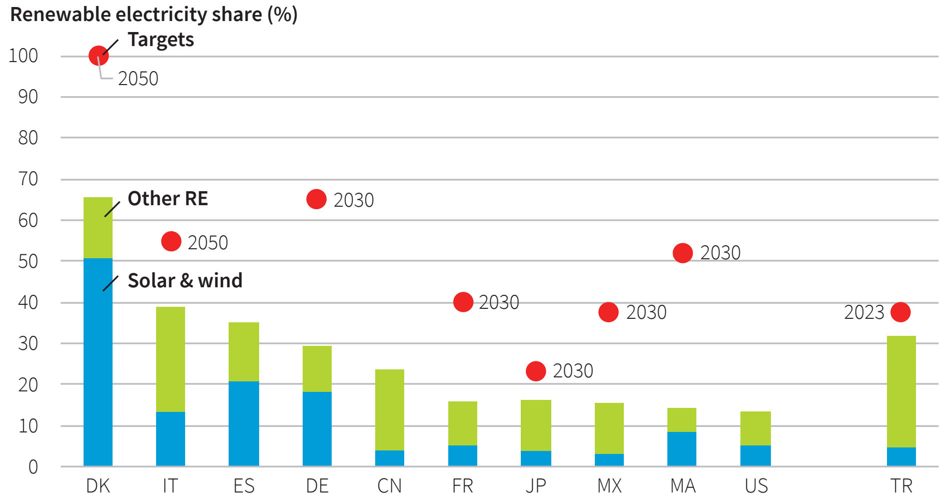
Turkey's only national renewable energy generation target is 37.6% for 2023 that is mentioned in its National Renewable Energy Action Plan (NREAP) (MENR, 2014). With a renewable energy share that fluctuates around 30% (depending on the seasonal effects impacting hydropower output), Turkey will most likely achieve its target in the next five years, by 2023. However, it should also be noted that this target was set in 2014, which naturally captured the favourable market and cost developments in solar PV to only a limited extent.

The current renewable energy strategy has two major shortcomings. First, Turkey's targets were drafted when renewable energy was still relatively expensive: as a result, its targets fail to reflect the myriad of economic and business opportunities that these technologies offer. Second, targets-along with the rest of Turkey's energy and climate policy-are set only in the short term: they focus on 2023, which is the centenary of the Republic of Turkey. A medium- to long-term renewable energy strategy is still to be implemented.

As shown by many country examples, long-term planning and target settings are essential in a market where investments have considerable lead times and long payback times. They provide for reliable market outlooks, increasing the appetite of and competition among investors in the short term and creating sustainable and growing markets. Many countries are regularly updating their targets, raising the ambition level and expanding the time horizon to reflect the declining costs of renewables and their benefits. Expanding the investment horizon in this way helps provide a clear and transparent market signal to investors interested in investing in Turkey for the long term.

With the rapidly declining costs and high rates of capacity installations, many countries have raised their renewable energy ambitions. Turkey is close to achieving its 2023 target, but as of today, there is a lack of medium-term political guidance regardingrenewable energy investment opportunities.

Figure 13: *Renewable energy share in selected countries in 2015 and comparison with national targets*



Costs of renewables and enabling policies

The solar PV and wind projects that were awarded in 2017 yielded favourable auction prices. These recent auction results put Turkey just below the global average for solar PV and wind costs in 2017 (see Figure 14). The record low auction price for wind reflects Turkey's track record in the wind power sector and is a testament to the country's existing manufacturing capacity and supply chains. The price for solar PV was twice as high as the winning wind power bid, despite the fact that other countries have shown that electricity from solar PV can be just as cheap as (if not even cheaper than) wind power today. While country conditions are not necessarily comparable with each other, recent results from other countries around the world, including the UAE, Mexico, and Chile show that solar auction prices have already declined below 50 USD per MWh in many countries (IRENA, 2018a). For instance, according to two recent bids in Senegal, solar PV will supply electricity at roughly 50 USD per MWh, providing one of the cheapest sources of electricity in sub-Saharan Africa (IFC, 2018); as such, generation prices in the same range as those obtained for wind power in Turkey should be feasible in the coming years, if not in the coming months.

As a result of these rapid changes in the industry, there are significant business opportunities in the coming years to leverage Turkey's domestic renewable energy potential to provide lasting benefits to consumers in the form of clean, affordable power.

The projects cited above have different capacity sizes. However, with few exceptions-namely, a wind project in Chile with 1.5 GW and two solar PV projects in Mexico and India with 1.853 GW and 6.8 GW-projects were usually of considerably smaller size than the 1 GW auctions that were awarded in Turkey. There is, of course, an economic rationale for larger projects, which may benefit from economies of scale, making them cheaper. Yet, these economies of scale, from a technological perspective, are rather limited when increasing project size from, say, 200 MW to 1 GW. On the other hand, somewhat smaller project sizes usually increase competition, since they allow more bidders to contribute to the tendering process and, over time, allow more companies to collect experience and develop a track record in the Turkish market (see Figure 15).

As various country experiences have shown, the choice of power plant locations also differs widely. At early phases of market creation, most countries tended to encourage renewable energy development in the regions of the country with the best resource potential. However, as the renewable energy market matures and the best locations are taken up, the geography of projects has become increasingly important (and often, increasingly political, particularly if land rights, conflicts over land use, and issues surrounding public acceptance emerge). This is even more relevant for the low prices achieved today, where, say, ten percent lower solar irradiation at a price of 50 USD per MWh would increase prices by 5 USD per MWh, whereas the difference was 20 USD per MWh at times when a megawatt-hour of electricity from solar PV cost 200 USD.

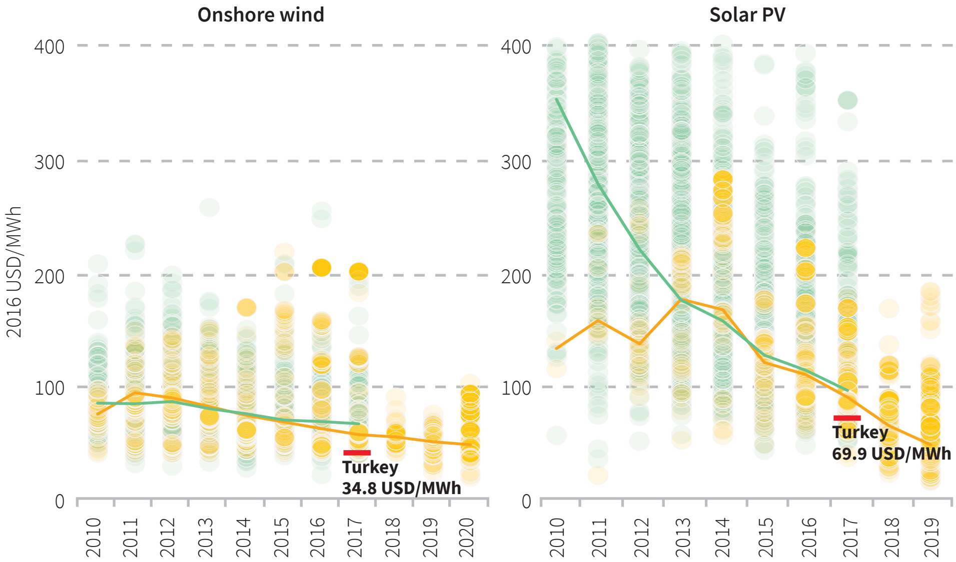
In countries like Germany, Denmark, and France, the governments have had some success in encouraging the geographic dispersion of renewable energy projects over the landscape in order to ease grid integration concerns and to ensure that regions with slightly less resource potential can still develop local projects profitably.
In recent years, other countries have attempted to encourage investors to develop projects nearer to load centres and in particular in areas where the available grid capacity is strong, partly in order to facilitate system integration. The experiences

from these countries will help Turkey as it discusses the next phase of its regulatory framework for renewables and auction design.

Currently, most installed solar PV capacity falls under the "unlicensed" capacity scheme for plants below 1 MW capacity, despite the initial focus being on licensed capacities. This shift was due to technical and economic reasons. At the beginning of this year, Turkey's Energy Market Regulatory Authority decided to postpone the process for pre-licensing 2 GW of wind capacity until 2020. This delay is rather worrying for the sector, since this is a crucial time for Turkey to improve the cost-competitiveness of renewables (Saygin et al., 2018b). Investors, in search for opportunities, have therefore focused on unlicensed projects in 2017. However, these have become more difficult in 2018 as a result of economic uncertainty and overcapacity in the power sector.

Awarded solar and wind projects in Turkey in 2017 were very competitive on the global scale.

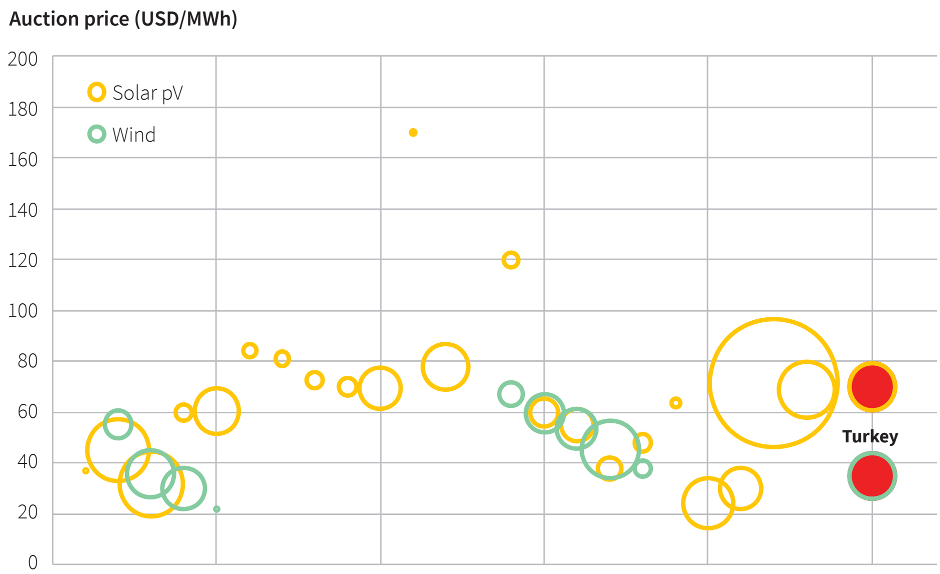
Figure 14: *Global levelised cost of electricity and auction price trends for onshore wind and solar PV, 2010–2020*



Source: (IRENA, 2018a)

The size of wind and solar projects vary from as low as 20–30 MW to 1.5 GW. Very large project sizes do not necessarily result in the lowest bids.

Figure 15: *Auction prices and capacity size of projects in selected countries, 2016*



Note: Data for Turkey is from 2017.

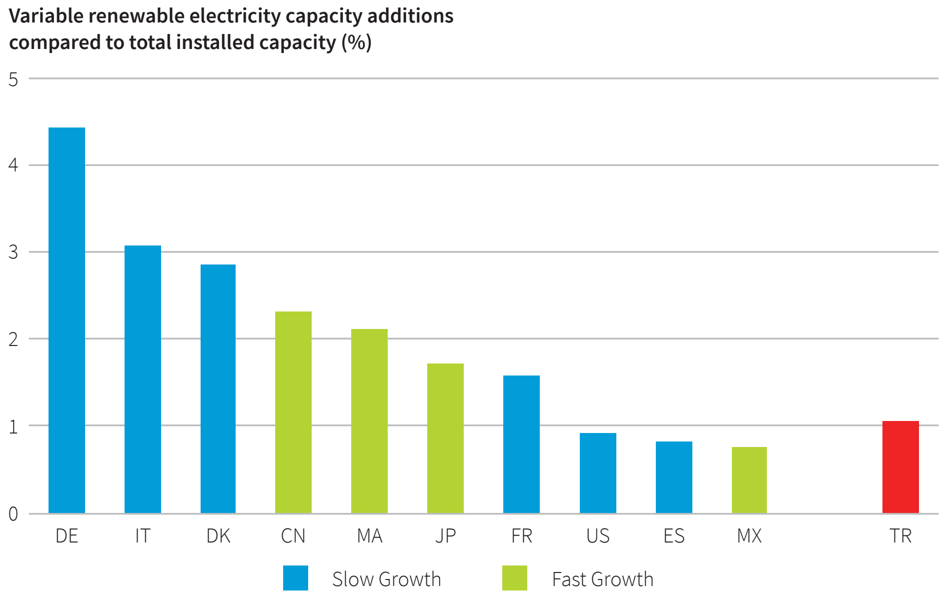
Source: (IRENA, 2017a)

System integration strategies and innovation

Denmark, Germany, Italy and Spain have achieved variable renewable energy shares between 15% and 44%, enabled by strong grids and interconnectivity, updating planning techniques and advancing market operation rules. Other selected countries in this study have lower shares that range between 3–8%. Turkey falls within this range.

Countries with high shares of renewable energy have achieved annual installations that make up 3–5% of their total installed capacity (Figure 16). For instance, experience in countries and states like Germany, Texas, and Italy shows that this can be reached without significant grid integration problems, if operational and planning strategies are adopted in the mid-term. China has achieved similar rates; however, here curtailment remains an issue, because policies and contracts limit the flexibility of the system required for efficient integration. Countries like Turkey and Mexico that are only now beginning to scale-up their renewable energy markets but have large growth in electricity demand have significant potential to ramp up the capacity installation rates. For example, doubling the capacity installation rates Turkey has so far achieved would put it on the pathway to achieve 40 GW solar and wind by 2026.

Figure 16: *Annual capacity additions from solar and wind compared to the total installed capacity, average of 2010–2015*



Countries with slow growth in electricity demand like France, Japan, or Germany have achieved annual solar and wind capacity growth rates between 1.6% and 4.5%. Growing countries like China and Morocco have managed to reach and even exceed these rates.

Integrating higher shares of renewables requires different strategies and technologies depending on the country's choices. The country analysis has pointed to several key measures that have been adopted by one or many of the countries covered here. These key measures include:

- Long-term and comprehensive energy planning, taking into account demand growth, energy efficiency, new technology options, storage, and demand response options: such national energy plans need to be regularly updated, based on detailed quantitative analysis and broad stakeholder consultation
- System integration measures: these include developing strong and modern transmission and distribution grids; improving the quality and frequency of forecasting; making use of leading data measurement and communication tools; making use of the benefits of digitalisation through the expanded use of

so-called “smart grids”, which improve the operational control and allow a more efficient use of network capacity; increasing the interconnection capacity both within the country as well as with neighbouring countries; and adopting grid codes for variable renewables similar to the US state of Texas that include specific requirements for reactive power, fault ride-through and frequency response, as well as defining clear roles and responsibilities for different generation technologies, including wind and solar plants
- Enabling innovative technologies and approaches like energy storage; coupling the power sector with the heating, cooling, and transport sectors to facilitate the balance of supply and demand; driving electrification of other sectors to promote flexibility and efficiently reduce carbon emissions
- Energy supply, demand, and system management for increasing the security and reliability of the system
- Technological innovation and innovation in market design, businesses, and finance models

Additional measures that will become increasingly important in Turkey in the years ahead include moving markets and dispatching protocols closer to real time: this can play a significant role in helping the market balance out variability and uncertainty in the system, thus reducing the operational challenges for TSOs.

As the share of solar and wind power in Turkey’s electricity mix grows, grid management and planning will become more important than ever. Balancing variable generation from different sources across Turkey with demand clustered mainly in the western parts will be challenging. To meet this challenge, ensuring the flexibility of the system and encouraging the development of so-called “grid-friendly” renewables will be key; SHURA’s recently released grid integration study offers concrete steps to help achieve these goals. At the same time, transmission and distribution grids need to become more renewable energy-friendly. A wide range of operational, market, and technological innovations have been implemented by frontrunner countries to improve the integration of variable renewables and enable countries and states to harness more of their domestically available renewable energy potential.

Renewable energy costs have declined significantly in recent decades, due to technological lessons and impressive market growth. Technological innovation has played a key role in the early stages of the energy transition and will continue to be essential for improving the efficiency of existing technologies, further driving down costs and developing breakthroughs like digitalisation and energy storage. However, innovation, research, and development cannot be limited to the technical side but will need to expand across financing, market design, and business models as Turkey’s energy transition enters its next stages.

Suggestions by action area for consideration of policy makers, investors and the renewable energy industry in Turkey

- **Long-term energy planning:** Turkey has developed its renewables and energy efficiency strategy until 2023. While progress has been made towards achieving these targets, now it is suggested to start planning further ahead and establish a medium- and long-term strategy toward 2030 and ultimately toward 2050. This strategy is expected to progressively increase Turkey’s ambitions in meeting its energy transition targets and it is advised to include all sectors of the energy system (electricity, heating and cooling, as well as transport and industrial energy use).

- **Policy design:** Renewable energy auctions have yielded successful results that were awarded with record prices for large-scale utility projects. Turkey is suggested to continue these efforts by considering its resource potential as well as encouraging project development to ease grid integration. As the costs of renewables go down, Turkey is suggested to continue implementing market-based policy mechanisms. In order to increase competition in the medium term, it might be beneficial to develop strategies for incentivising projects of different sizes, from large to medium commercial plants, as part of defining the framework after the expiry of the current feed-in tariff (FiT) system in 2020. These strategies are also suggested to include suitable policy frameworks for distributed generation, which has significant potential in Turkey and might yield strong benefits-both when it comes to reduced losses at the distribution and transmission systems and in terms of local and regional socio-economic value creation. It is suggested to complement these policies with similar instruments and financing for energy efficiency and widespread electrification in heating, cooling and transport sectors.
- **Grid integration and innovation:** As renewables' share increases in the electricity mix, this will require more system flexibility. Providing flexibility takes time and requires significant planning. As part of its energy system planning, Turkey is suggested to carefully analyse the costs and benefits of different flexibility measures, including strategies toward energy efficiency and coupling electricity generation with those sectors that consume the electricity. Setting adequate market framworks is suggested to be emphasised which would incentivise investment in flexibility, be it on the generation, demand, or storage side. Transmission and distribution system planning and operation is suggested to continue its pathway toward modernisation, thus facilitating smart and efficient integration. It is suggested to complement technological efforts toward renewables' grid integration with innovative approaches for new market design as well as new business models and new approaches to financing.

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Agora Energiewende develops evidence-based and politically viable strategies for ensuring the success of the clean energy transition in Germany, Europe and the rest of the world. As a think tank and policy laboratory, Agora aims to share knowledge with stakeholders in the worlds of politics, business and academia while enabling a productive exchange of ideas. As a non-profit foundation primarily financed through philanthropic donations, Agora is not beholden to narrow corporate or political interests, but rather to its commitment to confronting climate change.

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