IRENA
International Renewable Energy Agency

International Energy Agency

REN21 Renewable Energy Policy Network for the 21st Century

Renewable Energy Policies in a Time of Transition

Renewable Energy

ISBN 978-92-9260-061-7

Renewable Energy Policies in a Time of Transition

IRENA
International Renewable Energy Agency

International Energy Agency

REN21 Renewable Energy Policy Network for the 21st Century

ABOUT IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

As of April 2018, IRENA has 156 Members (155 States and the European Union) and 24 additional countries in the accession process and actively engaged.

www.irena.org

ABOUT REN21

The Renewable Energy Policy Network for the 21st Century (REN21) is the global renewable energy policy multi-stakeholder network that connects a wide range of key actors, with the goal of facilitating knowledge exchange, policy development and joint action towards a rapid global transition to renewable energy. REN21 brings together governments, non-governmental organisations, research and academic institutions, international organisations and industry to learn from one another and build on successes that advance renewable energy. To assist policy decision-making, REN21 provides high-quality information, catalyses discussion and debate, and supports the development of thematic networks. REN21 facilitates the collection of comprehensive and timely information on renewable energy, which reflects diverse viewpoints from both private and public sector actors, serving to dispel myths about renewable energy and to catalyse policy change.

www.ren21.net

ABOUT IEA

The IEA examines the full spectrum of energy issues including oil, gas and coal supply and demand, renewable energy technologies, electricity markets, energy efficiency, access to energy, demand side management and much more. Through its work, the IEA advocates policies that will enhance the reliability, affordability and sustainability of energy in its 30 member countries, 7 association countries and beyond.

The four main areas of IEA focus are:

- **Energy Security:** Promoting diversity, efficiency, flexibility and reliability for all fuels and energy sources;
- **Economic Development:** Supporting free markets to foster economic growth and eliminate energy poverty;
- **Environmental Awareness:** Analysing policy options to offset the impact of energy production and use on the environment, especially for tackling climate change and air pollution; and
- **Engagement Worldwide:** Working closely with association and partner countries, especially major emerging economies, to find solutions to shared energy and environmental concerns.

www.iea.org

ACKNOWLEDGMENTS

This report was written jointly by IRENA, IEA and REN21, under the guidance of Rabia Ferroukhi (IRENA), Paolo Frankl (IEA) and Christine Lins (REN21).

Individual chapter authors were as follows:

INTRODUCTION AND BACKGROUND

Hannah E. Murdock (REN21)

With input from Louise Vickery (IEA)

HEATING AND COOLING

Ute Collier (IEA)

TRANSPORT

Rana Adib (REN21)

With input from Pharoah Le Feuvre (IEA), Flávia Guerra, Archita Misra and Hannah E. Murdock (REN21)

POWER

Diala Hawila (IRENA)

With input from Sadie Cox and Sean Esterly (NREL), Caspar Priesmann (GIZ), and Hadley Taylor (EUEI-PDF)

SYSTEM INTEGRATION OF RENEWABLES

Emanuele Bianco and **Simon Müller** (IEA)

With input from Cédric Philibert, Oliver Schmidt, Oskar Kvarnström, Ute Collier and Zoe Hungerford (IEA)

POLICY CLASSIFICATION

Rabia Ferroukhi, Diala Hawila, Michael Renner and **Divyam Nagpal** (IRENA), **Christine Lins, Rana Adib and Hannah E. Murdock** (REN21), **Paolo Frankl, Ute Collier** and **Emanuele Bianco** (IEA)

With input from Barbara Breitschopf (Fraunhofer Institute for Systems and Innovation Research - ISI), Sascha Van Rooijen (Ecofys Group), Sadie Cox and Sean Esterly (NREL), Caspar Priesmann (GIZ), and Hadley Taylor (EUEI-PDF)

REVIEWERS

This report benefited from valuable feedback and inputs from: Henning Wuester, Dolf Gielen, Salvatore Vinci, Ahmed Abdel-Latif, Bishal Parajuli, Michael Renner, Divyam Nagpal, Abdullah Abou Ali, Celia García-Baños, Jinlei Feng, Emanuele Taibi, Francisco Boshell, Asami Miketa, Thomas Nikolakakis and Arina Anisie (IRENA), Paul Simons, Rebecca Gaghen, Elaine Atwood, Heymi Bahar, Oliver Schmidt, Renske Schuitmaker and Jacopo Tattini (IEA), Laura E. Williamson (REN21).

This report benefited from valuable feedback from: Aaron Robinson (United Airlines), Adam Johnston (Salay Consulting), Ahmed Hamza H. Ali (Faculty of Engineering, Assiut University), Alejandro Limón Portillo (Centro de Investigación Económica y Presupuestaria), Ashwin Gambhir (Prayas Energy), Barbara Breitschopf (Fraunhofer ISI), Bikash Kumar Sahu (Gandhi Institute for Education and Technology), Casper Priesmann (GIZ), Christy Aikhorin (TechnipFMC), Catharina Ringborg (Utmaning), David Napper (Enviro-Development), David Walwyn (University of Pretoria), Dieter Holm (Southern African Solar Thermal Training & Demonstration Initiative - SOLTRAIN), Dorothea Otremba (Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH - GIZ), Emilio Soberon (World Wildlife Fund Mexico), Emmanuel Branche (Électricité de France S.A.), Eros Artuso (ProQuest Consulting Ltd), Evan Musolino, Filip Johnsson (Chalmers University of Technology), Franklin Molina, Freyr Sverrisson (Sunna Research), Gaetano Zizzo (Università di Palermo), Gianluca Sambucini (United Nations Economic Commission for Europe - UNECE), Heather Rosmarin (InterAmerican Clean Energy Institute), Henrik Personn (Caribbean Community Climate Change Centre, Belize), Isabel Welten (Goodfuels), Janet Sawin (Sunna Research), Johanna Diecker (Global off Grid Lighting Association - GOGLA), Joshua Odeleye, Julian Barquin (Endesa), Kanika Chawla (Council for Energy, Environment and Water), Karl Peet (Partnership on Sustainable Low Carbon Transport - SLoCaT), Karla Solis (United Nations Framework Convention on Climate Change - UNFCCC), Kurtulus Deger (Durham University), Lisa Göransson (Chalmers University of technology), Lisa Wolf (Eurelectric), Maged Mahmoud (Regional Cneter for Renewable Energy and Energy Efficiency - RCREEE), Manjol Banja (European Commission), Manoj Singh (India Power), Michael Rask (Raskgreentech ApS), Miguel Schloss (Surinvest Ltd), Ming Yang (Global Environment Facility - GEF), Monica Zamora Zapata (University of California, San Diego), Nguyen Dang Anh Thi (Independent consultant), Nicholas Craven (UIC), Nikola Medimorec (Partnership on Sustainable Low Carbon Transport – SloCaT), Nikolay Belyakov (Hilti), Pablo Del Río (Instituto de Políticas y Bienes Públicos), Peter Krenz (GMX), Rainer Hinrichs (European Renewable Energy Federation),Ralf Christmann (Bundesministeriums für Wirtschaft und Energie - BMWi), Rina Bohle Zeller (Vestas), Robert J van der Plas (Marge), Sadie Cox (NREL), Sascha Van Rooijen (Ecofys Group), Sean Esterly (NREL), Sharon Denny (Global Futuremakers), Shehu Khaleel (Rendanet), Sigrid Kusch (ScEnSers Independent Expertise - Science and Engineering for Sustainable Environmental Resources), Stefanie Seitz (Deutsches Biomasseforschungszentrum gGmbH), Tineke Van der Schoor (Hanze University of Applied Sciences), Vimal Mahendru (International Electrotechnical Commission), Virendra Kumar Vijay (Indian institute of Technology Delhi), Yasemin Erboy Ruff (CLASP), Yann Loic Tanvez (World Bank), Zvirevo Chisadza (International Institute of Engineers, Zimbabwe Institution of Engineers).

Research Support: Mimi Lie (REN21)

FOREWORD

Renewables have progressed at an unprecedented pace over the past decade and have consistently surpassed expectations, with new records being set each year and an increasing number of countries committing to their respective energy transitions. Much of the advancement has been achieved thanks to effective policies and planning, coupled with ambitious targets. However, to meet the goals established in the Paris Agreement, the pace of the energy transitions will have to increase – and for this, policies enabling a rapid renewable energy deployment will be essential.

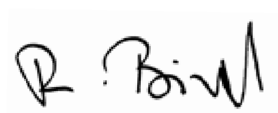
Policy support for renewables continues to be focused primarily on power generation globally, with efforts in the heating and cooling and the transport sectors significantly lagging behind. In the future, policy frameworks need to take a systems approach with more fully integrated policies across sectors, incorporating supporting infrastructure and measures for balancing supply and demand, taking advantage of synergies with energy efficiency, and harnessing distributed renewables for increased access to electricity and clean cooking. Above all, policies should be stable and transparent. Though many challenges remain, not least among them the continued subsidies for fossil fuels, more sophisticated policies continue to stimulate and support the increasing uptake of renewable energy worldwide.

The International Renewable Energy Agency (IRENA), the International Energy Agency (IEA), and the Renewable Energy Policy Network for the 21st Century (REN21) have joined forces to produce a new publication, Renewable Energy Policies in a Time of Transition, in a first collaboration of this nature. This publication aims to provide policymakers with a comprehensive understanding of the diverse policy options to support the development of renewables across sectors, technologies, country contexts, energy market structures, and policy objectives. It not only illustrates the changing landscape of policies for renewable energy in power, heating and cooling, and transport, but also highlights the importance of system integration and sector coupling, reflecting the expanding opportunities for integration with increasing renewable energy deployment.

Additionally, the publication presents an updated classification of renewable energy policies, jointly formulated by the three institutions, to illustrate the latest policy developments around the world and facilitate harmonised policy tracking. As policy design for renewables continues to evolve and increase in sophistication, the lines separating policies in the traditional classifications have become increasingly blurred. This new classification also captures the importance of the broader policy context – one that goes well beyond energy sector policy alone - required to achieve the energy transition in line with the appropriate socio-economic structures to support it.

On behalf of IEA, IRENA and REN21, we would also like to thank those who contributed to and reviewed earlier drafts of the document. We hope that this joint effort will prove helpful for policymakers around the world as they strive for further deployment of renewable energy across all sectors.

Adnan Z. Amin
Director General
International Renewable Energy Agency (IRENA)



Dr. Fatih Birol
Executive Director
International Energy Agency (IEA)

Dr. Arthouros Zervos
Chair
Renewables Energy Policy Network for the 21st Century (REN21)

Renewable Energy Policies in a Time of Transition

LIST OF FIGURES

LIST OF TABLES

LIST OF BOXES

ES

EXECUTIVE SUMMARY

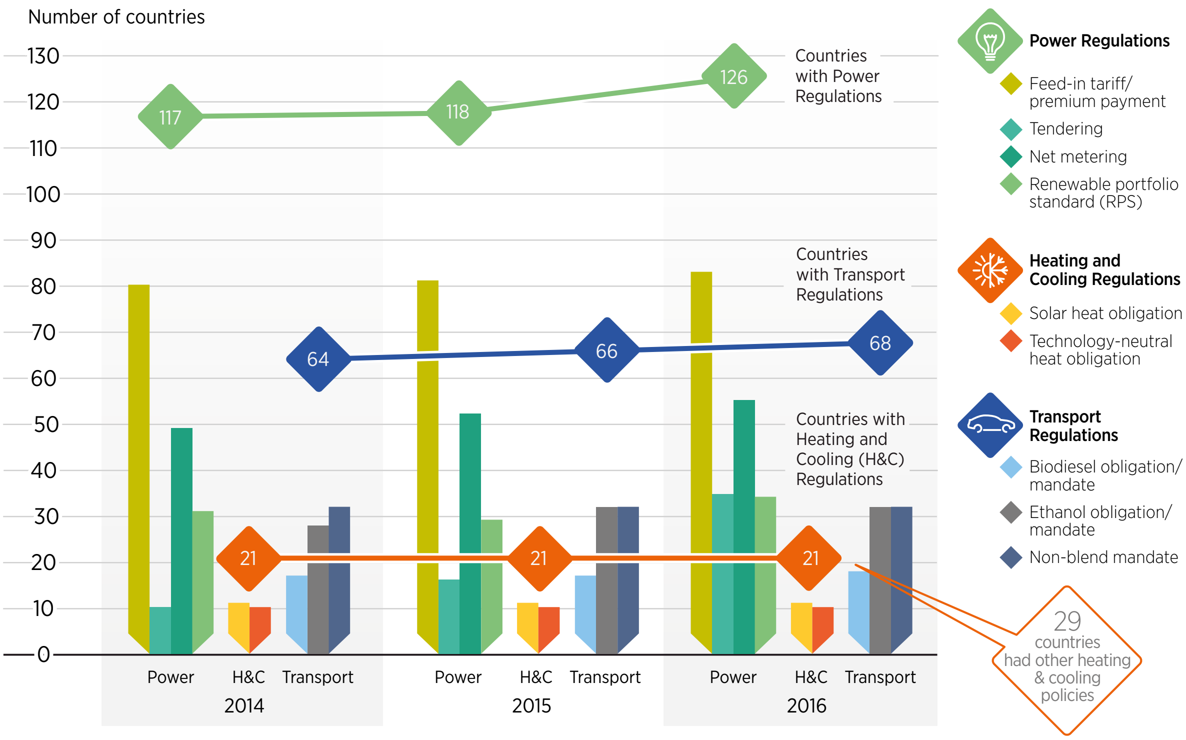
EXECUTIVE SUMMARY

Renewables have experienced a remarkable evolution over the past decade. Indisputably, they now form the leading edge – in combination with energy efficiency – of a far-reaching global energy transition. Spurred by innovation, increased competition, and policy support in a growing number of countries, renewable energy technologies have achieved massive technological advances and sharp cost reductions in recent years. Consequently, the growth in their deployment has come to outpace that of any other energy source.

In 2017, investments in new renewable power capacity outstripped the amount invested in fossil-based generating capacity, with most of the installation of new renewable energy capacity currently occurring in developing and emerging countries. With nearly every country in the world adopting a renewable energy target, renewables are now considered a technologically mature, secure, cost-effective and environmentally-sustainable energy supply option to underpin continued socio-economic development, while simultaneously combating climate change and local air pollution.

However, progress so far has not been homogenous across countries and sectors. Several key barriers still hamper renewable energy deployment, ranging from technology and financial risks in new markets to integration challenges in markets with high shares of variable renewables. Moreover, despite significant progress in the power sector, renewables are lagging behind for heating and cooling and transport applications, with fewer countries implementing regulatory measures for those end-uses (Figure ES.1). As renewable technologies mature, policy makers are confronted with new challenges. The rapid expansion of variable renewables, such as solar photovoltaics and wind power, requires more flexible energy systems to ensure reliable and cost-effective system integration. In general moving forward, renewable energy policy approaches will have to be more holistic and sophisticated to reflect the transformative changes induced by the energy transition on the energy sector, society and economy.

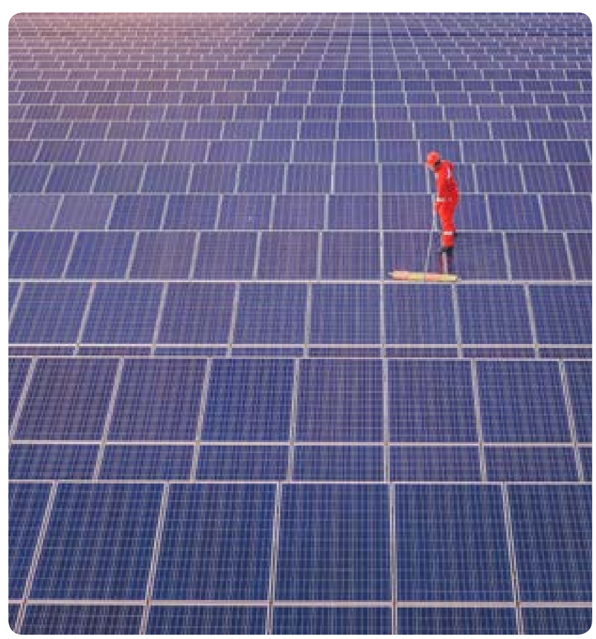
Figure ES.1 Number of renewable energy regulatory incentives and mandates, by type, 2014-16



Note: Figure does not show all policy types in use. In many cases countries have enacted additional fiscal incentives or public finance mechanisms to support renewable energy. Heating and cooling policies do not include renewable heat FITs (i.e., in the United Kingdom). Countries are considered to have policies when at least one national or state/provincial-level policy is in place. A country is counted a single time if it has one or more national and/or state/provincial level policies. Some transport policies include both biodiesel and ethanol; in this case, the policy is counted once in each category (biodiesel and ethanol). Tendering policies are presented in a given year if a jurisdiction has held at least one tender during that year.

Source: REN21, 2017b.

This report, produced jointly by the International Renewable Energy Agency (IRENA), the International Energy Agency (IEA), and the Renewable Energy Policy Network for the 21st Century (REN21), offers policy makers a comprehensive understanding of the options available to support the development of renewables. Beginning with recent deployment trends and the status of policies and targets globally, the report goes on to examine policies for each sector of energy use – heating and cooling, transport and power – and measures for integrating variable renewables into the power sector. Finally, an updated policy classification and terminology is presented and it aims to provide a global reference for policy instruments.



POLICIES IN THE HEATING AND COOLING SECTOR

Heating is the largest energy end-use, accounting for over 50% of total final energy consumption in 2015, with over 70% of that met by fossil fuels. Renewables can play a key role in decarbonising and providing a cleaner heating and cooling supply option. Dedicated policies and measures are crucial to drive this until now rather neglected aspect of the energy transition.

Slow renovation rates in existing building stock and a slow turnover of heating and cooling appliances in both buildings and industry necessitate a long-term strategy for decarbonising the sector. Countries should set dedicated targets for renewables in heating and cooling and develop strategies to achieve the set targets.

Multiple barriers call for a range of policy instruments, often in combination. Policy approaches vary according to differences in heat demand, infrastructure and other contextual factors and they can be clustered around support for renewables for district heating and cooling, industrial heating and hot water, clean cooking, and renewables competing with extensive individual natural gas heating. The most commonly used policies are mandates and financial and fiscal incentives.

Mandates and obligations, such as those for solar water heaters in some countries, offer greater certainty of increased deployment. Building codes can also implicitly support renewable heating and cooling from renewables by setting energy performance requirements. Although they apply mostly to new buildings only, they provide an opportunity to align energy efficiency with renewable energy requirements. Renewable heat and energy efficiency policies should be closely aligned to leverage synergies and accelerate the pace of transition.

Fiscal and financial incentives are often used to reduce the capital costs of renewable-based heating, and to create a level playing field with fossil fuels. They can be used to support district energy infrastructure which could enable the integration of multiple renewable heat options. Most recently, heat generation-based incentives are being applied, providing support over longer periods. Fiscal incentives are also sometimes available for renewable cooling solutions, although most policy effort has gone into improving the energy efficiency of air conditioners.

Carbon or energy taxes can also provide important price signals and reduce externalities, but design and implementation challenges remain, especially in contexts where energy-intensive industries are subject to strong international competition and may ask for exemptions.

Much more effort at the policy level is needed in a larger number of countries. Approaches to renewable heat policy will have to vary between countries, reflecting different circumstances (e.g. building stock, industrial heat demand, resource potential) and specific barriers that need to be overcome. While there is no one-size-fits-all solution, all countries should set themselves targets for renewables in the heating and cooling sector and develop strategies how to achieve them, coupled with measures for energy efficiency.

POLICIES IN THE TRANSPORT SECTOR

Transport is the second largest energy end-use sector, accounting for 29% of total final energy consumption in 2015. It remains heavily reliant on fossil fuels, with 96% of the sector's energy use coming from petroleum products. Conversely, transport accounts for 64.7% of world oil consumption in 2015.

With the exception of biofuels, there is little practical experience of fostering renewables in transport. The large majority of policy interventions to date have been related to biofuels, while policies aimed at developing electric-power transport based on renewables have only recently begun to emerge. A large uptake of renewable energy in transport requires simultaneous and integrated changes in three main areas: 1) the availability of energy carriers and fuels produced from renewable sources; 2) the deployment of vehicles that can use renewable fuels; and 3) the development of energy and fuel distribution infrastructure.

Policies and planning should aim at overcoming key barriers, such as the immaturity or high cost of certain technologies, inadequate energy infrastructure, sustainability considerations and slow acceptance among users as new technologies and systems are introduced. They should also foster improved understanding between decision makers in the energy and transport sectors, so as to enable integrated planning and policy design.

Considering the high dependence of the transport sector on fossil fuel, removal of fossil fuel subsidies is essential for decarbonising the transport sector. This is particularly true for shipping and aviation as both sectors currently benefit from fuel tax benefits and exemptions. In this context, a price on carbon would be a key tool to stimulate the decarbonisation of the transport sector, although implementation could be politically challenging and much work remains to reach a global consensus. Also, low carbon-fuel standards which include life-cycle GHG emission reduction and sustainability criteria are a useful measure to facilitate decarbonisation of transport.

In general, decarbonisation of the transport sector remains a huge task that requires a fundamental change in the nature and structure of transport demand, improvements in efficiency and changes in the energy mix, which all require major policy push.

POLICIES IN THE POWER SECTOR

Although the power sector consumed only about a fifth of total final energy consumption in 2015, it has so far received the most attention in terms of renewable energy support policy. Renewable energy deployment in the power sector continues to expand significantly. Renewable generation increased at an annual average rate of 6.4% between 2009 and 2014, outpacing growth in electricity demand and in generation from non-renewables. In 2015, renewables provided about 23.5% of all electricity generated, the bulk of which came from hydropower, followed by wind, bioenergy and solar photovoltaic (PV). These developments have been driven mainly by falling technology costs and support policies.

Investments in the sector are largely driven by regulatory policies such as quotas and obligations and pricing instruments, supported by fiscal and financial incentives. Quotas and mandates enable targets to cascade down to electricity producers and consumers. They are generally supported by tradable renewable energy certificates. To ensure the effectiveness of quotas and certificates, a robust framework to monitor and penalise non-compliance is needed.

Administratively set pricing policies (feed-in tariffs and premiums) need to continuously adapt to changing market conditions and regular tariff-level adjustment is one example of measures needed to reflect the falling cost of technology. In this context, auctions are being increasingly adopted, given their ability for real-price discovery. Auctions have resulted in electricity prices from solar PV in 2016 equal to almost a fifth of what they were in 2010, reflecting developments in the sector. Prices for onshore wind were almost halved in that period.

Notably, however, the success of an auction in achieving policy deployment and development objectives relies on its design. This is also true for any other instrument and there is not one policy that can serve as the preferred policy in all contexts. The choice of policy instrument should depend on the specific country conditions, state of the energy market, technology, and objectives to achieve. In many contexts, auctions are used for large-scale projects and feed-in tariffs and premiums for small-scale installations.

Distributed generation can be supported through net metering and net billing. However, careful consideration is needed to avoid jeopardising the system's cost recovery and prevent cross-subsidisation among those customers who self-consume and those who do not.

Voluntary and corporate purchase programmes for renewable energy are an increasingly important part of the energy transition going forward. They are often complemented by information awareness campaigns highlighting the benefits of renewable energy.

POLICIES FOR SYSTEM INTEGRATION

A number of countries and regions are reaching high penetrations of VRE in their power systems, and implementing policies to facilitate their system integration. VRE technologies have a number of unique characteristics which, with increasing penetration, can create challenges for the overall power system. Strategies for system integration of renewables (SIR), consisting of a coordinated sequence of measures, are crucial to minimise negative impacts, maximise benefits and improve the cost effectiveness of the power system.

Challenges emerge progressively as VRE shares grow in the power system. The increasing impact of VRE on the power system can be categorised by phases and, consequently, the system's ability to deal with VRE should be enhanced gradually following VRE impact. Co-ordination of VRE deployment and SIR measures is crucial to operate the system in a cost-effective, reliable and safe manner.

The very first VRE plants usually do not pose a particular challenge on the system. As the presence of VRE begins to be evident to system operators, new or revised grid codes, improved system operations, coordinated grid and VRE deployment may be necessary as SIR measures.

At higher shares of VRE, flexibility becomes an increasingly valuable characteristic in the power systems. The complexity of the power systems requires measures that address technical challenges, system operations, market design and the definition of roles and responsibilities. This would result in a deployment of flexible resources that is technically feasible, financially attractive and recognised by all power system stakeholders.

As the VRE shares expand, policies need to adapt to the changing system conditions. Further, as the transport, heating and cooling and power sectors become increasingly integrated, cross-linked decision making and policy design that is beneficial across sectors will be crucial.

In an age of inexpensive VRE, the success of SIR strategies is crucial for high shares of VRE to translate into low-cost electricity for consumers.

POLICIES FOR ENERGY ACCESS

Decentralised renewable energy solutions (stand-alone and mini-grids) will play a key role in achieving universal access to modern energy services by 2030 – a target within the Sustainable Development Goal (SDG) 7 on energy. These solutions also have the potential to contribute to other SDGs related to livelihoods, education, health, water, employment and gender equality. To realise these benefits, tailored policies are needed to support the deployment of decentralised renewables to accelerate the pace of energy access.

National energy access plans should consider both on- and off-grid solutions to reach universal access in a timely manner. Targets for electrification using stand-alone systems and mini-grids have been adopted by many developing countries. In the specific case of mini-grids, enabling regulatory measures are needed related to the right to generate and sell electricity, tariff-setting and main grid-connection, and fiscal and financial incentives such as subsidies, grants and tax breaks. Equally important are quality assurance frameworks, measures to facilitate access to finance, capacity building and linking energy services to livelihoods.

Greater attention is needed to reduce the use of traditional fuels for heating and cooking. Energy access plans should prioritise the adoption of clean-cooking systems and fuel switching towards modern fuels. Quality and standards, awareness raising and capacity building are key components for the delivery of clean-cooking solutions and should be integrated into energy access plans.

THE WAY FORWARD

Despite the significant progress made over the past decade and the growth in policy support, renewables have yet to reach their full potential and key barriers still inhibit further development. These relate to technology, awareness and capacity, cost, finance, infrastructure and public acceptance, in addition to policy, regulatory, institutional and administrative barriers. Unless renewable energy and energy efficiency are scaled up more rapidly, international climate objectives will not be met, and even the 2 degree Celsius limit for global warming, as set out in the 2015 Paris Agreement, will not be achievable.

Substantial efforts are still required to scale-up deployment (together with energy efficiency) to meet climate objectives. To this end, a combination of policy measures are needed, focusing on direct support (deployment), integration and enabling environment.

Direct policy support for renewable energy has to be increased in the power and end-use sectors, which both account for large shares in final energy consumption as well as energy related CO_2 emissions. In many countries, renewables continue to face competition from subsidised fossil fuel options. Meanwhile, **enabling policies** are needed to ensure effective operating conditions for renewables in energy systems and markets. As such, policy makers should make sure that renewable energy technologies can operate in the system on a level playing field with other technologies, facilitating innovation, supply and consumption of renewable energy in all end-uses.

Finally, renewable energy needs to be integrated into the daily life of consumers and prosumers, as well as into the institutional framework, to allow them to be part of the overall energy transition. **Integrating policies**, in this context, are those measures that allow the full integration in the energy system: for example, measures to encourage behavioural change (through raising awareness programmes) and policies to couple renewable energy technologies with livelihoods (in the access context).

In any area of energy use, no single instrument can fulfil all country objectives. Policies must be selected with care and designed or adapted to reflect specific national and local circumstances. The long-term stability of targets and policies is key to ensuring investor confidence and sustained growth. At the same time, policies need to continuously adapt to changing market conditions, to achieve greater cost-competitiveness and improved integration of renewables into the system. To ensure that the energy transition accelerates, greater attention must be paid to the transformative impact on society, institutions, financing, ownership structures and the wider economy. This requires supporting effective participation by all stakeholders.

Policy makers already have the tools necessary to support increased deployment, and a wide variety of actors, including traditional utilities, have already taken promising actions. The time has come to exploit the synergies in those actions, to break down the remaining barriers, allow for increased integration of renewable energy across sectors, and go beyond energy sector policy to broader development policy to achieve the energy transition.

01

INTRODUCTION AND BACKGROUND


Spurred by innovation, increased competition, and policy support in a growing number of countries, renewable energy technologies have achieved massive technological advances and sharp cost reductions in recent years. Consequently, their deployment has come to outpace that of any other energy source. Most countries now see renewable energy as a technologically mature, affordable and clean option in their development strategies. Specifically, renewables can drive economic growth, secure energy supply, and broaden energy access, while simultaneously combating climate change and air pollution.

However, progress is not homogeneous across countries and sectors. Several key barriers still hamper renewable deployment in some developing countries. Moreover, despite significant progress in the power sector, renewables are lagging behind for heating and cooling and transport applications, with fewer countries implementing regulatory measures for those end-uses. As renewable technologies mature, policy makers are confronted with new challenges. The rapid expansion of variable renewables, such as solar photovoltaic (PV) and wind power, requires more flexible energy systems in order to ensure reliable and cost-effective system integration. In general, the graduation of renewables into the mainstream calls for more holistic and sophisticated policy approaches, which can be perceived as a new challenge by some governments.

Produced jointly by the International Renewable Energy Agency (IRENA), the International Energy Agency (IEA) and the Renewable Energy Policy Network for the 21st Century (REN21), *Renewable Energy Policies in a Time of Transition* provides policy makers with an understanding of policy options that can support the development of renewables in a manner that is sensitive to technology, country context and the state of energy markets.

Beginning with recent trends in renewables and the status of policies and targets globally, this report takes an in-depth look at policies for heating and cooling, transport and power, with an additional chapter on integrating variable renewables into the power system. The updated policy classification and terminology presented in chapter 6 serve as a global reference for policy instruments. This chapter introduces trends in renewables; the main drivers, players and barriers for increasing deployment; and the global status of policies and targets[1].

1.1. THE RENEWABLE ENERGY ERA

Renewables have experienced a remarkable evolution over the past decade. Global installed capacity and production have grown exponentially, particularly in the power sector, as costs continue to fall. A record amount of newly installed renewable power capacity has been added in recent years – mostly solar PV, wind power and hydropower – and renewable energy accounts for almost two-thirds of all new generating capacity installed around the world in 2016. The cost of electricity from renewables is decreasing across technologies – quite rapidly for solar PV and wind – and observers are noting record low prices at auctions globally. Most of the installation of new renewable energy capacity is now occurring in developing and emerging countries.

As costs have declined, investment in renewables has climbed, with increased investor interest driven partly by public commitments and rapidly maturing technologies. By 2017, global cumulative investment in the sector totalled USD 2.9 trillion since 2004. In 2017, investments in new renewable power capacity far out-stripped the amount invested in fossil fuel generating capacity and developing and emerging countries overtook industrialised ones in renewable energy investments (as in 2015) (FS-UNEP/BNEF, 2018). Emerging economies are increasingly committed to transforming their energy industries as capital and operation costs fall and strategies for renewable energy deployment become more

1 Unless otherwise indicated, data and information in this chapter come from the REN21 *Renewables 2017 Global Status Report and Advancing the Global Renewable Energy Transition: Highlights of the REN21 Renewables 2017 Global Status Report* (REN21, 2017a, 2017b).

widespread. China has surged past other markets as the single largest developer of renewable power and heat since 2009.

Government support policies have been instrumental in the global increase of renewable energy investments. Renewable energy support policies have continued to expand across all regions, and nearly all countries now have at least one renewable energy target. The number of countries promoting renewables through direct policy support has tripled, from at least 48 in 2004 to at least 147 by 2017, and additional developing and emerging countries continue to adopt renewable energy targets and policies. Information and communication technologies, storage systems, electric vehicles and heat pumps are facilitating variable renewable energy deployment. The many synergies between renewables and energy efficiency point to the wisdom of considering the two together in integrated planning (see Box 1.1).

Despite the progress seen over the past decade, considerably more renewables deployment is necessary to achieve international climate objectives. Policy makers can play a key role in advancing the energy transition by enacting policies that support the increased deployment and integration of renewables. Support policies for renewable energy aim primarily at stimulating growth in capacity and production. Well-designed policies lead to increased deployment and cost reduction; they support growth in the renewables industry, market creation and expansion, and technology development; and they provide the security needed for renewables investment – all of which contribute to decreasing costs and increasing competitiveness.

BOX 1.1. THE LINK BETWEEN ENERGY EFFICIENCY AND RENEWABLE ENERGY

The stabilisation between 2014 and 2016 of global carbon emissions associated with energy consumption is attributable in part to the increase of renewable energy and energy efficiency. Energy efficiency is helping to decouple economic growth from the growth of global energy demand. Most of the world's regions have achieved improvements in energy intensity over the past decade; as a result, global energy intensity has decreased by an average of 2.1% per year since 2010. Without improvements in energy efficiency since 2000, estimated global energy use would have been 12% higher in 2016 – the equivalent of the energy use of the entire European Union (IEA, 2017a).

Many synergies exist between renewables and energy efficiency in both technical and policy contexts. As the delivery of energy services becomes more efficient, the provision of the same level of energy services requires less primary energy; and as the share of renewables in the energy mix increases, those renewables play a growing role in the supply of primary energy. Efficient appliances and lighting (LEDs), together with solar PV, are providing access to modern energy services where previously there had been none, with a particularly significant impact in resource-constrained settings where there is no connection to a centralised grid.

Energy efficiency targets are now in place at all levels of government in at least 149 countries, although only 137 countries have adopted policies and measures to achieve them. In many cases, countries have not yet implemented the policies, especially where energy remains subsidised and compliance rules are less strict. Furthermore, although most of the countries in the world have established targets and policies for both renewables and energy efficiency, the two are seldom systematically linked.

Currently, in cases where renewable energy and energy efficiency are addressed together, they are mainly encouraged through parallel targets or through clean energy targets, with the two being incorporated within a single policy (*e.g.* portfolio standards or building codes) or made subject to parallel implementation. Increasingly, policies are linking the two, particularly in the building sector through economy-wide targets and regulations, and at the local level (REN21, 2015). Globally, however, support policies for energy efficiency and renewable energy do not yet fully align, nor are they integrated as well as they could be.

Institutions such as the IEA and IRENA are working with policy makers and businesses to better understand the synergies and trade-offs of these two important tools and how to adapt policies to optimise impact, framing the issue in three ways:

1. Policy design should aim at delivering end goals – such as reduced emissions, increased access and energy security – in the most cost-effective and democratic way possible, and at addressing uptake barriers through certificates and auctions; through capacity markets open to energy efficiency, demand-side management, storage and renewables; and through support for the development and use of energy-efficient appliances and practices.

2. New policy thinking is required as the pace and scale of deployment grows – such as policy development processes that reduce compartmentalisation and tools and analysis that enhance the understanding of the overall effect of policies on the energy system and on end goals – such as the 2017 EU Clean Energy for All Europeans package of measures that cover the energy market, renewable energy and energy efficiency.

3. Technology innovation, particularly digitalisation, is opening new combined solutions, requiring changes to existing approaches to policy formulation and in behaviour and consumption, such as energy service models that combine energy efficient, low-wattage equipment with smart meters or solar power and batteries to create efficient home energy systems (IEA, 2017b).

1.2. RENEWABLES ADVANCING THE ENERGY TRANSITION

Many drivers are stimulating a range of actors – governments, investors, producers and consumers – to support increased renewable energy deployment (Section 1.2.1). Policy makers are enacting targets and policies to support renewables, while private companies are increasingly investing in renewables, and consumers are choosing to purchase renewable energy and invest in renewables themselves. In the course of the transition to renewables, key players have emerged, among them national, state and provincial governments; cities and local governments; large corporations; utilities and regulatory bodies, individuals and communities (Section 1.2.2). However, despite the overwhelming progress of and interest in renewables over the past decade, many barriers persist and new challenges have arisen. Considerable work remains to level the playing field for renewables and integrate them fully into the larger energy system (Section 1.2.3).

1.2.1. DRIVERS OF RENEWABLE ENERGY DEPLOYMENT

Many factors are driving the rapid uptake of renewable energy, the growing global support for renewables and progressively more ambitious targets. Chief among these are mitigating climate change; reducing local air pollution; strengthening energy security and system resilience; maximising investment revenues; creating local economic value and jobs; and increasing access to affordable, reliable and sustainable energy for lighting, heating and cooking.

Climate change mitigation has been one of the main rationales behind the call for a higher share of renewables in the energy mix. Of the 194 parties to the United Nations Framework Convention on Climate Change that submitted nationally determined contributions (NDCs) under the Paris Agreement, 145 referred to renewable energy action to mitigate and adapt to climate change, and 109 included quantified renewable energy targets (IRENA, 2017d). Most countries focus their renewable energy targets on power generation, but a few also address end-use energy sectors such as transport and heating and cooling for buildings. For example, 14 NDCs include targets for producing liquid biofuels, 11 promote biogas, and 8 include the deployment of solar water heaters. By 2030, owing to the implementation of current NDCs, an estimated 1.3 terawatts or more of renewable installed capacity will be added globally. However, renewable energy targets in NDCs are often less ambitious than those in other national energy plans and strategies. They do not capture the cost-effective potential of renewables, which leaves significant room for strengthening the renewable energy component in the next round of NDCs (IRENA, 2017d).

The goal of **reducing local air pollution and its associated costs and effects on health** is increasingly driving the push for renewables as people continue to move into urban areas. An estimated 7.3 million premature deaths per year are attributable to household and outdoor air pollution (WHO, 2018). Lower air pollution levels can be achieved by switching to cleaner energy. China, for example, has announced an increased investment in renewables, primarily to combat pollution in its major cities caused by coal-fired power plants and district heating boilers.

Renewables facilitate **increased energy security** by decreasing reliance on energy imports and guarding against unpredictable global energy markets. For example, several small islands are investing in renewables, citing security as an explicit driver (Fiji, 2015; Jamaica, 2009; IRENA, 2015). Singapore has sought to improve energy security partly through solar PV (Singapore, 2017), and the US military has indicated a need to increase the use of renewable power and fuels, particularly mini-grids, for its own operations, citing national security concerns. Similarly, renewables can enhance the **resilience of the energy system** in anticipation of more frequent climate change-related events and natural disasters. The use of distributed renewable energy systems and microgrid integration, along with an increased use of battery storage, can protect against the failure of an entire energy system.

Renewable technologies allow for **expanded energy access**. Grid extension is no longer seen as the only option as new business models and technologies foster the development of off-grid renewable energy markets. However, off-grid solutions still represent only a small percentage of the increase in electrification. Global sales of off-grid solar systems – an initial step toward increasing electrification – reached nearly 8.2 million products in 2016, an increase of more than 40% over the previous year. The renewable energy mini-grids market surpassed USD 200 million in 2016, while investment in pay-as-you-go solar companies reached a record USD 223 million. Similarly, the use of distributed renewable energy for **increased access to clean cooking and heating** as well as for cooling has grown in developing and emerging countries. Approximately 20 million clean cookstoves were installed in 2015, an increase of 18% from the previous year, and investment in clean cook stoves increased to USD 11.5 million in 2016, up from USD 9 million in the prior year.

Public and private actors alike are increasingly seeing renewable energy as a good investment that can provide **higher revenues** than other fuels. In several countries, renewables are or are becoming cost-competitive with other sources, even when not considering the negative externalities of fossil fuels and nuclear energy (or the fact that fossil fuels receive four times the subsidies given to renewables). Record-low prices for renewables are emerging at auctions, and these prices are often lower than those for fossil fuels (see Chapter 4). The short gestation period for renewables and long-term fixed-price contracts provide strong incentives to invest in renewable energy over other sources.

Some countries are pursuing renewables deployment as a means of promoting **local economic value** and **job creation**, as it offers the potential to lower energy spending, increase incomes, and enhance welfare and industrial development (IRENA, 2016a). Countries with stable policy frameworks for renewable energy support have experienced the best results in terms of local value generated by the sector. Globally, net employment in renewables has grown in recent years, particularly in solar PV. The renewables sector employed over 9.8 million people as of end-2016. However, in some major renewable energy markets, job losses occurred as a result of policy changes, lower investments and rising automation (IRENA, 2017c).

1.2.2. KEY PLAYERS AND EMERGING GAME-CHANGERS

Although renewable energy pioneers such as the United States and many European countries still play an important role in the renewable energy transition, new actors continue to emerge – from those enacting and implementing renewable energy support policies to investors, producers and consumers.

Globally, **national and subnational governments** remain key players in establishing policies and targets in support of renewable energy. Support policies in developed countries have been increasing capacity for several years, but recently there has been a rapid increase in the interest of emerging and developing countries in renewable energy. For nearly a decade, China has been the leading developer of renewable power and heat worldwide, and other emerging and developing economies are expanding their capacities and transforming their energy industries, benefiting from the efficiency and decreasing cost of renewables and from technological advancements. Subnational governments are also playing a growing role, with many enacting policies and targets that are more ambitious than those of their respective national governments and emerging as leaders in the global energy transition. These latter include California, South Australia and subnational groups such as R20 – Regions of Climate Action.[2]

Cities and local governments are playing an increasingly important role in driving the energy transition. This is crucial because cities account for 65% of global energy demand and 70% of anthropogenic carbon emissions (IRENA, 2016). Because so much occurs at the local level, local policy makers can have an enormous impact using their unique authorities. They can set local renewable energy targets; transition public transport and fleets to renewable fuels or electric vehicles powered by renewables; set building codes to include renewables; enact energy efficiency standards; develop renewables-based district heating and cooling systems; and choose to power, heat and cool municipal buildings with renewables. Numerous cities in Brazil have established solar mandates, including Sao Paulo, where 40% of the energy for heating water in new construction (residential or commercial) must now come from a solar source (see Chapter 2). As urbanisation increases, cities are becoming "smarter" and continue to integrate technological dynamism and digital advancement into their operations, creating more efficient, sustainable and secure urban environments (NLC, 2016). Organisations such as the Covenant of Mayors, C40 and ICLEI continue to bring cities together to collaborate on reaching renewable energy and climate mitigation goals.

Additional private sector **companies and corporations** outside the energy sector continue to commit to transitioning to 100% renewable energy. Corporate commitments have resulted in billions of dollars of investments in new renewable power projects owing to direct investment and negotiated advance purchase agreements and to reductions in investment risk brought about by renewable energy policies. In many instances, rather than waiting for public policies to compel corporate renewable procurement, companies have implemented policies unilaterally, often enabling them to take advantage of tax incentives or other available renewables policies in their jurisdictions. By the first quarter of 2018, 131 companies had committed to 100% renewable electricity as part of the RE100[3] initiative, with new members recruited from developing or emerging countries and industrialised countries alike. Information and communication technology companies continue to set targets for 100% renewable energy, including major players such as Facebook and Google (RE100, 2018). To drive further corporate sourcing of renewables, IRENA has developed the REmade Index in support of the Clean Energy Ministerial's Corporate Sourcing of Renewables Campaign to recognise companies sourcing renewables and to provide recommendations for furthering this trend (IRENA, 2017a) (see Chapter 4).

Utilities, because of their central position, can significantly influence energy production and use. Globally, they dominate the production of renewable electricity, and they continue to establish power purchase agreements with renewable energy providers. They invest in large-scale renewable energy projects, renewable energy technology companies, and transmission and distribution infrastructure that can better support the integration of variable renewable energy (VRE) and promote more efficient energy use. Some utilities are resisting the evolution of energy markets, perceiving distributed renewable energy systems as a threat, but many others are integrating renewables into their business plans and investment strategies. The role of utilities is shifting with the growth of distributed VRE, which allows them to be active managers of distributed resources in cooperation with customers using self-generated sources of energy (IRENA, 2017b).

Energy **regulatory bodies** can shape market reforms in a way that allows for increased renewable energy generation by energy producers. For example, the US Federal Energy Regulatory Commission, recognising that renewables have the potential to cost-effectively reduce emissions and diversify fuel sources, has pursued market reforms to allow all resources to compete on a level playing field. In early 2018, it began allowing energy storage in capacity, energy and ancillary services markets (FERC, 2017, 2018). Similarly, in 2017, the UK Office of Gas and Electricity Markets began to allow Renewables Obligation Certificates to be claimed for all generation of renewable electricity, including any used to charge storage devices, which complements the government's larger Smart Systems and Flexibility Plan (OFGEM, 2017).

Individuals and communities are also playing a role in the energy transition, as they are increasingly making decisions about their own consumption and becoming "prosumers" (REN21, 2016). In other words, through increased distributed generation, community generation and self-consumption, energy consumers are becoming energy producers. People are purchasing renewable electricity from utilities, installing solar panels on their houses, and investing in energy efficient appliances. They are purchasing electric vehicles at increasing rates, which, when powered by renewables, can contribute to lower emissions (see Chapter 3). At the community level, individuals are coming together to initiate community-owned renewable energy projects across technologies (*e.g.* solar and wind power, biogas digesters and biomass power and heat). Some countries have also implemented support policies for community renewable energy.

2 R20 Regions of Climate Action is a coalition of subnational bodies seeking to implement low-carbon projects and share best practices in renewables and energy efficiency at the subnational level. See https://regions20.org.

3 RE100 is a global initiative that unites businesses committed to using 100% renewable electricity. See http://theRE100.org/.

New players are emerging and developing innovative ways to increase shares of renewable energy, driven by trends such as digitalisation and demand shaping.[4] In the private sector, start-ups around the world continue to innovate around renewable energy and energy access with new business models, technologies and processes; while aggregators are enabling distributed renewable energy to deliver electricity services at scale (MIT, 2016). Digitalisation could have significant implications for energy demand and supply across the board, including smart energy systems facilitating consumer contributions to energy system management through demand response (IEA, 2017b).

1.2.3. REMAINING BARRIERS FOR INCREASED DEPLOYMENT OF RENEWABLES

Despite the powerful factors driving the global uptake of renewable energy and the number of players supporting the transition, multiple barriers inhibit further development in developed and developing country contexts. These vary based on specific markets and renewable energy technologies. Moreover, they can overlap, so that even if one is overcome, others may become apparent. (IEA, 2011). Subsequent chapters outline policy options for reducing barriers to permit further renewable deployment.

Awareness and capacity barriers relate to a lack of sufficient information and knowledge about renewables and their performance as well as a lack of skilled personnel and training programmes. Developing countries often struggle with limitations in capacity and training and therefore the lack of a qualified and skilled workforce and an insufficient local value chain (IRENA, 2012). Capacity barriers – such as an inability to properly carry out operation and maintenance activities – can cause renewable systems to fail after implementation.

Cost barriers pertain to the capital/investment costs of renewable energy technologies compared with competing technologies. Where sufficient resources exist, several renewable energy technologies are already cost-competitive compared with other fuels. Of all the renewable energy technologies, utility-scale solar PV has seen the most rapid decline in cost (IRENA, 2018). While costs have fallen as deployment has accelerated across renewable energy technologies, higher costs remain for some, although effective cost-reduction opportunities do exist. Lack of economies of scale can also contribute to higher costs for the system, particularly in the early stages of market growth (IEA, 2016).

Financial barriers pertain to the lack of adequate funding opportunities and financing products for renewables. This is sometimes a question of availability and cost of financing, difficulty of accessing suitable financial instruments (debt with long tenor, for example, or structured finance vehicles, including aggregation and securitization of assets), lack of institutional knowledge (in project finance, for example), or lack of access to and affordability of effective risk mitigation instruments (such as guarantees, currency hedging instruments or liquidity reserve facilities) (IRENA, 2016b).

Infrastructure barriers pertain to the availability of needed infrastructure to incorporate renewable energy into the energy system, which can include problems linked to system flexibility and the ability of the power grid to integrate renewable energy (IEA, 2016). As the deployment of renewable power capacity spreads, challenges to grid integration can arise, amplified by a weak grid infrastructure or a lack of required upgrades for transmission and distribution infrastructure. In some countries, these challenges can result in the curtailment of power from renewable sources. Restricted grid connection or access is another concern, particularly for distributed technologies and in cases of a vertically integrated power sector. In addition, a lack of district heating or adequate cooling infrastructure hinders progress in the heating and cooling sector, and the absence of appropriate engines in vehicle fleets hampers the deployment of biofuels in the transport sector.

Institutional and administrative barriers include a lack of institutions and authorities dedicated to renewables; the absence of clearly defined responsibilities; complicated licensing procedures; difficulty with land acquisition and permission; inadequate planning guidelines; and complex, slow, lengthy or opaque permitting processes. Political or other resistance to renewable energy – such as institutional corruption and anti-renewables lobbying – can impede further development (IEA, 2016).

Market barriers include inconsistent pricing structures that lead to disadvantages for renewables, irregular pricing of renewable energy products, information asymmetries, distortions in market power, fossil fuel and nuclear subsidies, and a failure to incorporate social and environmental externalities into costs. Many countries have energy tariffs that are not fully cost-reflective, as well as fossil fuel and/or nuclear subsidies that inhibit the deployment of renewables. Low fossil fuel prices can similarly slow the pace of deployment, particularly for renewable heating and cooling and transport. Trade barriers in some countries – such as import duties – also make importing renewable energy products more expensive.

Public acceptance and environmental barriers constitute constraints that could lead to a renewable energy project being found unsuitable for a specific location. A lack of public acceptance alone can lead to higher costs, delays and even cancellation of projects (Gonzalez et al., 2016). Local planning and zoning regulations and environmental features can further hinder the deployment of renewable energy in certain areas.

Regulatory and policy barriers include bad policy design, discontinuity of policies, perverse or split incentives, unfavourable or inconsistent policies, unclear agreements (such as power purchase agreements, feed-in tariffs or self-consumption) and a lack of transparency. Uncertainty and inconsistency about targets and policies, including retroactive changes, significantly hamper renewable energy expansion, as support schemes or procedures that are unclear lower confidence amongst investors and developers (IRENA, 2012).

4 Influencing demand to match planned supply.

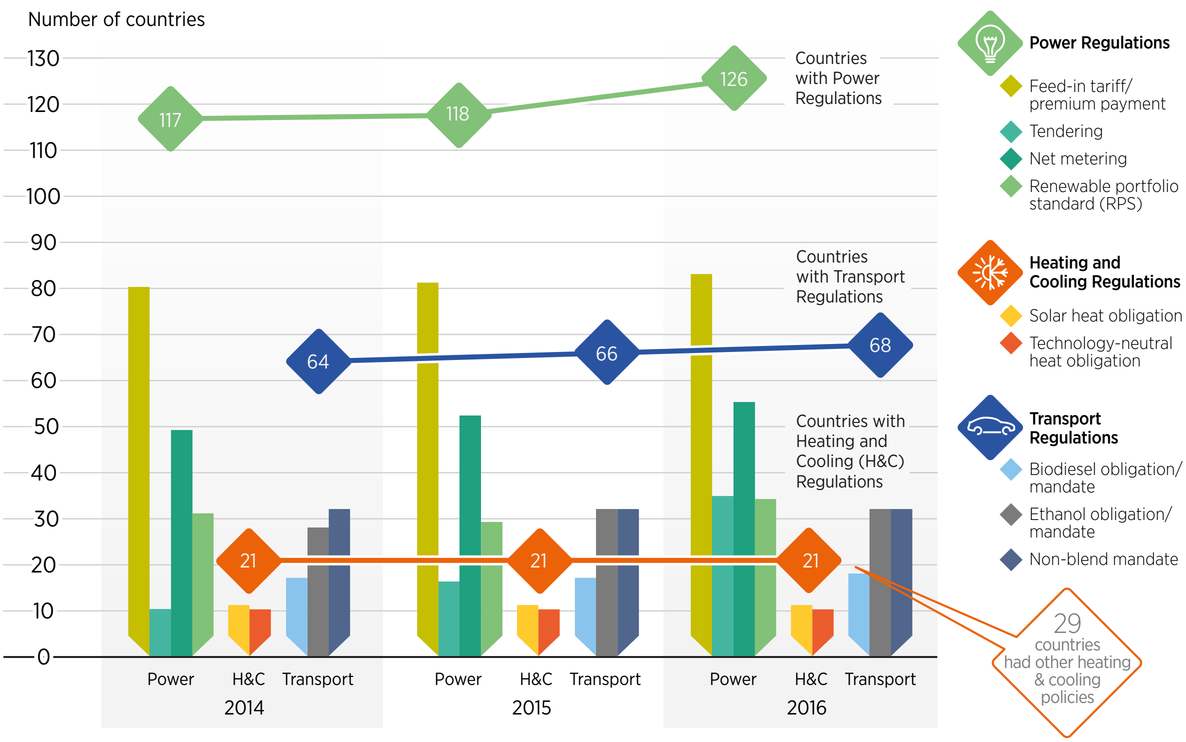
1.3. CURRENT STATUS OF TARGETS AND POLICIES

Many types of renewable energy policies are found at all jurisdictional levels, including targets, feed-in tariffs and premiums, auctions, renewable portfolio standards, regulatory mandates, building codes, direct financial support policies, fiscal support policies, and policies to facilitate the integration of VRE generation into national energy systems.

Renewable energy targets, which serve as a principal way for public and private actors to demonstrate a commitment to the energy transition, range from official government announcements to codified plans with fully developed metrics and compliance measures. Targets also vary in focus, from a single technology or sector to economy-wide. By the end of 2016, at least 176 countries had targets for renewable energy. At least 150 countries had adopted targets relating to the share of energy from renewables in power; at least 47 countries had renewables targets in place for heating and cooling; and at least 41 countries had targets for transport.

To be effective, targets need the support of cross-sectoral policies and measures spanning heating and cooling, transport, and power. Policies in support of the deployment of renewables adopted by countries, such as targets, are focused overwhelmingly on power generation; relatively few provide specific support for renewables in the heating and cooling or transport sectors. Regulatory policies for the power sector exist in almost twice as many countries as for the transport sector and six times as many as for the heating and cooling sector (Figure 1.1).

Figure 1.1. Number of renewable energy regulatory incentives and mandates, by type, 2014-16



Note: Figure does not show all policy types in use. In many cases countries have enacted additional fiscal incentives or public finance mechanisms to support renewable energy. Heating and cooling policies do not include renewable heat FITs (i.e., in the United Kingdom). Countries are considered to have policies when at least one national or state/provincial-level policy is in place. A country is counted a single time if it has one or more national and/or state/provincial level policies. Some transport policies include both biodiesel and ethanol; in this case, the policy is counted once in each category (biodiesel and ethanol). Tendering policies are presented in a given year if a jurisdiction has held at least one tender during that year.

Source: REN21, 2017b.

For the most part, to support the deployment of renewable **heating and cooling** technologies, policy makers continue to use financial incentives such as grants, loans and tax incentives, as well as market instruments such as renewable energy certificates and guarantees of origin. In recent years, some countries have adopted new or revised financial support mechanisms for renewable heating and cooling. Countries are also utilising building codes, mandates and obligations, and binding targets for renewable heating, as well as other policies to advance technological development. A few have also used feed-in tariffs and auctions to stimulate the sector. Policies for renewable heating and cooling continue to focus on buildings and are in many instances linked to energy efficiency measures. Renewable heat obligations exist in just 21 countries – a figure that has remained relatively stagnant over the past decade, as no new country has enacted this policy in recent years (see Chapter 2).

Decarbonisation of the **transport** sector has tended to focus on improving energy efficiency, expanding the use of biofuels and encouraging modal switches (*e.g.* public transport, biking, walking, etc.). To a lesser extent, advanced biofuels for aviation and maritime transport, hydrogen and synthetic fuels, and renewable electricity-powered electric vehicles are becoming focus areas for support policies but are not progressing rapidly. At least 68 countries have now enacted biofuel blending mandates (at the national or subnational level), up only slightly from previous years. Denmark and Italy are the only countries with an advanced biofuels mandate, while the United States has a cellulosic biofuel mandate. Austria is currently the only country with a policy linking electric vehicles and renewable electricity generation (see Chapter 3).

In the **power** sector, competitive auctions with long-term power purchase agreements are the most rapidly expanding form of policy support for renewables, and many countries are shifting away from administratively set tariffs or premiums toward auctions for the deployment of renewable projects.

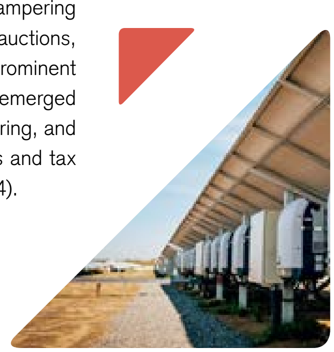
This trend has significantly contributed to the recent reduction in renewable energy prices.[5] Auctions were held in 34 countries in 2016, twice as many as the previous year. Auctions are also taking place in new markets, such as Malawi and Zambia. However, market continuity has decreased and uncertainty increased regarding scheduling delays, cancellations, and a failure to sign power purchase agreements for winning bids (*e.g.* Brazil and South Africa). And there is some evidence to suggest that the policy shift from feed-in tariffs to auctions (*e.g.* in Germany) is hampering community energy projects. With the exception of auctions, feed-in tariffs and feed-in premiums are still the most prominent form of regulatory policy support, but new trends have emerged that favour increased accessibility through virtual net metering, and many countries provide public funds through grants, loans and tax incentives to spur investment in renewables (see Chapter 4).

Policy, regulatory, investment and market strategies are evolving as shares of VRE increase. VRE challenges traditional policy, market and regulatory frameworks regardless of a country's market structure (IEA, 2017c). Policy to support **systems integration** and **sector coupling** aims at strengthening operational efficiency and flexibility of the power system as shares of VRE and distributed resources increase (see Chapter 5).

Many developing and emerging countries have put in place policy measures aimed at supporting the deployment of distributed renewables to increase **electricity access** and address barriers to the expansion of the off-grid market. Policies include fiscal incentives, regulations, auctions and exemptions from value-added taxes and import duties. Quality assurance frameworks have been introduced to minimise the sale of low-quality products on the market, particularly off-grid solar products. By the end of 2016, for example, Bangladesh, Ethiopia, Kenya and Nepal had adopted the Lighting Global quality assurance programme; and the Economic Community of West African States had adopted a quality assurance framework for off-grid rechargeable lighting appliances. Targets for electrification (and for distributed technologies and mini-grids, more specifically) have also been adopted by many developing countries (Power for All, 2017).

1.4. CONCLUSIONS

Despite the significant increase in renewable energy deployment over the past decade, propelled by the numerous drivers and players advancing renewables and efficiency and the steady increase in support policies and targets, renewables are still far from fully integrated into the larger energy system. Specifically, international climate objectives will not be met with current and proposed policies, and commitments in the NDCs submitted under the Paris Agreement are insufficient for even limiting global warming to two degrees Celsius, particularly because just over half of the 194 countries that submitted NDCs included renewable energy targets. Unless there is a rapid scale-up of renewable energy and energy efficiency, even the two-degree target is not achievable. Policy makers already have the tools necessary to support increased deployment; it is now time to break down the remaining barriers, allow for increased integration of renewable energy across sectors, and go beyond energy sector policy to broader development policy to achieve the energy transition.



5 Many other policies, including feed-in tariffs, played large roles in price and cost reductions over the past decade. Most of the projects that have won bids in auctions over the past few years have not yet been built, some may never be, and others will not come online for several years; bids therefore reflect expected future costs and prices rather than current ones.

02

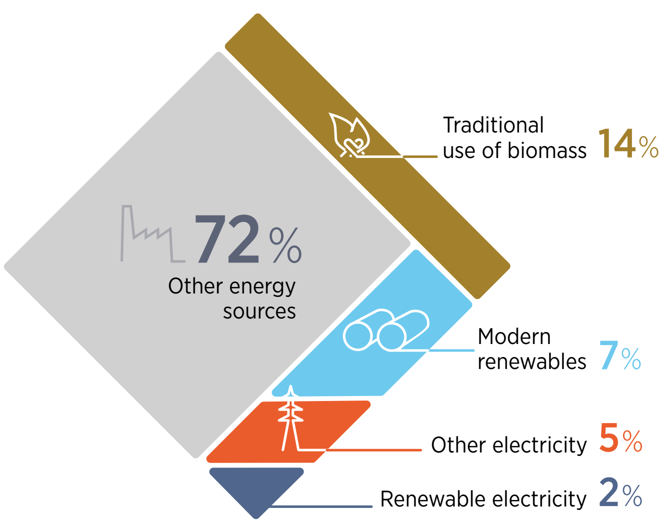
HEATING AND COOLING

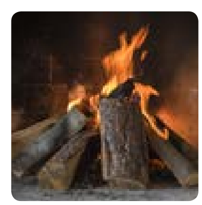
2.1. INTRODUCTION: STATUS AND MARKET TRENDS

Heat, the largest energy end use, accounts for more than 50% of global final energy consumption. Industry consumes around half of this heat, for example to produce steam for industrial processes; and the remainder is for heating buildings and water, for cooking, and for agricultural uses (*e.g.* drying). Cooling for purposes such as space cooling and refrigeration represents a fast-growing energy end use but at present accounts for only about 2% of global final energy consumption. Given its relative importance, the primary focus of this chapter is on heat, with some attention to cooling.

Heat consumption remains heavily fossil-fuel based, with over 70% of heat produced by natural gas, oil or coal (Figure 2.1). As a result, heat consumption is a significant contributor to carbon dioxide (CO_2) emissions; in 2015, it was responsible for around 12.5 gigatonnes of CO_2 – 39% of total annual energy-related emissions. The Energy Transition Commission, a group of leaders from the energy, investment and other key sectors, has described the decarbonisation of heating, cooling and cooking as one of the largest prizes in the energy transition (Energy Transition Commission, 2017).

Figure 2.1. Total global energy consumption for heat, 2015





Source: IEA, 2017a.
Note: Other major energy sources are gas, oil and coal; various non-renewable waste fuels are a minor source.

The traditional use of solid biomass accounts for almost 14% of global heat consumption – and the share is significantly higher in some regions. Biomass is widely used for cooking in rural areas of sub-Saharan Africa and in parts of Asia, usually in inefficient open fires or cookstoves, with serious effects on health (air pollution) and the environment (*e.g.* deforestation). The focus of this chapter is on the efficient, "modern" uses of renewables.

In 2015, modern renewable heat sources accounted for 9% of heat consumption, comprising the following:

- **Modern bioenergy**. Currently dominates renewable heat consumption and covers a range of options such as solid biomass boilers, solid biomass or biogas co-generation systems linked to district heating, biomethane injection into natural gas grids, and biogas used directly for cooking.
- **Solar thermal**. Used for water heating and some space heating in buildings and increasingly in large-scale applications to supply district heating systems, as well as for some industrial applications.
- **Geothermal**. Used in district heating systems, buildings, swimming pools and greenhouses, or industry.
- **Renewable electricity** (electricity produced from renewable sources and used for heating). Used to operate heat pumps that also make use of solar heat stored in the air or ground. May be deployed in residential, commercial, industrial and district heating applications, and coupled with solar photovoltaics (PV).[1]

In the long term, renewable electricity could also be used to produce hydrogen. In countries with extensive gas grids, such as the Netherlands and the United Kingdom, the use of hydrogen in natural gas is being explored as a low-carbon heating option. Decarbonisation require making better use of waste heat from industrial processes, among other sources.

The availability of data on cooling is poor, and no data are available on the global use of renewables for cooling. Cooling demand and solar availability are a potentially good match for distributed solar PV generation and self-consumption, which could increase with some cold storage (*e.g.* ice storage). There are also some direct renewables options for cooling (*e.g.* solar absorption chilling and groundsource cooling).

District energy networks provide promising opportunities for integrating both renewable heating and cooling solutions, together with energy efficient options such as the use of excess heat. Additionally, district energy can offer system flexibility for the generation of variable renewable electricity (see Chapter 5) through solutions such as power-to-gas, large-scale heat pumps, electric boilers and thermal storage.

The energy efficiency of buildings, heating and cooling appliances, and industrial processes affect demand for heating and cooling. Improving energy efficiency is a fundamental and cost-effective first step toward shifting heating and cooling to renewables. For example, buildings need to be well insulated for heat pumps to operate efficiently, while biomass boilers will require less fuel and become more cost-effective if heat demand is reduced through improvements in energy efficiency.

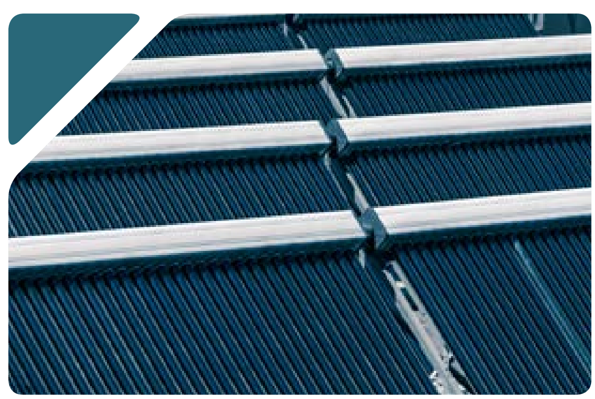
2.2. RENEWABLE HEATING AND COOLING POLICIES: OVERVIEW

The heating and cooling sector is complex and fragmented, and generally less well understood than the electricity sector. Its complexity makes effective policy-making challenging. Demand for thermal energy in buildings varies greatly based on climate, the efficiency of the building envelope, occupancy, behaviour and many other factors. Further, there is a range of heating and cooling requirements for a multitude of industry processes. On the supply side, many different space and water heating options are offered, with many involved actors – from large multinational manufacturers of heating equipment to small, local installers. Fuels also vary, as does the scale of heat production – from large combined heat and power plants to small open fires. Renewables-based heating and cooling face multiple barriers when competing against incumbent (mainly fossil) fuels.

Some barriers are generic – affecting renewables in general – such as high capital costs, low prices for fossil fuels and subsidies for fossil fuels (see Chapter 1). Some are more specific, such as suitability – for example, a lack of space for a biomass boiler or industrial temperature requirements that make it more challenging to use renewable heating solutions. Some barriers are shared with energy efficiency, such as split incentives in privately rented buildings (IEA, 2018). They also can overlap with one another and deter consumers and industry investors from opting for a renewable heat solution.

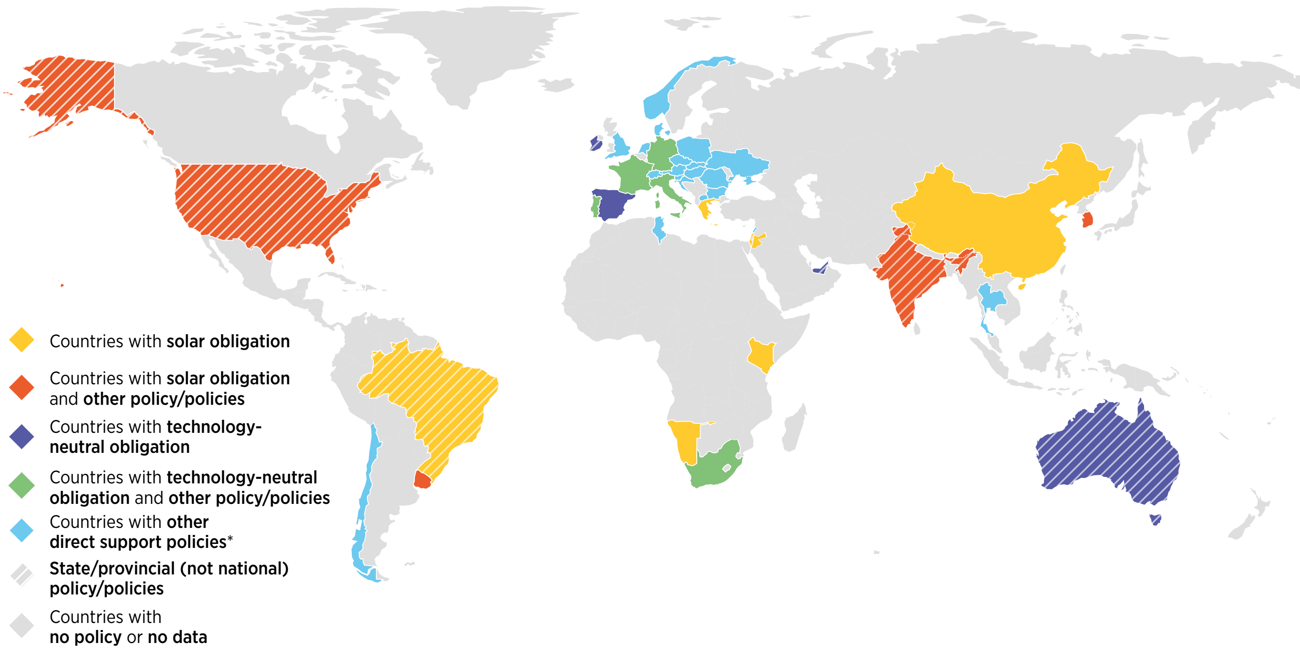
Despite the enormous contribution that heat consumption makes to final energy demand and emissions, in most countries, policy makers are still focusing their renewables policies on electricity supply. As Figure 2.2 shows, heating and cooling policies are still relatively rare.

Barriers and policy approaches to renewable heating and cooling are often country- or even location-specific, as is the nature of thermal energy demand. The following section is therefore organised in clusters based on key characteristics, such as differences in heat demand and heat supply infrastructure, with country examples provided for each (see Table 2.1). Policy approaches differ among the clusters, although several employ the same instruments – such as tax incentives and grants.



1 Heat pumps are an exceptionally energy efficient form of heating; some jurisdictions also accept them as a renewable energy technology. For example, the European Union Renewable Energy Directive recognizes that heat pumps use renewable energy sources from the air, water and ground, subject to a minimum performance factor. Global energy statistics do not presently capture the renewable heat produced by heat pumps.

Figure 2.2. Countries with renewable heating and cooling policies, 2016



* Indicates countries with other policies that directly support renewable heating and cooling technologies, including rebates, tax credits, FITs, tenders, etc.

Note: Figure shows countries with direct support regulatory policies and financial incentives for renewable heating and cooling technologies. Countries are considered to have policies when at least one national-level policy is in place; these countries may have state/provincial-level policies in place as well. Diagonal lines indicate that countries have no policies in place at the national level but have at least one policy at the state/provincial level.

Disclaimer: The designations employed and the presentation of material in this map do not imply the expression of any opinion whatsoever concerning the legal status of any region, country, territory, city or area or of its authorities, and is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers or boundaries and to the name of any territory, city or area.

Source: REN21, 2017.

Table 2.1. Policy clusters

	Main characteristics	Example countries
Cluster 1. District heating approaches	Cold winter climate with high demand for space heating (at least regionally).	China, Nordic countries
	Extensive existing district heating networks.	
Cluster 2. Competing with extensive individual natural gas heating	Above-average demand for space heating.	Netherlands, United Kingdom, United States
	Extensive natural gas grid and use of individual boilers.	
	Relatively low gas prices.	
Cluster 3. Industrial heat and hot water with focus on emerging economies	Demand for heat primarily in industry and for heating water, fast-growing demand for cooling.	Brazil, India, South Africa, Tunisia
Cluster 4. Clean cooking	Reliance on inefficient solid biomass for cooking, with significant health and social impacts.	Bangladesh, India and most of sub-Saharan Africa

2.3. CLUSTER 1 – DISTRICT HEATING APPROACHES

Many countries with above-average climate-related demand for heat have extensive district heating networks (see Table 2.2) that developed over time. District heating can run on a variety of fuels, and while it is often fossil-fuel based, it offers promising opportunities for integrating renewable and waste sources of heat, often more easily and at a lower cost than with individual applications (IEA, 2018). District heating can therefore be an enabler for renewables, and as such, policies that promote it can have a positive impact. Countries in this cluster have also promoted renewable heat more broadly through a variety of policy instruments, often in combination with one another (see Box 2.1 for the example of Sweden).

2.3.1 POLICIES TO PROMOTE DISTRICT HEATING

District heating is capital-intensive. In most countries, networks have been built as **public infrastructure** (*e.g.* financed through access to cheap loans), often by local authorities or municipal energy companies. Policies such as targets, heat zoning and mandated connection have sometimes supported district heating as well. For example, in Denmark, the transformation of the heating sector began during the oil crises of the 1970s, when individual oil boilers still dominated the Danish heating supply. To improve the security of supply, the 1979 Heat Supply Act introduced the concept of heat zoning in heat-dense areas that are suitable for collective heat systems and obligated municipalities to develop heat-supply plans. The country met its 60% district heating supply target in 2000, with most of the supply initially coming from fossil fuel based cogeneration. Finland and Sweden have also supported district heating during this timeframe. More recently, China has been expanding its district heating systems – now found in about half of its major cities.

Some countries with low district heating penetration are providing **financial incentives** for its expansion – and increasingly for combined heating and cooling as well. Such schemes are specifically intended to increase the deployment of renewable heat. For example, Germany launched a programme in 2017 that offers grants of up to 60% of investment costs for new, innovative heating and cooling networks based on at least 50% renewable heat. Similar support is available in France under the Heat Funds (*Fonds Chaleur*) programme.

Table 2.2. District heating and renewable heat shares in selected European countries

	Share of renewables in heat consumption 2015 (%)	Percentage of residential heat demand met by district heating 2015 (%)	Heating Degree Days 2016	Main renewable heat source
Sweden	68.6	51	5 125	Biomass
Iceland	63.4	92	4 962	Geothermal
Finland	52.8	39	5 338	Biomass
Latvia	51.8	30	4 003	Biomass
Estonia	49.6	62	4 208	Biomass
Lithuania	46.1	56	3 827	Biomass
Denmark	39.6	64	3 136	Biomass

Sources: Euroheat and Power, 2017; Eurostat, 2017a; Eurostat, 2017b.

Note: Heating degree days is a standardised measurement designed to quantify the demand for energy needed to heat a building. A higher number of days signifies a colder climate. In the European Union, the average number of heating degree days is 2 904.

BOX 2.1. SWEDEN: A GLOBAL LEADER IN RENEWABLE HEAT

Sweden has the highest share of renewable heat in the European Union, with almost 70% of heat demand met by renewables. Energy and carbon taxes, introduced for reasons of energy security and environmental protection, have been the main drivers of the shift toward renewables, although the country has deployed several other policy instruments as well.

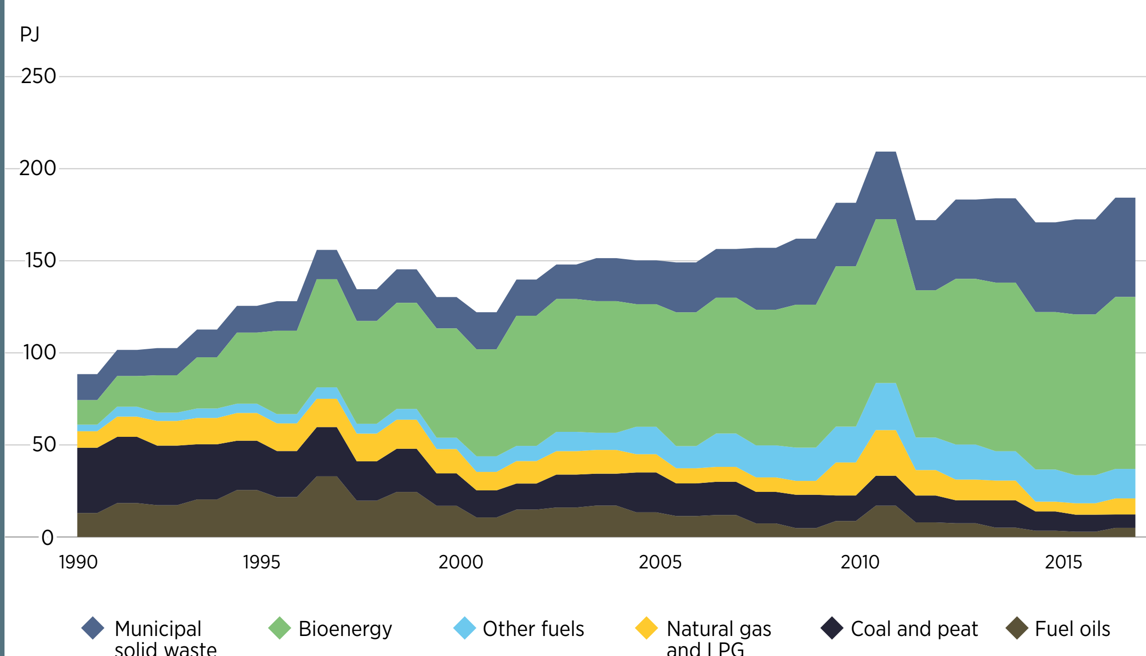
In 1985, Sweden introduced an energy tax on natural gas used for heating, followed in 1991 by a carbon tax on fuels. A tax on heating oil has been in place since the 1950s. Biomass – a local and renewable energy source – is exempt from these taxes. Over time, the taxes have risen substantially, and by 2017, the combined carbon and energy tax on natural gas was USD 187 per tonne of CO_2 (tCO_2) compared with a carbon price of about USD 11 per tCO_2 in early 2018 under the European Union Emission Trading System. As a result of the high taxes, Sweden's natural gas prices are the highest by far for domestic customers in the European Union, with taxes accounting for almost 50% of the price per kilowatt hour.

This taxation has resulted in a switch away from individual fossil fuel heating to district heating in urban areas, with district heating now supplying 60% of heat demand. High taxes, combined with a landfill ban, have resulted in the transition from fossil fuels to biomass and municipal solid waste, some of which is renewable. A tradeable renewable energy certificate programme (see Section 2.3.2) also helped this process by incentivising biomass-based cogeneration. Biomass and municipal waste now account for 80% of fuel input into district heating (Figure 2.3).

In single or smaller multi-family houses, heat pumps are the preferred heating technology. Sweden has used a relatively large share of electricity for heating since the 1980s due to relatively cheap power supplies from hydropower and nuclear power (80% of generation in 2016). Initially, most electric heating came from inefficient resistance heating, but heat pumps currently dominate this market segment. Sweden's high carbon and energy taxes already make heat pumps competitive, while the addition to tax credits adds to their attractiveness. Large-scale heat pumps are also deployed in district heating networks.

Despite the progress to date, Sweden still needs to make further progress in heat decarbonisation if it is to meet the objectives of the climate change law passed in June 2017, which requires the country to become a net-zero carbon emitter by 2045.

Figure 2.3. Fuel input for steam and hot water in Swedish CHP and heat-only plants, 1990-2016



Source: Statistics Sweden (2017).

2.3.2 POLICIES TO SWITCH TO RENEWABLE HEAT

Countries in this cluster have achieved a shift to renewables – both in district heating and individual heat applications – through a variety of policy instruments, often used in combination. **Energy taxes** have been an important driver of the shift to renewable fuels in Nordic countries. For example, Sweden's energy and carbon taxes have made fossil fuels uncompetitive compared with biomass, which has been exempt from taxation (see Box 2.1). Denmark has also applied energy taxes to fossil fuels for heating, with some exemptions for biomass. Finland was an early adopter of carbon taxes but provided exemptions for peat and natural gas. While the tax reform in 2011 imposed a carbon tax on natural gas, peat remains exempt, despite being a high-carbon fuel.

Additionally, countries have deployed other **financial incentives**. Combined heat and power systems and renewables often benefit from feed-in tariffs and feed-in policies (see Chapter 4). For example, Denmark has supported biomass cogeneration with a feed-in tariff premium for produced electricity. Finland has a specific "heat bonus" in addition to the feed-in premium for biogas and biomass cogeneration. There are also investment grants available to companies, municipalities and farmers for individual renewable heat installations.

Targets have been important for the expansion of district heating in the past, but more recently, countries in this cluster have adopted ambitious targets specifically for renewable heat or carbon reduction. Finland announced that it will phase out all coal by 2030, a significant step for the heat sector since coal currently accounts for 30% of heat consumption. Denmark aims at having an energy system free of fossil fuels by 2050, and heat will play a crucial role in achieving this goal.

China currently has a low share of renewable heat – 2% of final consumption, but their 13th Five-Year Plan (2016-20) includes ambitious targets for solar thermal, geothermal and biomass heating:

- **Solar thermal**. An additional 400 million square metres (m^2) installed, reaching a total of 800 million m^2.
- **Geothermal**. An additional 1.6 billion m^2 of buildings connected.
- **Biomass for heat**. Scale-up from around 8 million tonnes consumption in 2016 to 30 million tonnes by 2020.

China's desire to reduce local air pollution from coal-fired boilers is partly driving these targets. Measures to achieve them include a five-year plan to convert northern Chinese cities to clean heat during the winter between now and 2021, including funding for pilot cities and investments in geothermal heat by the state-owned Sinopec Corp (IEA, 2017b).

Several countries have applied **regulatory measures**, particularly in the building sector. Denmark, for example, has adopted bans on fossil fuels for space heating:

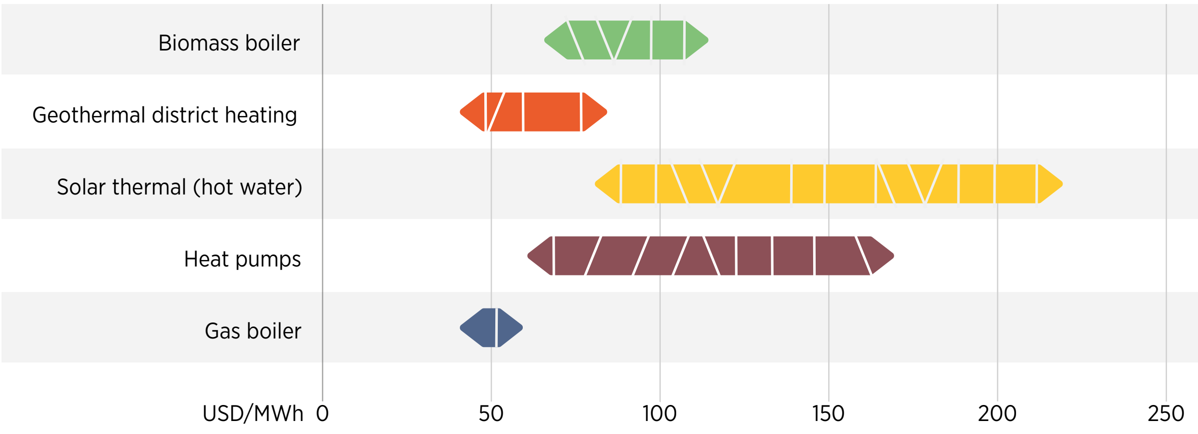
- Since 2013, no oil or gas heating has been allowed in newly buildings.
- Since 2016, the installation of new heating oil units has been prohibited in existing buildings in areas supplied by district heating or natural gas.

In addition, all Scandinavian countries have coupled the shift to renewable heat with high energy efficiency standards in new buildings using **building code** requirements. Finland's building code, for example, considers the carbon intensity of a building's heating supply (Hannon, 2015).

2.4. CLUSTER 2 – COMPETING WITH EXTENSIVE NATURAL GAS GRIDS

A switch to renewable heat is particularly challenging for countries where: 1) a majority of residential and commercial buildings connect to a gas grid; 2) district heating is scarce; and 3) most homes are single-family units rather than apartment buildings. The capital cost of gas boilers is much lower than renewable heat alternatives, such as biomass boilers and heat pumps, especially when used in small-scale, residential applications. Furthermore, residential gas prices are relatively low in some of this cluster's countries – including the United Kingdom and the United States – which makes most renewable heat options uncompetitive compared with gas (Figure 2.4).

Figure 2.4. Indicative cost ranges for delivered renewable heat versus gas boilers, residential sector



Source: IEA analysis.

Note: Costs include capital and operational costs. The range for heat pumps includes air source and ground source systems because the cost of delivered heat for each is similar. The ranges of gas and electricity prices reflect prices observed in the three countries in cluster 2.

Fiscal incentives and grants, sometimes also available for commercial sector applications, have provided broad support for building-scale renewable heat technologies. More recently, some countries have implemented renewable portfolio standards and performance-based incentives, similar to feed-in tariffs. These types of instruments can be implemented on the national or state level.

The most common use of financial incentives is to help bridge the cost gap between renewable heat and traditional fossil fuel options. For example, the Netherlands uses **grants** under the Sustainable Energy Investment Subsidy Scheme to support small renewable heating installations in homes and businesses (*e.g.* EUR 650 for solar thermal and EUR 1 500 for ground source heat pumps). Similar levels of support are available in Germany under the *Marktanreiz* (market incentive) programme.

Tax incentives support renewable heat in the United States, on the federal, state and local levels. From 2018, federal tax credits (30%) are available for solar water heating and geothermal (ground source) heat pumps. This credit phases out by 2022. Examples at the state and city levels include:

- Sales tax exemptions in many states for various renewable heat technologies.
- Tax incentives and rebates in 11 states for wood stoves and biomass boilers (Alliance for Green Heat, 2017).
- A range of incentives offered by New York State for biomass heating systems, air and ground source heat pumps, and biodiesel blended with conventional heating oil (New York State, 2017).

Renewable portfolio standards (RPS), which had in the past focused on electricity generation, have recently begun to include renewable heat. Of the 29 US states with such schemes, 12 include renewable heat technologies.[2] New Hampshire was the first state to require that a specified portion of its renewable portfolio come from heat, starting in 2014 (Stori, 2017). By 2025, 2% of the energy must come from thermal renewables, as part of a total RPS of 24.8%. Renewable energy certificates are awarded to owners of renewable heat installations based on metered heat output. There are currently 25 participating hospitals, schools and manufacturers (Niebling, 2017). Electricity ratepayers fund thermal renewable energy certificates and have compliance costs that are lower than those for electricity.

Some countries have deployed **production-based incentives**, similar to feed-in tariffs for renewable electricity. In the United Kingdom, a renewable heat incentive (RHI) was initially introduced for commercial and industrial applicants in 2011 and then extended to the residential sector in 2014. The owner of the renewable heat equipment receives a tariff per kilowatt hour generated, with the scale depending on the technology used. Commercial installations receive payments over a 20-year period based on actual heat generation, while homeowners receive payments for seven years based on estimated heat generated for 20 years. The aim of the RHI is to provide an attractive rate of return to compensate for the higher capital costs of some renewable technologies, as well as other non-economic barriers. The current annual budget is about USD 750 million, although RHI spending has been consistently below budget.

2 Arizona; Washington, DC; Maryland; Massachusetts; Nevada; New Hampshire; North Carolina; Pennsylvania; Texas; and Wisconsin have mandatory renewable portfolio standards; Indiana and Utah have voluntary standards.

In the Netherlands, under the Stimulation of Sustainable Energy Production Scheme (SDE+), medium and large-scale renewable heat and electricity options compete in a tendering procedure. The tender is organised in steps, starting with the cheapest options and moving on to more expensive ones until the budget limit is reached. This process tends to benefit low-cost renewable heat and biogas. In 2012, 2013 and 2015, renewable heat accounted for the majority of the scheme's budget.

Despite these support schemes, the Netherlands and the United Kingdom have the lowest shares of renewable heat in the European Union: in both countries renewables met just 5.5% of demand for heating in 2015 (Eurostat, 2017a). The Dutch government has plans to reduce the role of gas for heating buildings as a crucial part of its **long-term targets** for reducing CO_2 emissions. A first step is an amendment to the Heat Act that will remove the right to a gas connection in new homes. In the United Kingdom, long-term CO_2 targets figure in the 2009 Climate Change Act, which established a system of legally binding, five-year carbon budgets. However, the RHI has so far failed to address the dominance of natural gas heating, and the United Kingdom lacks the carbon and energy taxes or the regulatory instruments that have been effective in some of the cluster 1 countries. Tax rates for natural gas are amongst the lowest in the European Union. Low tax levels for gas also keep fossil fuel energy prices down in the United States.

Due to the low penetration rates of renewable heat in cluster 2 countries, **policies that promote public awareness** and confidence (such as certification) are essential. Some countries have deployed supportive policies, such as renewable heat incentive roadshows and a certification scheme for installers in the United Kingdom, but more must be done over a sustained period.

2.5. CLUSTER 3 – RENEWABLE HEATING AND COOLING POLICIES IN EMERGING ECONOMIES

Space heating is important in some emerging economies, but for many, demand for heat comes from industry and it is growing rapidly, driven by economic growth. For example, industrial heat demand in India grew by 30% between 2010 and 2015. Demand for hot water and space cooling is also on the rise. Policies to support renewables for these applications are still relatively rare, but some countries in this cluster have deployed technology-specific incentives, and carbon taxation is beginning to gain ground.[3]

2.5.1. RENEWABLE HEAT POLICIES IN INDUSTRY

In industry, cogeneration with biomass has been incentivised by policies such as **loans** and **performance-based instruments**, for example in Brazil and India. Both countries have substantial sugar industries, so bagasse is frequently used for cogeneration. In India, the Renewable Energy Development Agency provides loans for biomass power and bagasse cogeneration projects. Plants can then participate in the Renewable Energy Certificate mechanism, which is linked to the state's renewable purchase obligations (see Box 2.2). Brazil, which has the highest global rate of bioenergy use for heat in its industrial sector, has provided subsidies for bagasse cogeneration.

Solar thermal is also meeting some of the demand for industrial and commercial heat. South Africa, for example, has enormous untapped potential in the agri-processing and textile industries (WWF, 2017). The deployment of solar thermal technologies for industrial application receives its main support in the form of **capacity building** and awareness raising. In countries of the Southern African Development Community[4], the Southern African Solar Thermal Training and Demonstration Initiative (SOLTRAIN) is a regional initiative focusing on capacity building and demonstration of solar thermal systems. It is funded by the Austrian Development Agency and co-funded by the OPEC Fund for International Development.[5] However, further support, such as financial incentives, is needed to advance solar thermal in industries in the region.

Industrial solar thermal has also received support under the Prosol Industry programme in Tunisia, launched in 2010 with financial support from the Italian Ministry of Environment and the United Nations Environment Programme. A Benetton textile factory installed a **demonstration plant** in 2016, consisting of a 1 000 m^2 flat plate collector field, and there are plans to duplicate it in other industries to reach the national target of 14 000 m^2 of solar process heat installations by 2020 (Solarthermalworld, 2017a).

2.5.2. POLICIES FOR SOLAR WATER HEATERS

Demand for hot water in buildings is an important driver of growth in the demand for energy in emerging economies. In these countries, hot water is often produced with inefficient electric immersion heaters, which can contribute to electricity shortages and blackouts. Because many of them have excellent potential for solar energy, solar thermal water heaters offer a good alternative; several countries have already enacted policies to promote them.

Solar thermal growth has been particularly impressive in China (Figure 2.5), driven by ambitious solar thermal targets and low prices for the systems. The country's 12th Five-Year Plan (2011-15) had a target of reaching 400 million m^2 of solar water collector surface, which it exceeded by 10%. A total of 800 million m^2 is planned for installation during the 13th Five-Year Plan period.

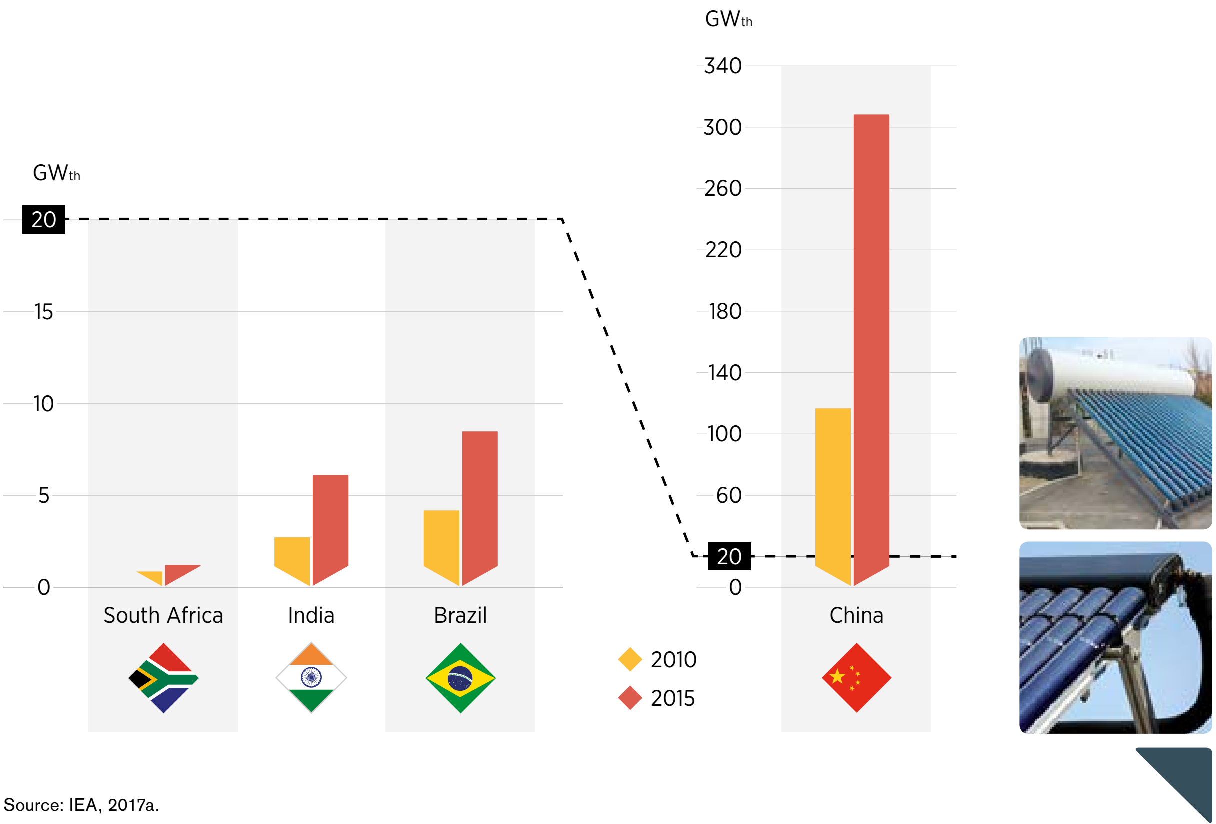
South Africa has been less successful in achieving its targets for solar water heating. In 2009, it set a target of one million systems installed within five years. But while only around 400 000 systems were installed, solar thermal capacity increased by more than 50% between 2010 and 2015 (Figure 2.5). Since then, the country has updated its target. It now aims at having 1.75 million systems installed by 2019 and 5 million by 2030.

3 Policies covered in this section (*e.g.* solar water heating mandates) are also deployed in industrialized countries. However, emerging economies tend to have different drivers.

4 Angola, Botswana, Democratic Republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe.

5 http://soltrain.org

Figure 2.5. Solar thermal capacity growth in selected countries, 2010-15



Source: IEA, 2017a.

Several countries have **mandated solar water heating in new buildings**, often through **building codes** at either the national or local level. The first country to do this was Israel in the 1980s, which now has one of the highest levels of penetration of solar water heating in the world. Building codes and mandates are often regulated at the **city level** because that is where municipal governments tend to have the authority to act.

Numerous Brazilian cities have established solar mandates. Through Law 14459 of 2007, for example, Sao Paulo mandated that, for new construction (residential and commercial), 40% of the energy to heat water had to come from solar. At the state level, Rio de Janeiro requires all new and refurbished public buildings to meet at least 40% of their water heating needs with solar energy under State Law 5184 of 2008 (IRENA, 2015). Solar water heaters are also a requirement for new social housing projects.

In India, the revised Energy Conservation Building Code, published in March 2017, has the potential to drive solar thermal deployment in commercial buildings. It proposes that solar thermal meet 20-40% of the demand for hot water in new buildings located in cold climate zones, as well as in new hotels and hospitals across the entire country. While the Indian national building code is not mandatory, some states and municipalities use it to regulate construction activity, although the implementation may take some time.

Although building codes and mandates work well for new buildings, **financial incentives** are important to support the switch to solar water heaters in existing buildings. Incentives include a range of grants, low-interest loans and tax incentives. For example, Tunisia established the Prosol programme in 2005 to provide a comprehensive financing model. The programme offers capital grants combined with a value-added-tax exemption, reduction of customs duties and reducedinterest loans paid back through electricity bills. The programme has recently been extended to 2020 (Solarthermalworld, 2017a).

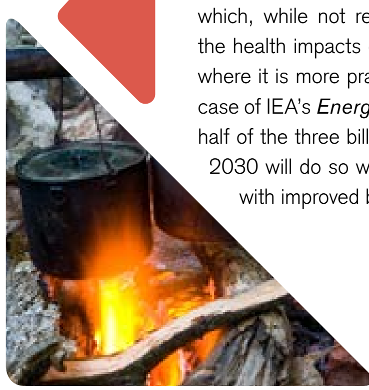
In South Africa, ESKOM, the national electricity company, originally provided rebates to households and businesses and provided free installation to low-income households through the solar water heater programme. In 2015, the Department of Energy took over the programme's operation, which has since experienced delays (Rycroft, 2016).

Electric utilities have also played a key role in Brazil. Since 2000, the electricity supplier's **energy efficiency obligation** (*Procedimentos do Programa de Eficiência Energética* – PROPEE) has incentivised switching from electric shower heads to solar water heaters (Solarthermalworld, 2017b). The Brazilian approach seems to have succeeded: solar thermal capacity doubled between 2010 and 2015 (Figure 2.5).

Cooling

Demand for cooling is rapidly growing in most emerging economies, where it is being met primarily through electric air conditioning. Most clean-energy solutions for cooling revolve around energy efficiency standards and renewable electricity. For example, the countries of the Association of Southeast Asian Nations (ASEAN) have an initiative to harmonise energy efficiency standards for residential air conditioners (ASEAN Shine, 2017). Some cities are also promoting district cooling, focused largely on energy efficient solutions.

Finally, some emerging economies have introduced **carbon taxes**, which, over time, should help incentivise renewable heat, as well as renewable and efficient cooling solutions. For example, Mexico introduced a tax on carbon from fossil fuel use in 2013, charging USD 3.50 per ton of CO_2. However, natural gas has been zero-rated. India introduced a tax on coal in 2010, which is now equivalent to a carbon tax of USD 6 per tCO_2, with some of the revenue going into the National Clean Environment Fund, which has funded renewable energy projects. To date, these taxes are at a low level, but they could play an important role.



2.6. CLUSTER 4 – CLEAN COOKING

Globally, 2.8 billion people lack access to clean cooking facilities, primarily in Asia and sub-Saharan Africa (IEA, 2017c); among them, 2.5 billion people cook with biomass in inefficient and polluting stoves. In India, almost 60% of households still cook with biomass. In 20 countries of sub-Saharan Africa, dependence on solid biomass for cooking exceeds 90% (IEA, 2017c). The health impacts are severe: an estimated 2.8 million people die every year from diseases linked to indoor air pollution associated with the use of polluting fuels for cooking and lighting. In addition, the biomass often comes from unsustainable sources.

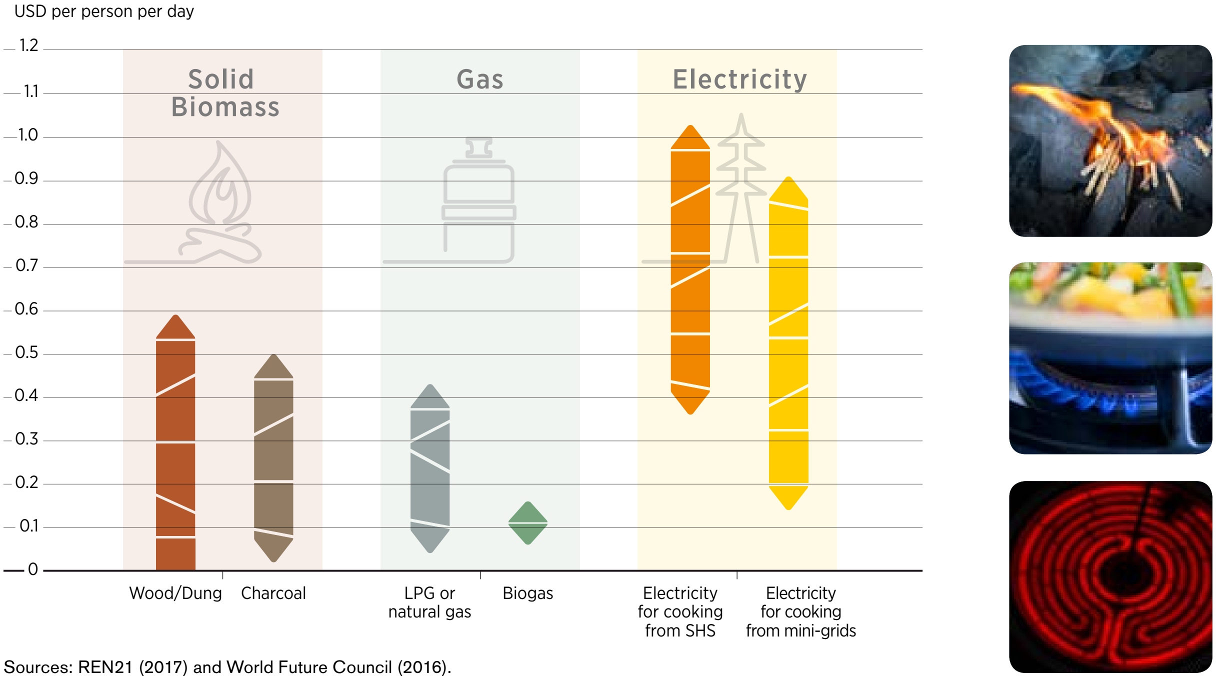
Most of the traditional use of biomass for cooking is in rural areas, and many of the affected households lack access to electricity. Renewable solutions for clean cooking in areas without access to electricity are mostly focused on improved and advanced biomass cookstoves.[6] However, these must use a sustainable fuel source to be considered renewable. At present, few improved biomass cookstoves meet World Health Organization standards for exposure to indoor air pollution, but a few advanced, well-performing models are available. Biogas digesters based on wastes, such as dung, offer a clean alternative and cheap fuel source, but as they have higher upfront costs and are more complex to install, policy support for their deployment is needed. Additionally, various solar cooker designs have been utilised.

In areas with a grid connection, electricity, which may come from renewable sources, can be an option for clean cooking. Currently, electricity is used as a main cooking fuel by just 8% of households in developing countries. An exception is South Africa, where 80% of the population cooks with electricity (IEA, 2017c). In areas without grid access, electrification strategies typically focus on small solar home systems, with panels typically 50 watts or less and electric cooking not a viable option. Where electrification is achieved through microgrids and in combination with batteries, electricity may become an option for some cooking tasks, especially where rice is a food staple and efficient electric rice cookers can be used. However, to date, electricity tends to be a more costly option (Figure 2.6), although this will change as the cost of solar PV continues to fall.

Many countries are promoting a switch to liquefied petroleum gas, which, while not renewable, is an important option for reducing the health impacts of solid fuel cooking, especially in urban areas where it is more practical to establish fuel supply networks. In the case of IEA's *Energy Access Outlook's* "Energy for All" more than half of the three billion people who gain clean cooking facilities by 2030 will do so with liquefied petroleum gas, and the remainder with improved biomass cookstoves, biogas and electricity.

6 In addition to clean cooking, decentralised renewable energy solutions for heating can be introduced at various segments of the agrifood chain such as the drying of fruits and vegetables, with many socio-economic benefits (IRENA, 2016).

Figure 2.6. Costs of various cooking technologies



Sources: REN21 (2017) and World Future Council (2016).

The clean cooking policy landscape is complex, with various international, multilateral, bilateral and national initiatives and programmes. While it differs from renewable heat policies discussed in relation to the other three clusters, some approaches, such as financial incentives and capacity building initiatives, are similar to those found elsewhere.

International and multilateral initiatives include the inclusion of *clean cooking solutions* as one of 11 action areas of the Sustainable Energy for All initiative, and progress in clean cooking is essential for achieving United Nations Sustainable Development Goals, such as SDG7 on affordable and clean energy. The African Development Bank, through its New Deal on Energy for Africa, aims at providing access to clean cooking for 130 million households by 2025. Furthermore, the Global Alliance for Clean Cookstoves (GACC), a public-private partnership with the goal of getting 100 million households to adopt clean and efficient cookstoves and fuels by 2020, has been operating since 2010. Donors include bilateral, multilateral, corporate, civil society and philanthropic donors. For example, the World Bank committed to support the GACC with a USD 60 million programme. The alliance has prioritised engagement with eight countries – Bangladesh, China, Ghana, Guatemala, India, Kenya, Nigeria and Uganda.

On the ground, projects and programmes, often supported by multilateral or bilateral development aid, tend to support either capacity building in the supply chain or the take-up of clean cooking solutions. **Capacity building** is important to ensure that local enterprises can drive the shift to clean cooking. GACC operates a capacity building facility that helps local enterprises bring their operations to scale, and achieve commercial viability and leverage private investment. Training and capacity building has also been an important part of Bangladesh's National Domestic Biogas and Manure Programme. With the support of international development aid, this has provided both financial and technical support for the expansion of biogas technology in rural areas, with an estimated 80 000 small-scale systems that use animal waste in operation (GIZ, 2016).

In addition, in conjunction with capacity building, clean cooking programmes often aim at improving **access to finance**. For example, the GACC's Working Capital Fund, in partnership with Deutsche Bank, provides loans and loan guarantees to enterprises that cannot access traditional debt financing mechanisms.

In terms of promoting **end-user take-up**, clean stove policies and programmes tend to provide **financial incentives** focused on enhancing the affordability of stoves. Many projects give away cookstoves for free or for a nominal fee, typically funded by aid programmes, foundations or voluntary carbon credits. Some require households to buy more efficient fuels, such as pellets, to ensure that pollutants are effectively reduced.

Many previous clean cookstove projects have failed owing to acceptability problems. GACC is trying to overcome this through a communication programme focused on **awareness** and behaviour change. It is working with local partners in Bangladesh, Ghana, Guatemala and Uganda, using innovative communication channels such as soap operas to reach millions of households (REN21, 2017). In Ghana, efforts also include the development of a school curriculum to educate students on the benefits of clean cooking and engagement with and training of women's groups on the benefits of switching to improved cookstoves.

In spite of intensifying efforts, programmes and policies to address the clean cooking challenge have so far had limited impact. In 2015, 20 million clean cookstoves were distributed globally with support of various schemes (REN21, 2017). This represents a growth of 18% over 2014 but is still a relatively small number in view of the scale of the problem. While in some countries, such as China and Indonesia, there have been large reductions in the share of the population relying on solid fuels for cooking, the overall number of people without access to clean cooking has stayed flat since 2000 as population growth has outpaced improvements in access (IEA, 2017c). In India, the number of people without access to clean cooking has actually increased. More effective policies are needed (see Box 2.2).

BOX 2.2. SLOW PROGRESS WITH CLEAN COOKSTOVES IN INDIA

Programmes promoting improved cookstoves have been in place in India since 1983 (CEEW, 2015), and the country has subsidised liquefied petroleum gas for over three decades to facilitate the move to clean cooking. However, these programmes have had only limited success, with 64% of the population still dependent on solid fuels for cooking, particularly in rural areas. Fewer than 1% of rural households use improved cookstoves.

The current programme (known as Unnat Chulha Abhiyan) started in 2014 with a target of disseminating 2.4 million household-level improved cookstoves and 3.5 million community-sized stoves by the end by 2017. However, many of the subsidised cookstoves have poor emission specifications and therefore do not meet the objective of significantly reducing the health impacts of biomass cookstoves (NITI Aayog, 2017). Despite the significant market potential, the number of manufacturers of clean cookstoves is limited, as many lack standard protocols for design and testing, and none has achieved scale or profitability. There is also a dearth of information about the long-term benefits of clean cooking fuels and the negative effects of traditional fuels and cookstoves.

India's Draft National Energy Policy, published in June 2017, proposes a National Mission on Clean Cooking to coordinate efforts on cooking fuels, efficient cookstoves, and related research and development aimed at achieving comprehensive clean cooking fuel coverage by 2022 (NITI Aayog, 2017).

2.7. CONCLUSIONS

Renewables for heating and cooling have received much less policy attention than for electricity. There has been a steady, if slow, growth in the global share of renewables used to meet the demand for heat in recent years, reaching 9% in 2015, but the pace is much slower than the growth in renewable electricity (IEA, 2017a). Renewable cooling solutions are even less prevalent. Accelerated deployment is needed to meet climate change targets and help address air pollution and other issues.

The use of renewables for heating and cooling faces multiple economic and non-economic barriers. Policy interventions are necessary to overcome those barriers, and they should be carefully designed to reflect specific national and local circumstances. Various policies are already being used to support the deployment of renewable heat, often in packages that include a combination of several instruments. Some tend to be limited to certain types of countries (*e.g.* carbon/energy taxes mainly in cluster 1), while others are more universally applicable (*e.g.* grants and tax incentives). Table 2.3 summarises the strengths and limitations of the policy instruments.

Key policy takeaways

- Rapid progress in renewable heating and cooling can be difficult to achieve. Slow renovation rates in the building stock and a slow turnover of heating appliances in both buildings and industry necessitate a **long-term strategy** for heat decarbonisation.
- Multiple barriers call for a **range of policy instruments**, often in combination. Policy approaches will vary from country to country due to differences in heat demand, infrastructure and other contextual factors.
- It is often difficult for renewable heat options to compete with cheap fossil fuels; **carbon and energy taxation** are very useful tools to address this issue.
- Renewable heat and **energy efficiency policies** should be closely aligned to ensure that waste heat is minimised.

Table 2.3. Strengths and limitations of policy instruments used to promote the use of renewables to produce heat

Policy instrument	Strengths	Limitations
Targets (generic or technology- or fuelspecific)	Provides clear direction of travel; sends signals to consumers and industry.	Not effective on their own; need policy measures for implementation.
Financial incentives (*e.g.* grants, tax credits and investment subsidies)	Improves the competitiveness of renewable heat compared with fossil fuels, can help address barrier of higher capital costs.	Support levels subject to frequent changes due to shifting political priorities.
Heat generation-based incentives (similar to feed-in tariffs)	Provides support over a long period of time.	Can entail high cumulative costs; does not deal with issue of high upfront costs.
Carbon or energy taxes (with exemptions for renewables)	Serves as important price signal; deals with externalities; can be ratcheted up over time.	Politically difficult to implement; exemptions often given to certain industries, making them less effective.
Renewable portfolio standards (quota for renewable heat)	Provides certainty over deployment levels.	Generally much less ambitious for heat than for electricity.
Mandates, often technology-specific **(*e.g.* requiring installation of solar water heaters)**	Mandatory; provides greater certainty of increased deployment.	Mostly for new-build only, thus covering limited share of heat demand.
Building codes (setting energy performance requirements, including for renewables)	Provides an opportunity to align energy efficiency with renewable heat requirements.	Mostly for new-build only, thus covering limited share of heat demand; rarely applied to existing buildings.
Ban **on fossil fuel heating options**	Mandatory; provides greater certainty of success.	Suitable alternatives must be available
Information (*e.g.* awareness campaigns and labelling)	Essential for creating awareness about options, costs and benefits.	Most effective when done as part of personalised energy advice which is expensive to deliver.
Standards and certification	Important for supply chains and increasing consumer confidence.	Unlikely to result in much deployment without financial incentives.
Capacity building (*e.g.* installer training)	Important for supply chains.	Unlikely to result in much deployment on their own.
Demonstration (pilot) projects	Important for testing local suitability.	Unlikely to result in much deployment on their own.

03

TRANSPORT

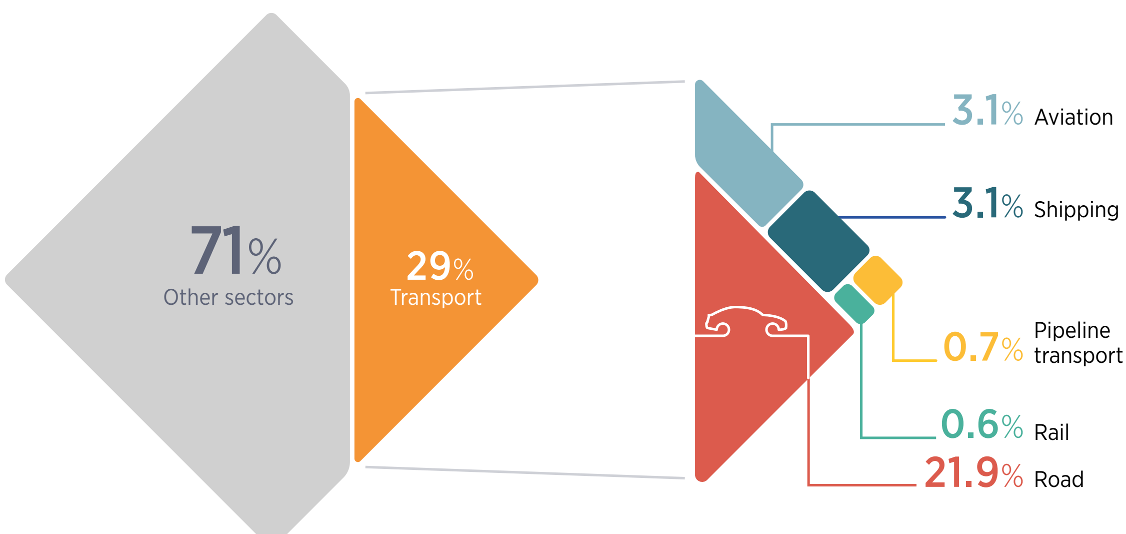
3.1. INTRODUCTION: STATUS AND MARKET TRENDS

The transport sector involves the movement of passengers and freight by various means, and may be divided into several sub-sectors, including road transport, aviation, shipping, and rail. The energy needs in the transport sector are complex due to the various transport modes, vehicle types, energy carriers and fuels, and related transport and distribution infrastructure (IRENA, 2016a).

Transport is the second largest energy end-use sector, accounting for 29% of final global energy consumption in 2015 (Figure 3.1). Over 75% of this is for road transport, two-thirds of which pertains to passenger mobility and only one-third to freight (IEA, 2017a). International and national aviation accounts for 10.7% and shipping for 9.5% of final energy demand for transport. The International Energy Agency expects the sector's demand for energy to increase.

Because of the importance of energy density in the sector, transport remains heavily reliant on fossil fuels. As of 2015, 96% of the sector's energy use came from petroleum products, representing 64.7% of world oil consumption in 2015 (IEA, 2017g). Non-renewable electricity represents 1.0% of the transport sector's total final energy consumption. In 2015, renewable energy accounted for only 3.1% of final energy demand for transport, significantly lower than that for electricity and heat, with a breakdown of 1.6% from ethanol, 0.8% from biodiesel, 0.4% from other liquid biofuels, 0.01% from biomethane, and 0.3% from renewable electricity (Figure 3.2) (IEA, 2017a).

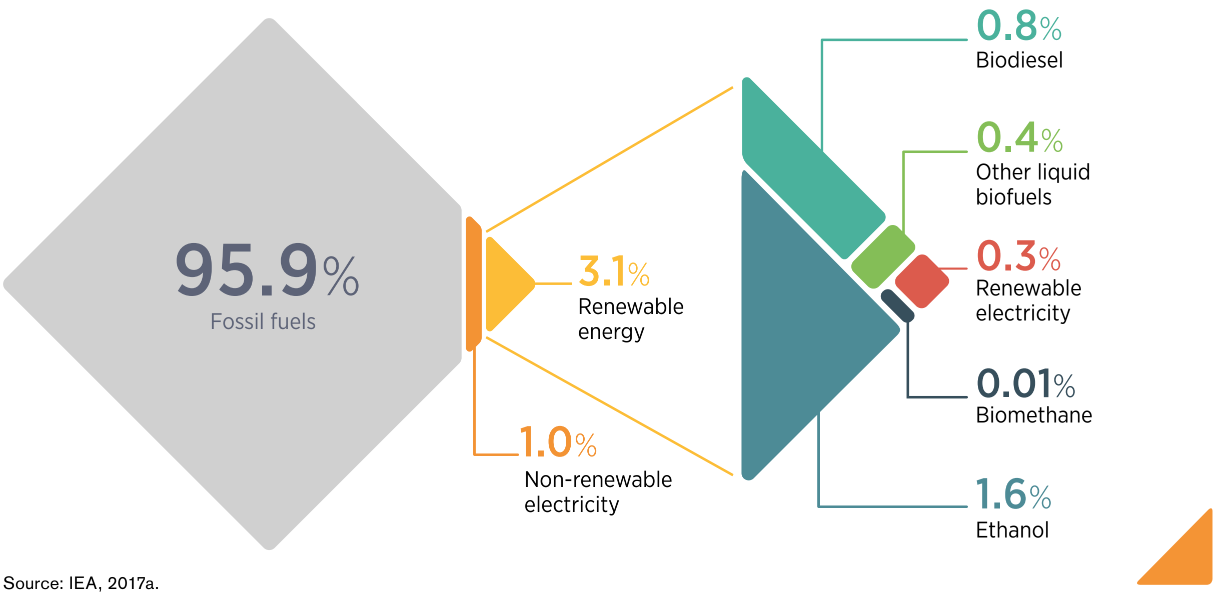
Figure 3.1. The role of transport in total final energy consumption, 2015



Source: IEA, 2017a.

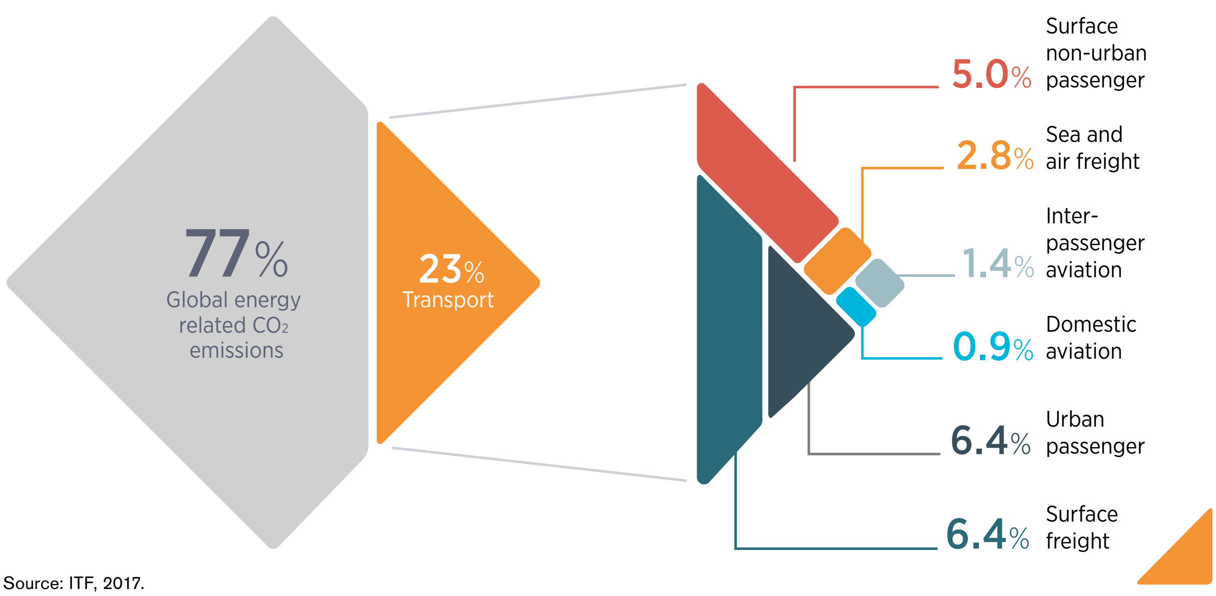
Consequently, the transport sector is a significant contributor to global carbon dioxide (CO_2) emissions, representing 23% of all such global energy-related emissions – and almost 80% of that is from road transport (Figure 3.3). Between 2010 and 2015, emissions in the transport sector increased by 2.5% annually (IEA, 2017b).[1] To date, strategies to decarbonise the sector are clustered into measures to "avoid, shift and improve" (see Box 3.1). Of these measures, increasing energy efficiency and the use of renewable energy (part of the "improve" cluster), are central to completely decarbonising the transport sector.

Figure 3.2. Transport energy use by transport fuel, 2015



Source: IEA, 2017a.

Figure 3.3. CO_2 emissions by transport mode, world, 2015



Source: ITF, 2017.

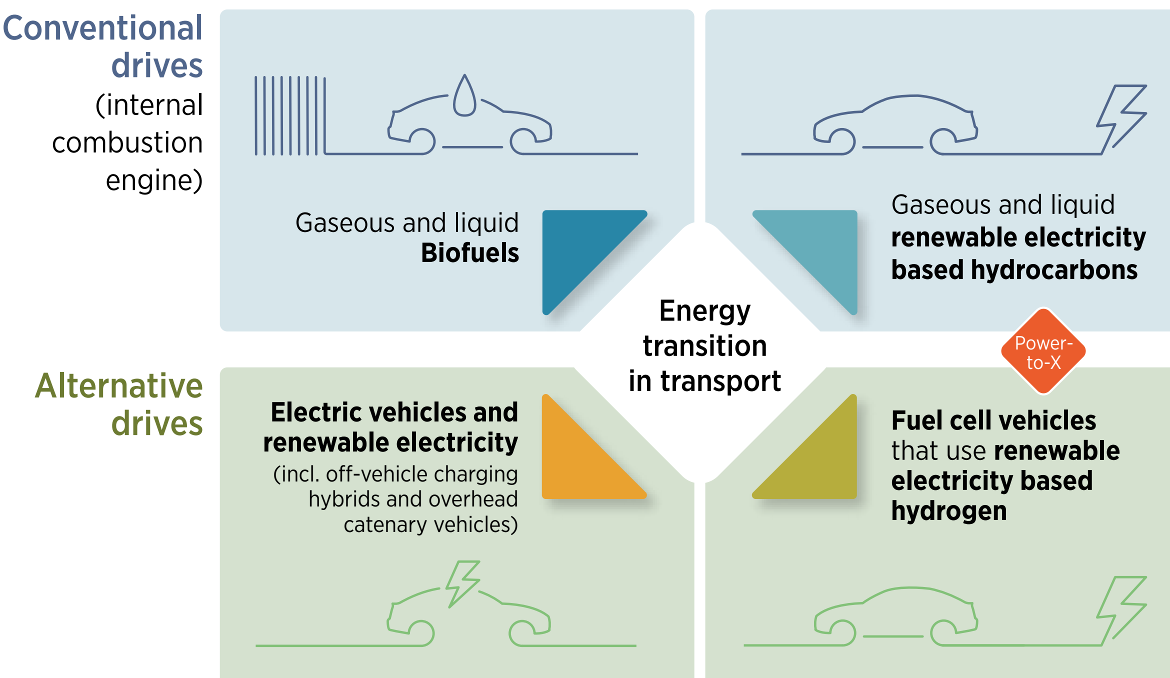
1 This was mainly due to an increase in demand for transport in emerging and developing countries, which led to an increase in the number of vehicles, mileage, and so on.

The use of renewable energy in transport offers numerous benefits, such as enhanced energy security, reduced transport-related carbon emissions and increased opportunities for sustainable economic growth and jobs (*e.g.* there are more than 1.7 million jobs in the biofuels industry worldwide) (IRENA, 2017a). Depending on the renewable fuel, it may also improve local air quality.[2]

In regions with no or low access to energy, off-grid renewable electricity can facilitate access to motorised transport (*e.g.* solar photovoltaics for electric two-wheelers). Nevertheless, the benefits of renewable energy in transport vary significantly by country/region.

Renewable energy solutions for transport range from liquid biofuels, biomethane, renewable electricity, and renewable electricity-derived hydrogen, to ammonia and synthetic fuels (power-to-X or P2X). Some of these energy carriers can be used in conventional vehicles (internal combustion engines), whereas others require the use of alternative vehicles (Figure 3.4). Fuels and vehicle technologies vary greatly in terms of their technical maturity and level of sustainability (AFDC, 2018a).

Figure 3.4. Renewable energy supply options for transport



Source: Hochfeld, 2016.

2 The air quality benefits from biofuels relative to fossil fuels vary according to fuel used and vehicle type; however, analysis indicates biofuels can reduce carbon monoxide, hydrocarbons and particulate matter emissions. A modal switch from internal combustion vehicles to electric vehicles cuts tailpipe emissions, resulting in improved local air quality, especially in urban environments, apart from the benefits of using electricity produced by renewable sources to fuel vehicles.

Currently, renewable energy plays a range of roles in the transport sector:

Road transport. Liquid biofuels (ethanol and biodiesel) provided around 4% of global road transport fuel in 2016 (ITF, 2017). The increasing electrification of road transport offers opportunities for using renewable electricity in this sector (IEA, 2016). In 2016, globally, 26% of the electricity consumed by electric vehicles was renewable (IEA, 2017c). However, the use of renewable energy is very limited in long-distance road transport, particularly of long-haul road freight (currently 30% of global transport related energy demand) (IEA, 2017e). This is despite the existence of technically mature freight vehicles and high-energy-density biofuels that include biodiesel (in blends up to 20%), hydrotreated vegetable oil, biomethane and ED95 ethanol (IEA, 2017c).

Aviation. The aviation sector uses renewable energy in the form of biofuels blended into traditional jet fuel at various levels, also known as *bio-jet* or *bio-jet fuels*. To date, over one hundred thousand commercial flights have used sustainable aviation fuels (IATA, 2018). Alternative propulsion technologies, such as electric- or solar-powered aircraft and the use of cryogenic hydrogen, may offer ways to integrate renewable energy over the long term (IRENA, 2017b) but are still at an early stage.

Shipping. Ships can use biofuels and other renewable-based fuels (*e.g.* electricity-based hydrogen or ammonia) for propulsion, or they can directly incorporate wind[3] and solar energy. The Lloyd's Register assesses that biofuels and ammonia are the best options for green shipping (Lloyds-UMAS, 2017). Regardless, the integration of renewable energy in the shipping sector does not seem to be advancing (IRENA, 2015). But while renewable energy does not yet play a major role in the sector, there are examples of electric and hybrid-electric ferries in Denmark, Finland, Norway and Sweden, and biodiesel ferries in the United States (WSDOT, 2018).

Rail. Rail can incorporate biofuels in fleets fuelled by oil products (around 57% of the total rail fleet), and renewable electricity in fleets powered by electricity (around 36% of the total rail fleet) (REN21, 2017).[4] To date, the penetration of renewables into the rail sector has been predominately to meet electricity demand. The renewable electricity share in the total energy mix of the world's intercity railways increased from 3.4% in 1990 to around 9% in 2015, meeting 21% of electricity demand for railways (UIC, 2017).[5] Some countries, in particular in Europe, have reached up 100% penetration of renewables in the rail sector (REN21, 2017).

BOX 3.1. UNDERSTANDING THE TRANSPORT SECTOR: KEY DRIVERS OF TRANSFORMATION

Understanding the trends and drivers of the transport sector is essential to increasing renewable deployment. The renewable energy share in transport is lower than in other sectors; further opportunities linked to renewables warrant exploration. For example, out of the 152 countries that refer to transport in their nationally determined contributions, only 14% mention the use of renewable energy and alternative fuels (SLoCaT, 2017). Also, the High-level Advisory Group on Sustainable Transport concludes that, under Sustainable Development Goal 7, only the energy efficiency target is related to transport (UN, 2016). It is thus not acknowledged that renewables are essential to decarbonising the sector.

The following elements are indicative of the challenges the transport sector is currently facing:

- **Climate change.** Transport represents 23% of global energy-related carbon emissions; it is impossible to address climate change without decarbonising transport (UN, 2016). The goal is to reduce emissions in the transport sector from 7.7 gross tonnes of emissions per year to 2-3 gross tonnes per year by 2050 (PPMC, 2017).
- **Air pollution.** The human and financial costs of air pollution from road transport are significant, with costs estimated at close to USD 1 trillion per year just for the countries belonging to the Organisation for Economic Co-operation and Development (OECD, 2014).
- **Road safety.** Every year, 1.25 million people die in road accidents, with millions more injured (WH0, 2018). Technologies such as buses, bus rapid transit and rail can improve safety while they reduce greenhouse gas emissions.
- **Congestion.** The annual cost of congestion in the United Kingdom is an estimated EUR 5.4 billion, in France EUR 5.9 billion and in Germany EUR 7.5 billion (VTPI, 2017).
- **Access to transport and social sustainability.** Transport is key to economic development; transport strategies must be inclusive, allowing equal access to jobs, services and other opportunities.
- **Technological and socio-economic innovation and disruption.** Technological developments such as digitalisation, electric cars and autonomous vehicles, as well as the emergence of shared mobility models, are changing the transport sector (IEA, 2016).

3 Sails, kites and Flettner rotors, for example, can be used to harness wind energy as a partial replacement of fuels.

4 The remaining share is fuelled by coal.

5 The share of biofuel is 0.4% (UIC, 2017).

Four primary elements have driven political changes affecting mobility and transport over the past few years:

- The **United Nations Sustainable Development Goals**, adopted in 2015, contain explicit and implicit sustainable transport goals and targets.
- The **Paris Agreement on Climate Change**, adopted in late 2015, set an overall long-term direction for climate change policy and created momentum to develop a roadmap towards carbon neutrality in the transport sector.[6]
- The **New Urban Agenda**, adopted in 2016 at the United Nations Conference on Housing and Sustainable Urban Development (Habitat III), is a framework for planning and managing cities for sustainable urbanisation, including guidelines for sustainable urban and urban-rural transport over the next 20 years (UN, 2017).
- **Local and municipal governments** play an essential role in shifting the paradigm for transport provision by, for example, rolling out electric vehicles or stimulating the use of biofuels in captive fleets (*e.g.* biomethane buses).

The international agenda now defines **sustainable transport** as:

"… the provision of services and infrastructure for the mobility of people and goods – advancing economic and social development to benefit today's and future generations – in a manner that is safe, affordable, accessible, efficient, and resilient, while minimizing carbon and other emissions and environmental impacts." (UN, 2016)

Current strategies to reach sustainable transport goals, and more specifically transport decarbonisation goals, take one of three main approaches (UN, 2016):

- **Avoid:** Reduce transport demand by avoiding inefficient or unnecessary travel or transport, *e.g.* through improved and integrated urban planning, trip and route optimisation, telecommuting, and less complex and extended supply chains.
- **Shift:** Switch transport modes to the most efficient or environmentally friendly mode(s) to improve trip efficiency, *e.g.* non-motorised transport, public transport or carpool.
- **Improve:** Increase operational and energy efficiency and switch fuels to improve the environmental performance of transport to make it less carbon-intensive.

Demand reduction, modal shifts, and efficiency (collectively called the **mobility transition** or **transport transition**), represent the bulk of the potential reduction in energy demand, and thus carbon emissions (IRENA, 2017b). To date, the focus has been on avoiding unnecessary travel, shifting to shared and more efficient transport modes, and increasing energy efficiency. These measures have numerous co-benefits, including an improvement in air quality – and thereby health – as well as a reduction in congestion. However, to fully decarbonise the transport sector and transform it into a net-zero emitter, renewables must meet the remaining energy demand, thereby achieving an **energy transition** in transport.

6 Although domestic aviation and shipping are included in the Paris Agreement, international aviation and international shipping are not.

3.2. POLICIES THAT DRIVE RENEWABLES IN TRANSPORT: OVERVIEW

Digitalisation, new transport modes and electrification are fundamentally transforming the transport sector, making it particularly challenging to assess the future role of renewables. Numerous emerging pathways, coupled with evolving technologies, limited policy experience and low market deployment make for a rapidly evolving sector. This section explores the current role of policies to advance renewable deployment in the transport sector, focusing on policy instruments directly or indirectly driving renewable energy uptake.

A large uptake of renewable energy in transport requires simultaneous and integrated changes in three main areas: 1) the availability of energy carriers and fuels produced from renewable energy sources; 2) the deployment of vehicles that can use renewable fuels; and 3) the development of energy and fuel distribution infrastructure (IEA-RETD, 2015). Policies and planning should aim at overcoming barriers such as the immaturity or high cost of some technologies, the lack of energy infrastructure, sustainability considerations and low rates of acceptance among users. They should also foster improved understanding between the energy and the transport sectors. Examples of policies and measures that support renewable energy in transport include those that:

- Encourage the adoption, development and use of **energy carriers and fuels** produced from renewable sources.
- Stimulate investments, purchases or operation of transport technologies and modes – the **vehicles** – that use renewable energy carriers and fuels.
- Stimulate investments in energy and fuel distribution **infrastructure** that allows for the production and distribution of renewable or renewable-derived fuels.

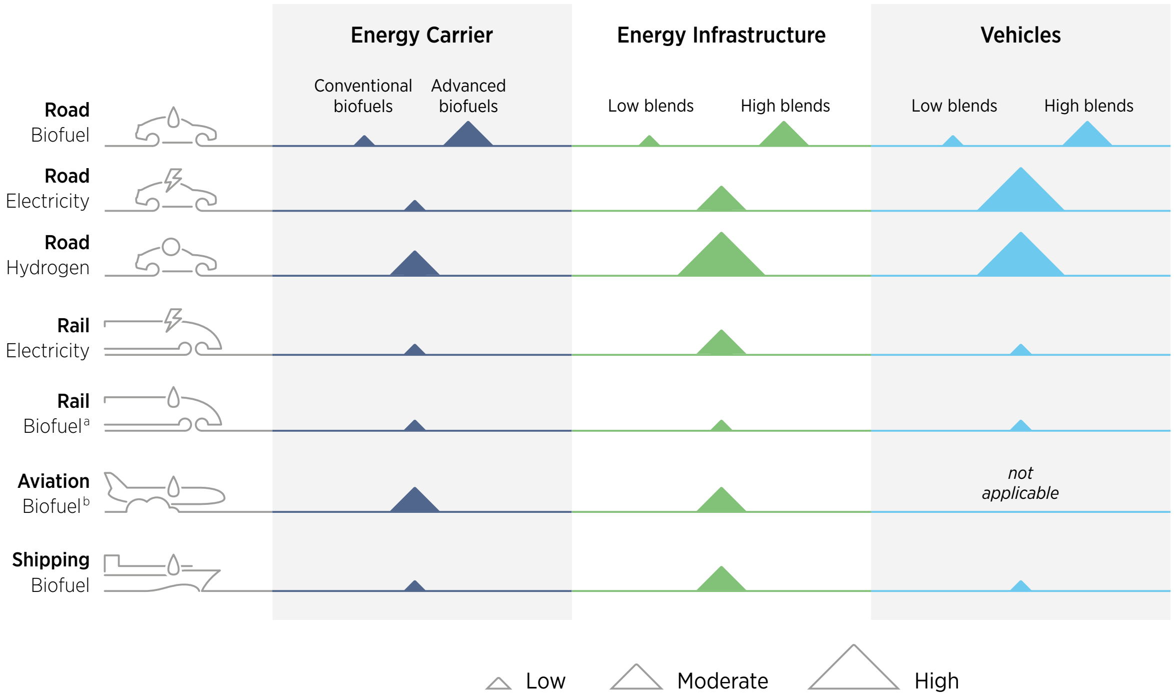
Supportive policies are being implemented at the international, regional, national and subnational levels. Some are relevant to the transport sector overall while others are sub-sector specific (*e.g.* road, aviation and shipping) or include components that are specific to sub-sectors. This variation in policy focus arises out of differences in transport modes, energy carriers and infrastructure, as well as maturity levels and barriers.

All supportive policies should consider industry and transport users – businesses and individuals. Consumer awareness, particularly among individuals, greatly influences the evolution of road transport, especially in urban settings (*e.g.* minimising unnecessary trips, carpooling, taking public transport and choosing a fuel-efficient car).

Considering the high dependence of the transport sector on fossil fuel, removal of fossil fuel subsidies is essential for decarbonising the transport sector. This is particularly true for shipping and aviation as both sectors currently benefit from fuel tax benefits and exemptions (IEA, 2017b; EEA, 2018). Also, a price on carbon would be a key tool to stimulate the decarbonisation of the transport sector. Figure 3.5 presents a schematic representation of market barriers to developing renewable energy in the transport sector along the supply chain, which policy measures must address. The assessment takes into account technical and economic barriers, whereas environmental or social barriers are not regarded.

Current policy interventions that are specifically focused on renewable energy in the transport sector typically relate to the production and consumption of biofuels, the purchase of alternative fuel vehicles or the installation of alternative refuelling equipment. Policies aimed at developing renewable power in transport have only recently begun to emerge along with increasing electrification rates.

Figure 3.5. Technical barriers to developing renewable energy in transport sub-sectors



Note: a) Low blend biofuels; b) Drop-in biofuels

3.3. BIOFUEL POLICIES

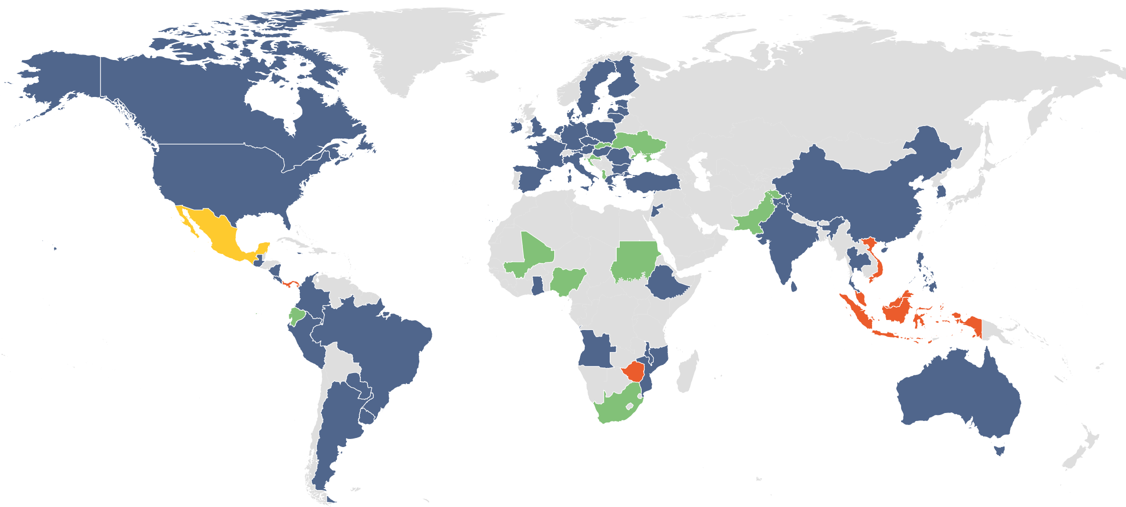
Biofuels are primarily used in road transport, but can also be used for rail, shipping and aviation. Using low-level blends with conventional energy infrastructure and vehicle fleets, biofuels can power the existing transport system. High-level blends often require adjustments in engines and fuel distribution infrastructure.

High-level blends are necessary for deep decarbonisation – in low-level blends, petroleum products complement the biofuel. The technical barriers to moving to higher-level biofuel blends are relatively low, but unless it is a drop-in fuel – a renewable fuel that is interchangeable and compatible with conventional fuels – high-level blends can require the adaptation of engines and distribution infrastructure. Another significant challenge is the market transition to encourage the purchase of suitable vehicles and the expansion of fuel availability.

To date, biofuels, especially conventional biofuels like ethanol and biodiesel, have received the most attention as a strategy to foster renewables in the transport sector. The most common forms of support for renewable energy in the transport sector are **blending mandates**, as well as a variety of **fiscal incentives** and **public financing**.

The number of countries that have adopted a **biofuel obligation/ mandate** increased from 36 in 2011 to 68 in 2017 (REN21, continuous). Figure 3.6 shows the countries that had biofuel obligations in 2016. Only seven adopted blending requirements for biofuel shares higher than 10% (REN21, continuous). In many countries, including Brazil, the United States and numerous member states of the European Union, biofuel mandates have successfully created markets for biofuels in road transport (IRENA, 2016b). Most have also introduced policies expanding infrastructure for the distribution of biofuels.

Figure 3.6. Countries with biofuel obligations for transport, 2016



Source: REN21, 2017.

Disclaimer: The designations employed and the presentation of material in this map do not imply the expression of any opinion whatsoever concerning the legal status of any region, country, territory, city or area or of its authorities, and is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers or boundaries and to the name of any territory, city or area.

Some countries have implemented **fiscal and financial incentives** to promote biofuel production, distribution and consumption, as well as conducting research and development into new technologies. In 2016, for example, Argentina put in place tax exemptions for biodiesel production; Sweden reintroduced tax cuts on ethanol and biodiesel; and Thailand supported E20 and E85 blends as well as a trial programme for the use of B20 in trucks and B10 for military/government use (REN21, 2017). Some countries, such as Brazil and Thailand, have successfully introduced policies expanding their fleet of flexible-fuel vehicles.[7] This has facilitated the widespread deployment of higher-level biofuels (high blends of 27% in Brazil or 20% and 85% in Thailand), and the use of unblended biofuels in flexible-fuel vehicles (see Box 3.2).

Although limited to road transport, countries including the United States and Brazil have been able to create long-term policy frameworks that facilitate investments by biofuel producers and original equipment manufacturers. However, policies and strategies have not yet included aviation, rail or shipping to the same extent.

Policy makers are beginning to introduce **sustainability criteria** for conventional biofuels. The European Union's criteria envision a 50% higher minimum reduction in greenhouse gas emissions compared with fossil fuels and prohibits growing biofuels in areas converted from land with previously high carbon stock (*e.g.* wetland or forest) or producing them from raw materials obtained from land with high levels of biodiversity (*e.g.* primary forest or grassland). Only biofuels that comply with all criteria are eligible to receive support and can contribute to national renewable energy targets (EC, 2018a). Canada has released a set of guiding principles for sustainable biofuels; and the state of California has defined policy frameworks requiring a reduction in life-cycle carbon intensity for transport fuels (IEA-RETD, 2015). In some cases, sustainability concerns can lead to revisions in support policies, such as the new package of clean energy and emissions reduction goals proposed by the European Commission, which includes a scaling down of conventional biofuels and an increasing role for advanced biofuels and other low-carbon alternatives, such as renewable electricity, in transport fuels.[8]

The sustainability discussion contributes to growing policy support for **advanced biofuels** derived from waste, residue or lignocellulosic materials; that do not compete with food production, and that have scant or no emissions from land-use change. Advanced biofuels from waste and residue feedstocks generally have more potential than crop-based conventional biofuels to reduce greenhouse gas emissions[9], but advanced biofuels are still at an early stage of technological readiness and need to overcome barriers such as immature supply chains, high production costs, dependence on unreliable incentives and uncertainty around market size.

7 Flexible-fuel vehicles have an internal combustion engine capable of operating on gasoline or any blend of gasoline and ethanol up to E85 (AFDC, 2018b). In Brazil, more than 95% otto-cycle (gasoline-suitable) vehicle sales are flexible fuel vehicles, and an estimated 70% or more of the gasoline-suitable fleet are flexible-fuel vehicles (UNICA, 2018).

8 This legislation is still being discussed and developed (EC, 2018b).

9 Greenhouse gas emissions from biofuels depend on a range of factors specific to each fuel production pathway, *e.g.* feedstock combination, process and logistical issues.

Governments can help address these issues by introducing specific **mandates for advanced biofuels** and putting in place direct **financial incentives**. Given the high investment costs, **financial de-risking measures**, *e.g.* soft loans, are also important. Currently, only Denmark, Italy and the United States have introduced mandates for advanced biofuels. The United States, through the Renewable Fuel Standard[10], and California, through the Low Carbon Fuel Standard, also support advanced biofuels by giving them a higher value than conventional biofuels in trading mechanisms designed to enable market actors to comply with the US standard. The United States and other countries, including Australia, continue to support the development of advanced biofuels with grants for research and development (REN21, 2017).

Looking ahead, transport policies and industry efforts might focus on biofuel deployment within the heavy-duty vehicle, aviation and shipping sub-sectors, where electrification is more challenging. If power-to-X fuels reach commercial production, they could also contribute to these sectors.

BOX 3.2. BIOFUEL POLICIES: COUNTRY EXAMPLES

Since 2004, **Brazil** has adopted a broad framework of regulations and legislation to support biofuels, creating long term stability in its policy. The current biofuel mandate requires standard gasoline to contain 27% ethanol and standard diesel to contain 10% biodiesel by 2019 (TransportPolicy.net, 2018). Moreover, taxes on biofuels are lower than on fossil fuels. Beginning of 2018, Brazil has established RenovaBio, a new national biofuel policy that sets national emission-reduction targets for the national fuel supply. Fuel distributors can meet these targets by increasing sales of all biofuels (ethanol, biodiesel, and biomethane), which is expected to lead to a significant increase in their production and use (Voegele, 2018). Complementary laws on ecological zoning, industrial activities, forest preservation and agricultural practices facilitate the enforcement of sustainability (Low Carbon Technology Partnerships initiative, 2015). The popular use of biofuels in Brazil is evident in its vehicle fleet: flexible-fuel vehicles that can use up to 85% ethanol constitute around 95% of the sales of new cars and represented 72% of the light vehicle fleet in 2016. As a result, 24 million vehicles can use pure (unblended) ethanol (IEA, 2017f).

In the **United States**, the Renewable Fuel Standard prescribes an increasing volume of biofuel within defined categories – *e.g.* total renewable fuels, including biomass based diesel, cellulosic biofuels and advanced biofuels to be used in the national transport fuel supply. Statutory requirements for total biofuel volume set an increase from around 13 billion US gallons in 2010 to 36 billion US gallons by 2022. Biofuels have to meet a life-cycle reduction in greenhouse gas emissions of at least 20%. The Renewable Fuel Standard also defines target volumes for biofuels that either offer life-cycle greenhouse gas emission reductions greater than 50% or whose production originates with cellulose, therefore creating demand for cellulosic and advanced biofuels (AFCD, 2018a; 2018b). The system is flexible through the renewable identification number trading mechanism. In addition to federal laws, states and cities have introduced regulations, tax breaks and grants to encourage the use of alternative fuels. For example, California's Low Carbon Fuel Standard aims at reducing the carbon intensity of the state's transport fuels by at least 10% by 2020. The State and Alternative Fuel Provider Fleet Program requires covered fleets[11] to meet the Energy Policy Act requirements and reduce their petroleum consumption through one of two methods:

- *Standard compliance*, by acquiring alternative fuel vehicles or creditable electric vehicles; investing in alternative fuel structures, alternative fuel non road equipment or emerging technology; purchasing biodiesel; or using or buying alternative fuel vehicle tax credits.
- *Alternative compliance*, by submitting and implementing a plan to reduce petroleum consumption, thereby obtaining a waiver from the standard compliance's requirements for the acquisition of alternative fuel vehicles (EPAct, 2018). Programs like this can create crucial demand for vehicles and fuels and can help develop the infrastructure for the distribution of biofuels.

Thailand has adopted a range of supportive policy measures to deploy fuel ethanol (IEA, 2017c). Long term targets for transport biofuels, set by its alternative energy development plan, aim to reach 32% average blending by 2032. Petroleum transport fuel taxes are deposited in a state oil fund used to help finance E20 and E85 – which are exempt from taxes, making them more price-competitive. In addition, tax incentives are available for the purchase of flexible-fuel vehicles. As a result, ethanol production has grown annually since 2010, the use of E10 ethanol is widespread, and the number of service stations E20 offering E85 ethanol blends is growing (IEA, 2017c).

10 The Renewable Fuel Standard is a national policy requiring a certain volume of renewable fuel to replace or reduce a quantity of petroleum-based transportation fuel, heating oil or jet fuel. The four renewable fuel categories under the Renewable Fuel Standard are: 1) biomass-based diesel; 2) cellulosic biofuel; 3) advanced biofuel; and 4) total renewable fuel.

11 Covered fleets own, operate, lease or otherwise control 50 or more non-excluded light-duty vehicles (less than or equal to 8,500 pounds) and at least 20 of those vehicles are primarily used within a single metropolitan or consolidated metropolitan statistical area and are capable of being centrally fuelled (EPAct, 2018).

3.4. POLICIES SUPPORTING RENEWABLE ELECTRICITY AS TRANSPORT FUEL

Electricity has been playing an increasing role in the transport sector and is crucial for the development of future energy pathways. The electrification of transport creates opportunities for greater integration of renewable electricity for trains; light rail; trams; and two-, three- and four wheeled electric vehicles (REN21, 2017). However, policies that support the uptake of electric mobility only lead to renewable energy deployment if accompanied by renewable energy-based decarbonisation of the electricity sector.

The deployment of renewables can be driven by **explicit measures** that integrate policies to stimulate the use of renewable electricity in transport[12], *e.g.* by introducing renewable electricity mandates or binding financial and fiscal incentives for electric mobility to the use of renewable electricity. For example, in the proposed revision of the Renewable Energy Directive, the European Commission suggests a fuel supplier obligation scheme, committing all fuel suppliers of the transport sector to include a minimum share of renewable fuels that explicitly includes electricity (EC, 2017). Deployment can also be encouraged **implicitly**, with policies that support the uptake of renewable electricity in parallel or independently of policies that support electric mobility. In this case, the share of renewable electricity in the transport sector would depend primarily on the share of renewables in the electricity mix. Policy strategies differ by electric mobility sector – road transport; private, public, and freight; or rail – and they depend on the penetration of renewable electricity.

In either case, **integrated planning** for electric mobility and renewable electricity production, transmission and distribution is crucial. The uptake of electric mobility will increase the electricity demand and without proper management (*e.g.* smart-charging strategies) could increase peak demand, which is a burden to the grid and requires additional investments.

Although not common, some countries are implementing **financial incentives** to support research and development into new technologies that integrate renewable electricity directly into vehicles. The government of Uganda has, for example, supported the development of a solar-powered bus that integrates photovoltaics on the roof (REN21, 2017).

Road transport: Electric vehicles

There has been a recent uptake in the electrification of short-distance vehicles (light-duty vehicles, electric buses, trolley buses, and two- or three-wheelers). In 2016, 775 000 electric cars were sold, putting the total number of electric vehicles on the road at over 2 million (REN21, 2017). According to the International Energy Agency, there could be 9-20 million electric vehicles on the road by 2020, and 40-70 million by 2025 (IEA, 2017d).

Energy security (owing to the higher energy efficiency of electric mobility[13]), urban air quality, noise mitigation and the potential for a reduction in greenhouse gas emissions drive the deployment of electric vehicles. Facilitated by technological advancements and improving economics, it is mainly policies that drive the uptake of electric vehicles, as these are strategic for fostering sustainable transport (ITF, 2015) (see Box 3.3.)

Deploying electric vehicles offers opportunities to increase the renewable share in road transport by providing renewable electricity to the transport sector as well as to develop electric vehicle-to-grid services, *e.g.* frequency of regulation, spinning reserves and capacity market, by allowing the electric vehicle to act as storage when connected to the grid (see the "In Focus" section on sector coupling in Chapter 5).

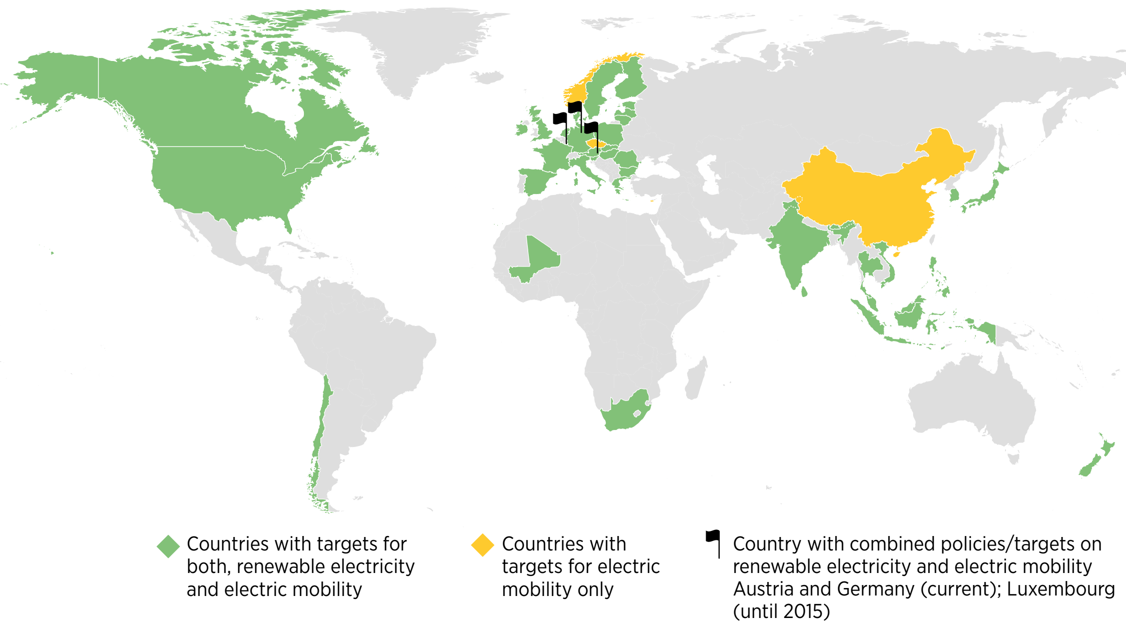
The opportunities for linking renewable energy and electric vehicles in road transport to transform energy use in the transport sector are slowly gaining political attention (REN21, 2017). However, at present, the use of renewable energy in electric vehicles for road transport is primarily being implicitly advanced. In 2016, almost all countries with policies in place to support electric vehicles had also introduced a renewable electricity target (SLoCaT, forthcoming).

To align the targets, countries could implement a hard coupling between the market share for electric vehicles and renewable electricity targets (IEA RETD, 2015). There are only a few identified examples of policies integrating such a component that specifically fosters the use of renewable electricity. Until 2015, Luxembourg provided a grant of EUR 5 000 for the purchase of flexible, plug in hybrid and extended range electric vehicles. Only purchasers who had also signed a renewable electricity contract with their energy provider received the premium (IEA RETD, 2015). In their current e mobility policy, applicable from 2017 to 2018, Austria provides a grant for a range of electric vehicle and two wheelers if they use renewable electricity or hydrogen for fuel (Klimafonds, 2017). In 2017, Germany established a tendering programme of EUR 300 million to stimulate the deployment of charging infrastructure for electric vehicles. Only charging stations that supply renewable electricity for charging (renewable electricity procurement or self generation) qualify for the grant (BAV, 2017).

12 Electric vehicles include any road-, rail-, sea- or air-based transport vehicles that use the electric powertrain and can take an electric charge from an external source, or hydrogen in the case of fuel-cell electric vehicles.

13 Electric vehicles are 5 10 times more energy efficient than renewable liquid fuel vehicles and over 3 times more energy efficient than comparable internal combustion engine vehicles; and renewable electricity is significantly more energy-efficient to produce compared with renewable liquid fuels (GREET model, 2017).

Figure 3.7. Countries with electric vehicle targets that do or do not have renewable electricity targets and explicit measures of renewable energy in electric vehicles



Disclaimer: The designations employed and the presentation of material in this map do not imply the expression of any opinion whatsoever concerning the legal status of any region, country, territory, city or area or of its authorities, and is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers or boundaries and to the name of any territory, city or area.

Note: European Union electric mobility target is not reflected at the country level.

Source: REN21 Policy Database, SLoCaT (2017a).

Mainly driven by **public procurement policies**, electric vehicles are becoming increasingly integrated into public transport, and to a lesser extent public car fleets. Procurement policies can include the use of renewable electricity as an energy carrier. It is useful to extend it to vehicle leasing, which is quite common to public fleets. Considering the contribution of light-duty transport to energy demand and carbon emissions, cities are critical players in decarbonising transport. Public procurement policies are therefore crucial at the local and subnational levels.

With an increasing number of electric vehicles, charging could have a sizeable impact on the grid capacity required at certain times and locations. **Integrated planning** is particularly important for electric vehicles. Not only does it ensure the adequacy and quality of electricity supply, it also reduces the risk of increased costs for users and of negative impacts from advancing the electrification of transport. Further, integrated planning allows for the leveraging of synergies between electric vehicles and variable renewable energy[14], for example, by strengthening demand side management opportunities related to vehicle charging practices (smart charging, vehicle-to-grid strategies), planning charging infrastructure along with the renewable electricity production[15], and developing vehicle-to-grid services (IEA, 2017d) (see "In Focus" section on sector coupling in Chapter 5).

The development of vehicle-to-grid services is still in the early stages, implemented only in pilot and demonstration programmes. Some preliminary policy guidance does exists, however: public policies in support of electric vehicles and vehicle-to-grid services should include electric vehicle purchase financial incentives, the strategic development of supply equipment for electric vehicles and the removal of market barriers for grid services from electric vehicles; and they should enable targeted research and development in components for electric vehicles (Kempton et al., 2017) The California Public Utilities Commission, for example, has developed some early regulations that will accelerate the market viability of service providers of electric vehicles, allowing third parties to resell electricity without regulatory oversight (INL, 2012).

In the Netherlands, 325 Dutch municipalities, several companies, universities and grid operators have joined the Living Lab Smart Charging platform. Supported by the national government, the platform's ultimate objective is to ensure that solar and wind energy power all electric vehicles in the country. The lab is converting existing charging stations and installing thousands of new "smart-charging ready" stations for research and testing with the aim of developing international standards based on the programme's findings and innovations (REN21, 2017).

14 Uncontrolled vehicle charging could significantly exacerbate load peaks on the regional power grid. Conversely, if vehicle charging times shifted to off-peak hours, and if they managed to coincide with renewable power generation, the increase in electricity demand associated with electric vehicles could be accommodated.

15 For example, to make best use of the solar generation during the day, it is necessary to develop charging infrastructure in office buildings so that the electric vehicles can charge while solar output is at its highest level.

BOX 3.3. TRANSPORT POLICY SUPPORT FOR ELECTRIC VEHICLES

Policies are the main driver of the uptake of electric vehicles, and while they rarely include a renewable energy component, a better understanding will help in the development of integrated policy approaches.

A conducive policy environment for electric vehicles facilitates multiple market agents by making vehicles attractive to consumers, investors and manufacturers. In turn, electric vehicle market growth requires actions by many local, state and utility stakeholders to lower barriers through policies and incentives. An example of such a broad based approach is the Zero Emission Vehicle program in California, which "catalyzes automaker marketing and model availability, complementary policy incentives, and sustained investment in charging infrastructure" (ICCT, 2017a).

Policy support for electric vehicles can take various forms, including:

- **Assistance** with research and development of new, disruptive, and innovative technologies to improve performance and drive down costs;
- **Targets, regulations and mandates** for concrete goals and policy deliverables;
- **Financial incentives** to make electric vehicles competitive with conventional vehicles in the form of tax breaks, rebates or exemptions in favour of low emissions. Countries including Brazil, China, 20 members of the European Union and South Africa levy *"differentiated taxes on vehicle registration and/or circulation based on their fuel economy or* CO_2 *emissions performance"* (IEA, 2017d).

China, Europe, Japan and the United States – which represent the uptake markets for electric vehicles – indicate that strong fiscal policy and regulatory mechanisms, with a mix of *"vehicle efficiency regulations, strong consumer incentives, and direct electric vehicle requirements"*, have been early stimulants (ICCT, 2017a).

The link between government support (national and local) and the penetration of electric vehicles is clear, especially in the Nordic countries (IEA, 2018). Governments play key roles in the early market deployment phase, putting forward measures that reduce the purchase price of electric vehicles. These can be coupled with the application of higher tax levels on vehicles that exceed certain emission levels (IEA, 2018). A long term commitment from national policy makers helped Norway successfully deploy electric vehicles, using incentives and tax derogations to close the purchase price gap in relation to conventional vehicles. With a market share of 29% of EVs in 2016, Norway is the country with the highest EV penetration globally (IEA, 2017d). At the regional level, electric vehicles are exempt from tolls and, in some cities, have free access to parking, bus lanes and public charging stations (IEA, 2018).

At the same time, policy support for electric vehicle supply equipment can also serve as an important leveller for the market growth of electric vehicles, including the development of standards to ensure the interoperability of public charging infrastructure within and across country borders, financial incentives, regulations and permits (IEA, 2017d). Furthermore, government programs can pave the way for the private sectors' robust engagement in the long term by promoting competition and innovation in the deployment of electric vehicle supply equipment. In this way, Norway and the Netherlands – leaders in the global market for electric vehicles – have more than 10 times the number of public charging points per capita than the average market (ICCT, 2017b).

Local policies also play a major role in the uptake of electric vehicles. Amsterdam's demand based approach to deploy its network of electric vehicle supply equipment by conditionally providing publicly accessible chargers to electric car owners by request is an interesting example. In Paris, electric car owners are incentivised by the benefits of free parking along with a mandate that allows them to charge their cars at Autolib' charging stations (IEA, 2017d).

Electric rail

Rail based transport is either used to move many people (*e.g.* subways, light rail and trams within a city; trains and occasionally high speed rail for intercity travel) or freight (mostly via train). An escalation of the shift of passengers and goods to rail, a mode of transport with one of the lowest carbon footprints, is expected.

With 36% of the overall rail fleet powered by electricity, the rail sector's electrification is ongoing, with urban rail infrastructure and services largely electrified. Decarbonising the rail sector goes along with a continuing electrification of the fleet, as well as with the use of renewable electricity (PPMC, 2017).

The rail sector has a long history of using renewable energy, spurred by national and subnational **obligations and mandates**. However, rail companies have been the primary drivers of renewable energy as part of their effort to decarbonise their businesses, increase energy security and reduce energy costs. In 2015, prior to the Paris Agreement, the rail sector had already committed to an industry wide initiative aimed at reducing the sector's CO_2 emissions and energy consumption (PPMC, 2017) through the following targets:

- A 50% reduction in CO_2 emissions from train operations by 2030, and a 75% reduction by 2050;
- A 50% reduction in energy consumption from train operations by 2030, and a 60% reduction by 2050[16].

The railways of Austria, Denmark, Finland, the Netherlands, Norway, Sweden and Switzerland are running on 100% renewable electricity, either purchased from renewable energy providers or produced in renewable energy plants owned and operated by the rail companies (UIC, 2017).

In 2011, Infrabel, a Belgian infrastructure manager, began operating 16 000 photovoltaic panels on top of a 3.4 kilometre long high speed rail tunnel, designed primarily for the protection of wildlife in a forest area and to reduce noise from the rail and highway (IEA/UIC, 2013). The total installed capacity is nearly 4 megawatts, with 3.3 gigawatt hours of electricity generated every year. The energy powers fixed infrastructure (*e.g.* railway stations, lighting, heating and signalling) as well as the trains.

In 2014, the government owned Delhi Metro Rail Corporation in India began to invite bids from private solar developers through a tendering process. It has now commissioned an installed capacity of 20 megawatts of solar energy on the roofs of 21 of its metro stations through power purchase agreements. The company has also signed a power purchase agreement with the state government of Madhya Pradesh for 24% of the electricity generated from its Rewa Ultra Mega Solar Project (IRENA, forthcoming).

Renewables are also charging public transit systems. In 2016, Chile announced that as of 2018, Santiago's subway system – the second largest in Latin America after Mexico City – would be powered by solar photovoltaic (42%) and wind energy (18%) (REN21, 2017).

3.5. POLICIES SUPPORTING FUTURE RENEWABLE TRANSPORT FUELS

Power to X, or P2X, refers to any technology that converts electricity to a gaseous or liquid energy carrier. Electrolysis converts electricity to hydrogen to use directly as a fuel or to react with either carbon (in the form of CO_2 or carbon monoxide) or nitrogen to produce a range of gaseous or liquid fuels (*e.g.* methane, ammonia, methanol, Fischer-Tropsch diesel, formic acid and hydrocarbons).

Interest in P2X has emerged primarily out of climate change concerns – more specifically from policies that mandate the decline of the carbon intensity of fuels. In this context, the use of renewable electricity is essential. P2X offers another option for deploying renewable energies in transport, including variable renewables, due to its potential for load shaping at times when the penetration of variable renewable energy is high. It also allows producers to turn abundant renewable electricity, *e.g.* in areas with low energy demand, into energy products that can be shipped to areas with higher energy demand (see the "In Focus" section in Chapter 5).

Developing P2X is crucial because it plays a key role in decarbonising long haul road transport, aviation and shipping sectors that are difficult to decarbonise[17]. Currently, however, P2X fuels are not commercially distributed in the transport sector and are still subject to ongoing research and development (IEA, 2017d). Policy measures therefore focus on providing **funding for research, development, and demonstration**.

An exception is hydrogen, which is being developed in the road transport sub-sector, though, currently, the bulk of hydrogen is not produced from renewable electricity. Although still under represented, several hydrogen fleets are being deployed, often in the frame of demonstration programmes (IEA RETD, 2016). Barriers to the deployment of renewable hydrogen are the high cost of fuel, the high cost of vehicles, an underdeveloped infrastructure for filling, the low share of electrolysis in hydrogen production and the small number of adapted vehicles. A combination of appropriate policies could help address these barriers and stimulate renewable hydrogen mobility[18]: green public procurement in public transport and public fleets; direct financial incentives for hydrogen vehicles; regulation of the infrastructure for distribution and filling, and financial support to deploy them; carbon and energy taxation; and support for pilot projects (IEA RETD, 2016). The overall recommendation for developing P2X is to focus on the development of ammonia for the shipping sector as well as long haul road transport, where few or no competing low carbon technologies exist and P2X is expected to be economically viable.

16 Specific average CO_2 emissions (emissions per passenger kilometre and per tonne/kilometre) and total final energy consumption relative to the baseline of 1990.

17 P2X is only considered completely "green" if it uses renewable energy electricity.

18 Almost all of these measures seem suitable for supporting the market launch of power-to-gas technologies in the transport sector (IEA-RETD, 2016).

3.6. POLICIES SUPPORTING RENEWABLE ENERGY IN AVIATION

Aviation is the fastest-growing transport sub sector – with increasing carbon emissions and energy demand – and it is also one of the hardest to decarbonise. Apart from technological challenges, the deployment of renewables in aviation faces numerous barriers, mainly resulting from the cross-boundary nature of the sector and industry. The International Civil Aviation Organisation (ICAO)[19] regulates the international aviation sector; domestic aviation is subject to national jurisdictions. Consensus is therefore needed among the international aviation community to drive the sector's decarbonisation or the deployment of renewables for aviation.

At present, international agreements exempt international aviation fuel from taxes. Supply chain development and measures to reduce cost premiums over conventional jet fuels are needed if alternative sustainable aviation fuels are to be developed (IEA, 2016). In this context, removing fossil fuel subsidies and putting a price on carbon are essential (IEA, 2017b; EEA, 2018), although implementation could be politically challenging and much work remains to reach a global consensus.

The aviation industry recognises the need to address climate change and has adopted a number of targets, including a 50% reduction in net aviation CO_2 emissions by 2050 (relative to 2005 levels) (IATA, n.d.).

There have also been some policy developments in support of the uptake of renewables in the aviation sector. In 2016, after eight years of negotiation, ICAO adopted the Carbon Offset and Reduction Scheme for International Aviation (CORSIA) to ensure that CO_2 emissions are reported and emission increases are offset[20]. As of 11 January 2018, 73 states, representing 87.7% of international aviation activity, have voluntarily participated in the scheme (ICAO, 2018). Although CORSIA comes into effect only in 2021, and participation is voluntary until 2027, it could foster the production and use of sustainable bio-jet fuels and the purchase of carbon offsets over the long term – and both are key to meeting the industry's decarbonisation targets. United Airlines, among other airlines, has begun to use commercial-scale volumes of alternative fuels for regularly scheduled flights (Robinson, 2017).

As a complement to ICAO regulations, and often with the objective of surpassing ICAO minimum standards, some governments have facilitated the deployment of renewable aviation fuels. The EU Emissions Trading System includes aviation, although this regulation is valid only for inter-European flights (under pressure from ICAO member states, the European Union excluded flights from or to non European Union countries) (Waltz, 2017). Support for biofuels or other renewable fuels – mainly mandates, obligations or financial incentives – include sustainable aviation fuels in some countries. Australia has awarded funding to construct a bio-crude and advanced biofuel laboratory, potentially resulting in the capability of producing renewable diesel and jet fuel from plant material. Under the Sustainable Biofuels Innovation Challenge, the United States provided funding for the development of a demonstration-scale facility capable of producing renewable diesel and renewable jet fuel out of gases from industrial waste (REN21, 2017). The US Renewable Fuel Standard also includes domestic aviation. In the Netherlands, a public-private partnership aims at getting a bio-jet fuel supply chain up and running to supply significant quantities of sustainable jet fuel to Schiphol Airport. Bioport Holland involves aviation and bio-jet fuel stakeholders at the main Dutch ports and airports[21]. Geneva, Montreal, Oslo and Stockholm are participating in similar initiatives.

3.7. POLICIES SUPPORTING RENEWABLES IN SHIPPING

Shipping is one of the fastest growing transport sub sectors. It is inherently the most efficient means of transporting cargo across the globe. The shipping sector mainly uses heavy fuels that contain sulphur and heavy metals, which increases the sector's already large carbon and environmental footprint[22]. Along with aviation, it is one of the hardest transport sub sectors to decarbonise.

Apart from technological challenges, the deployment of renewables in shipping faces numerous barriers, such as the large price gap between renewable and conventional fuels and very limited regulations, particularly regarding the CO_2 content of maritime fuels.

International shipping is regulated by the International Maritime Organisation (IMO)[23]. Since the Paris agreement (which did not include international shipping), the IMO has been trying to define a reduction strategy for greenhouse gas emissions. An initial strategy is expected by April 2018 and a revised strategy by 2023 (Merk, 2017). An unambitious target and postponement until 2023 of any policy measure at the international level could stifle innovation and increase the likelihood of a patchwork of uncoordinated, potentially ineffective regional and national measures. The European Union has already indicated that shipping would be integrated into its Emissions Trading System by 2023 if no significant progress were made by the IMO. China has embarked on an ambitious national programme to decarbonise its shipping sector through carbon pricing (OECD Observer, 2018).

19 ICAO is a United Nations specialised agency that manages the administration and governance of the Convention on International Civil Aviation (Chicago Convention).

20 Reporting on CO_2 emissions during 2019 and 2020 would serve to establish the emission baseline.

21 Current partners include KLM NV, Schiphol Airport, SkyNRG, Port of Rotterdam, Neste and the Dutch ministries of economic affairs and infrastructure and environment.

22 For example, sooty particles contribute to the melting of the ice and acidification of the sea.

23 IMO is the United Nations specialised agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships.

Although there is still no international policy defining the strategy or measures for carbon or renewable energy for shipping (as opposed to the aviation sector), in 2016, the IMO agreed to a 0.5% sulphur cap by 2020[24]. The implementation of this cap will have implications for the burning of heavy fuel oil and offers opportunities for the development of renewable-based fuels. As it is more difficult to produce the supply of 0.5 sulphur blends, it is likely that the majority of the shipping industry will switch to using marine diesel oil or a low sulphur fuel oil. A smaller proportion of the shipping industry is considering using heavy fuel oil in combination with the installation of an on board scrubber or switching to liquefied natural gas. However, capital costs for switching to gas are high, and therefore this will likely be considered for only a small proportion of new ships. Advanced biofuels and synthetic fuels could serve as alternatives but are currently much more expensive (REN21, 2017; Lasek, 2017).

International agreements enable the exemption of shipping fuel from national taxes, and the shipping sector is thus currently subject to low or no fuel taxes – another challenge not sufficiently addressed by the IMO.

Despite playing a limited role in driving the global sector's decarbonisation and the deployment of renewables for shipping, national policies and a few initiatives are contributing to more environmentally friendly domestic shipping.

The Norwegian ship-building and shipping industries are now taking steps to develop a new fleet of "greener" ships by 2050 as part of their Green Coastal Shipping Programme (Richardsen, 2016). The new ships will use the same technology as electric cars but with a battery the size of a storage container, or with a combination of battery power and liquefied natural gas, or some other cleaner-burning fuel such as hydrogen. Norway[25] operates the world's first battery-driven passenger ferry, the *MS Ampere*, with a route crossing the Sognefjord (Kamsvag, 2018).

Current incentives driven by ports and the private sector play a significant role in the uptake of marine biofuel: there are biofuel bunkering projects in the Netherlands and Singapore that aim at supplying advanced biofuels to the domestic shipping sector. The below50 initiative, led by the private sector, is another example. Biofuel producers such as Goodfuels have also begun developing innovative business models. The Dutch company Port Liner, supported by a EUR 7 million grant from the European Union, is building two e vessels, called "Tesla ships", which will sail the Wilhelmina Canal in the Netherlands by this autumn 2018. The carbon free energy provider Eneco, which sources solar power, windmills and other renewables will charge the container ships on the shore (Lambert, 2018).

The Netherlands maintains a marine opt in system (see Box 3.4). There is also a standardised marine biofuel specification under the International Organisation for Standardisation and International Maritime Organisation which forms the key element for the global uptake of sustainable marine biofuel.

BOX 3.4. THE NETHERLANDS: BIOFUEL FOR ROAD, RAIL, AVIATION AND SHIPPING

The European Union Renewable Energy Directive applies to *"all modes of transportation"*. Transposed to the national law of most member states, the scope of the biofuel target is usually limited to road transport and non road mobile machinery, except for a few countries, such as the United Kingdom, which has a biofuel blending mandate that also applies to inland waterway vessels.

The Netherlands has established a biofuel obligation for road and rail: fuel suppliers to these sectors must sell a certain amount of biofuels every year: 7.75% of total volume sold in 2017, 8.5% in 2018, 9.25% in 2019 and 10% in 2020 (USDA Foreign Agricultural Service, 2017). The country also introduced a complementary voluntary certification scheme that does not only apply to road and rail, but also to domestic and international aviation and shipping. Any fuel supplier to the Dutch transport system can claim the delivery of "renewable energy units". Biofuels supplied voluntarily to airplanes or ships are eligible for claims that can be resold to road fuel suppliers, who have a blending obligation. This system functions because these claims are available for trade on the open market, either with another company or with a trader.

For example, a supplier that sells biofuels to a ship operator willing to pay for renewable fuels despite the absence of an obligation to do so can apply for "HBEs" – tickets or claims that can then be sold to third parties to allow them to contribute towards its obligation under the blending mandate.

24 The current global sulphur cap is 3.5%. The average share of sulphur in maritime fuel is around 2.7%.

25 Norway's electricity supply is almost all renewably generated (Hockenos, 2018).

3.8. CONCLUSIONS

Decarbonising the transport sector is key to decarbonising the energy sector. It is a huge task that requires a fundamental change in the nature and structure of transport demand, improvements in efficiency and changes in the energy mix. This transition requires technology developments, behavioural changes and a major policy push.

Renewable energy is an important complement to measures aimed at reducing unnecessary transport, shifting to cleaner and more efficient modes of transport and increasing efficiency to reach targets relating to climate change and sustainable development. Yet the share of renewable energy in transport is lower than in any other sector, and renewables for transport have received little policy attention.

As a result, with the exception of biofuels, there is little practical experience fostering renewables in transport. Most policy interventions to date have related to biofuels. Policies aimed at developing renewable electricity in transport have only recently begun to emerge. Research shows that integrated policies and planning for transport and energy creates opportunities for both sectors.

In general, policies need to address three dimensions in an integrated way: 1) the availability of energy carriers/fuels produced from renewable energy sources; 2) the deployment of vehicles that can use renewable energy fuels and 3) the development of infrastructure for energy and fuel distribution. Table 3.1 presents an overview of the most common policy instruments.

Table 3.1. Renewable transport policy instruments: Strengths and limitations

Policy instrument	Strengths	Limitations
Research and development, demonstration funding. Financial de-risking measures (*e.g.* for capital intensive advanced biofuels, could also apply to power-to-X)	Necessary to support the delivery of initial commercial projects for technologies with long-term market potential but high investment risk.	Financial risk associated with potential project failure.
Rollout of alternative fuelling or charging infrastructure	Necessary for increased use of electric and alternative fuel vehicles.	Need to balance costs of infrastructure while demand is low in early stages.
Vehicle standards	Ensures fuel suitability for vehicles.	Financial and time investment required by original equipment manufacturers.
Low-carbon fuel standards	Technology neutral; favours technologies able to offer the most significant decarbonisation relative to cost.	Unlikely to stimulate demand for higher-cost, less-developed technologies with long-term potential.
Vehicle emission standards (road, air and shipping)	Leads to more efficient use of fuel, regardless of type, as well as the switch to more efficient power-trains (*e.g.* from internal combustion engine to electric generator).	Requires transparent and representative performance testing; can increase capital costs; requires liaising with original vehicle equipment manufacturers.
Zero-emission vehicle mandates	Mandatory; greater certainty of increased deployment, which is key to stimulating private sector investment.	Requires transparent and representative performance testing; can increase capital costs; requires liaising with original vehicle equipment manufacturers.
Obligations and mandates for the share of renewables in fuel	Mandatory; greater certainty of increased deployment.	Need suitable governance to ensure compliance.
Fuel taxes based on the life-cycle of greenhouse gas emissions for fuel or consumption (*e.g.* greenhouse gas emissions per kilometre)	Increases the competitiveness of low-carbon renewable options with fossil fuels.	Determining life cycle well to wheel emissions is complex and time-consuming; results depend on assumptions and are thus subject to debate.
Public procurement of renewable carriers for transport	Can serve as a starting point for increasing deployment more generally.	Only accounts for a certain share of demand and must be complemented with measures to aid broader penetration.

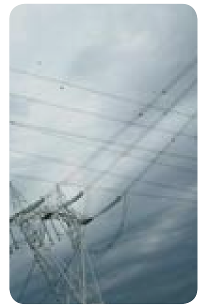
Source: IEA, 2017b.

Key policy takeaways

- Challenges in the transport sector are numerous. Deployment of renewable energy **needs priority attention and must be underpinned by policy**.
- The link between the energy and transport sectors needs to be strengthened to further exploit existing synergies. This is critical to **integrated planning and policy design**, especially for the deployment of electric vehicles.
- **A range of policy instruments need to be planned and implemented** in a combined way to address the issues that make up the transport sector: multiple renewable energy carriers and fuels, transport sub-sectors, etc.
- **Eliminating fossil fuel subsidies and implementing carbon and energy taxes** are important measures to increase the competitiveness of renewable fuels in the shipping and aviation sub-sectors. Low-carbon fuel standards that include life-cycle reduction of greenhouse gas emissions and sustainability criteria support decarbonisation in a technology-neutral way.
- High percentage blends or drop-in sustainable biofuels can contribute to the decarbonisation of the transport sector. **Earmarked blending mandates can be instrumental in guaranteeing demand** for advanced bio-fuels and securing needed investment.
- Technologically less mature renewable fuels (*e.g.* advanced biofuels and power to X) are expected to be essential in some transport sub sectors, including long haul transport, aviation and shipping, where less alternatives are available. **Financial instruments for research and development, and demonstration as well as specific fuel targets are important policy tools.**

04

POWER

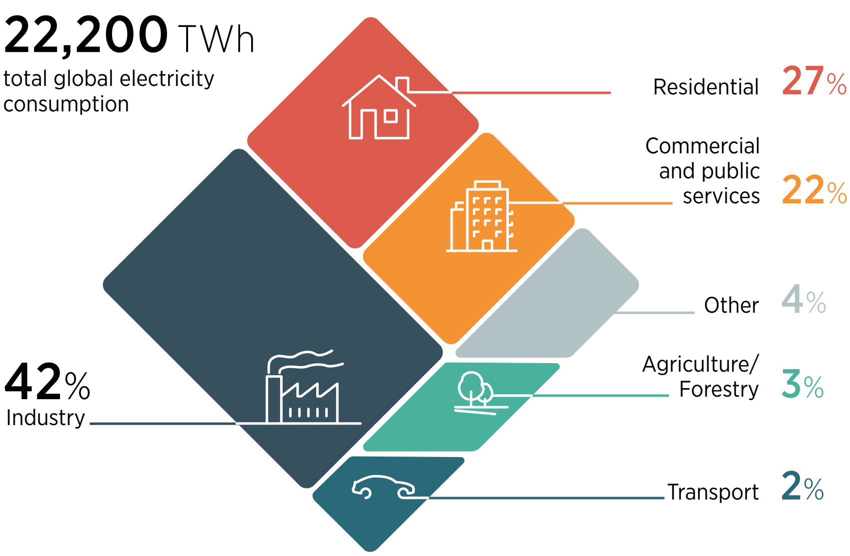


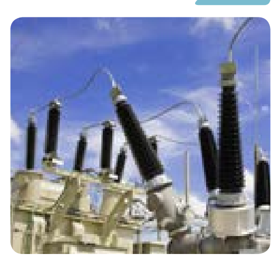
4.1. INTRODUCTION: STATUS AND MARKET TRENDS

Over the past 10 years, global electricity generation grew at an average of 2.8% per year (BP, 2018) and totalled 24,100 terawatt hours (TWh) in 2015 (IRENA, 2017a). By far the largest consumer of power in 2015 was industry, at 42%. The residential and commercial and public services sectors took 27% and 22%, respectively (Figure 4.1).

Renewable energy deployment in the power sector continues to expand significantly. Renewable generation increased at an annual average rate of 6.4% between 2009 and 2014. During the same period, the annual growth rate outpaced growth in electricity demand and in generation from non-renewables (with an annual average growth rate of 2.6%). In 2015, renewables provided about 23.5% of all electricity generated[1] (IRENA, 2017a), the bulk of which came from hydropower, followed by wind, bioenergy and solar photovoltaic (PV) (Figure 4.2).

Figure 4.1. Global power consumption by sector, 2015

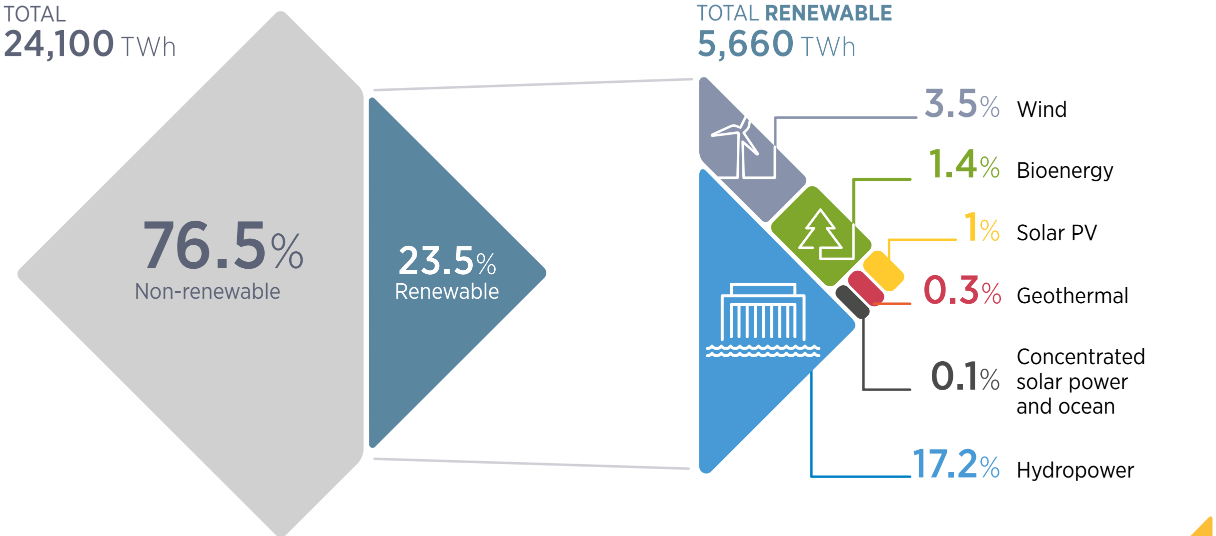




Source: IEA, 2015.
Note: TWh = terawatt hours.

1 Around 66% of global electricity was generated from fossil fuels in 2015, resulting in more than 12 giga tonnes (Gt) of carbon dioxide (CO_2) emissions (IEA, 2015).

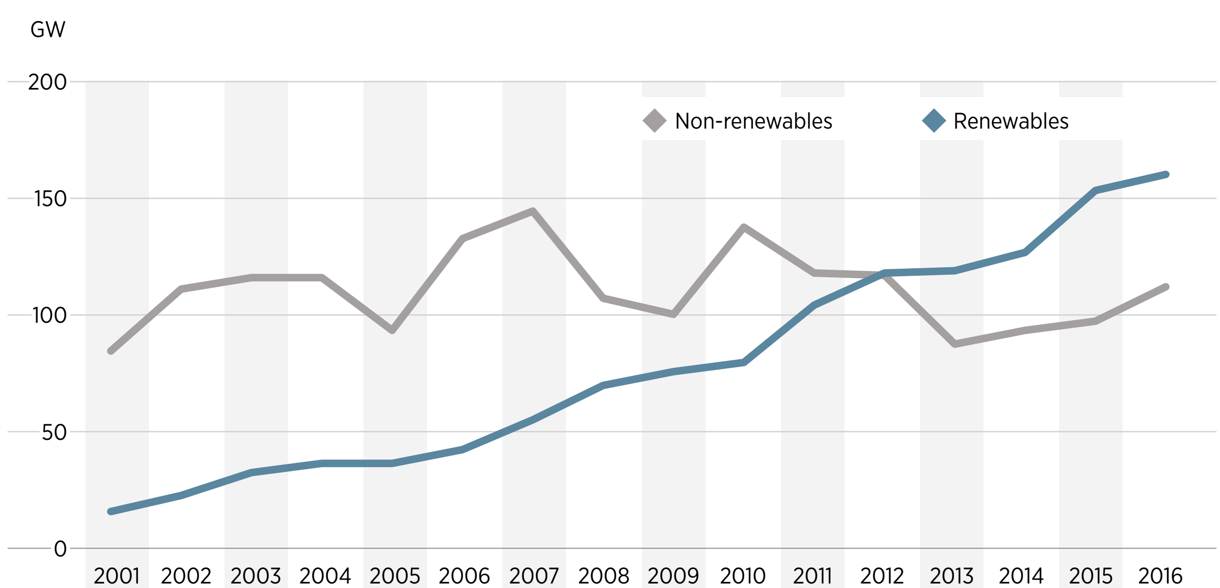
Figure 4.2. Global electricity generation by source, 2015



Source: IRENA, 2017a.
Note: TWh = terawatt hours.

Renewables represented almost 60% of the capacity added worldwide in 2016. In fact, renewable power capacity installations have exceeded those of non-renewable capacity since 2012 (Figure 4.3).

Figure 4.3. Renewable and non-renewable power capacity additions, 2001-16

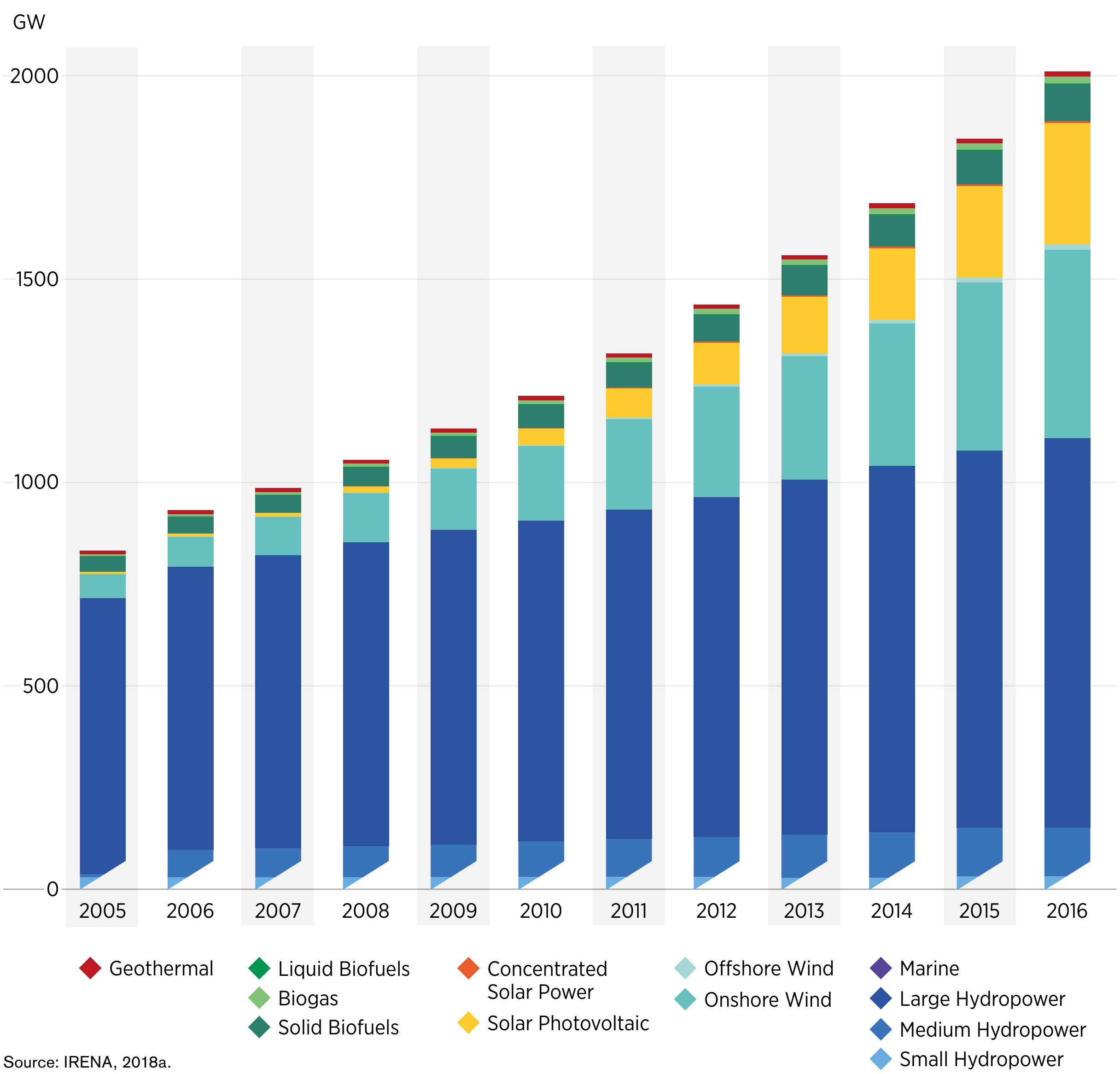


Sources: IEA, 2017 and IRENA, 2018a.
Note: GW = gigawatts.

By the end of 2016, the installed capacity of renewables exceeded 2 000 gigawatts (GW), constituting more than 28% of the world's total power-generating capacity. The bulk of installed capacity was from hydropower (56%), followed by wind power (23%) and solar power (mostly solar PV, at almost 15%) (Figure 4.4). Between 2005 and 2016, the global installed capacity of solar PV increased more than seven-fold and of onshore wind almost three-fold. This expansion was driven mainly by dedicated policies, technological advancement and falling costs. Costs have decreased at a truly impressive rate.

The price of PV modules dropped by more than 80% and the cost of electricity from solar PV fell by almost 75% in the years between 2010 and 2017. The price of wind turbines dropped by about 50% (depending on the market) over the same period, and the costs of onshore wind electricity fell by almost 25% (IRENA, 2018b).

Figure 4.4. Trends in renewable installed capacity, by technology, 2005-16



Source: IRENA, 2018a.
Note: GW = gigawatts.

4.2. RENEWABLE POWER POLICIES: OVERVIEW

Efforts to advance the deployment of all types of renewables in the power sector have been led by government targets and policies. **Targets** provide a high-level signal to various actors to encourage investment in renewable energy and provide the foundation for many of the support policies and measures covered in this chapter. Key policies that enable the translation of targets into concrete actions include mandates, market-based approaches, finance mechanisms, and voluntary consumer and corporate programmes. By 2017, 150 countries had adopted renewable electricity generation targets; 126 had implemented dedicated policies and regulations (REN21, 2017).

This chapter discusses the evolution and trends in regulatory and non-regulatory policies to support renewable energy in the power sector. **Quotas and obligations** mandating that a percentage of power must be generated from renewables, along with **tradable renewable certificates**, are applicable to all stakeholders for installations of various sizes, as discussed in section 4.3.

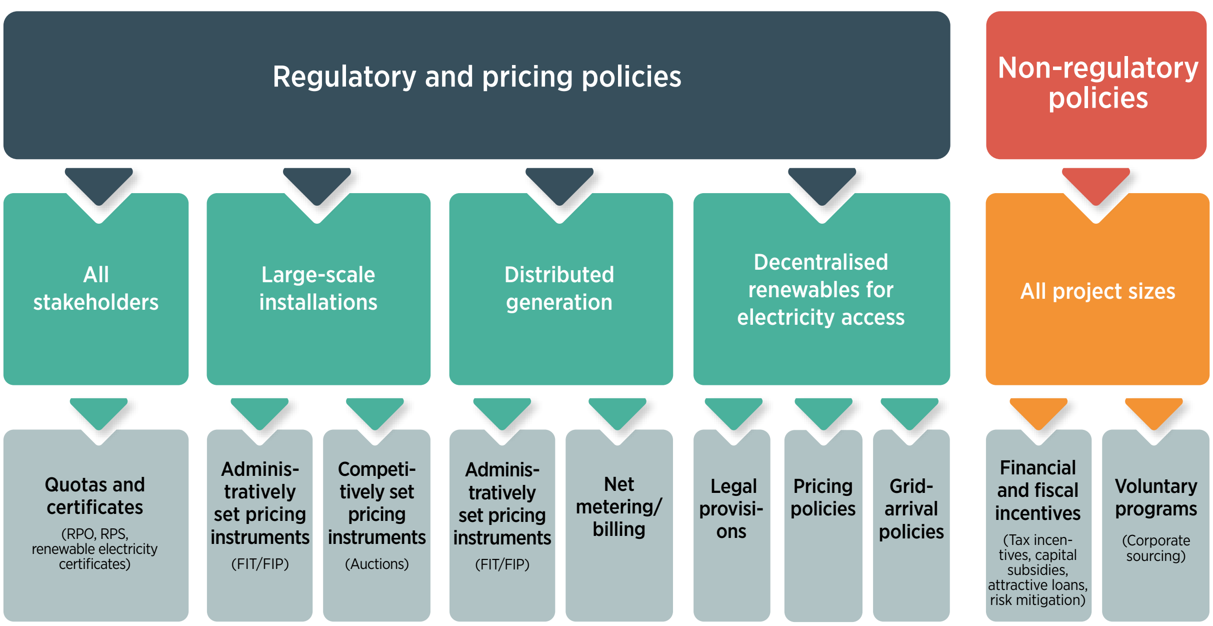
Initially, investments in solar PV and onshore wind were largely driven by regulatory and pricing policies such as fixed **feed-in tariffs** (FITs), offered along with guaranteed access to grids and priority dispatch. As renewable technologies have matured and their costs have fallen, large-scale power projects have been increasingly supported by **auctions**, which can be designed to fulfil multiple policy objectives. The evolution of regulatory and pricing policy design to support large-scale renewable energy technologies is discussed in section 4.4.

As renewable energy technologies, such as solar PV, have become more affordable, decentralised and small-scale applications (*e.g.* rooftop solar) are being scaled up, particularly in countries with a supportive policy environment. Key measures are also enabling the expansion of less widespread technologies, such as bioenergy for power or cogeneration. Regulatory and pricing policies to support distributed generation are discussed in section 4.5. Decentralised solutions (*e.g.* stand-alone and minigrid installations) are also critical in expanding electricity access. Specific regulatory and pricing measures to support such solutions are presented in section 4.6.

Non-regulatory policies play an equally important role. **Financial and fiscal instruments** that facilitate investments in renewable power and measures that encourage voluntary programmes are discussed in section 4.7.

Building on the progress described above and lessons learned around the world, this chapter presents key policies and measures that can support the further scaling up of renewable energy deployment. Figure 4.5 presents a framework for categorising the renewable energy policies covered in the chapter.

Figure 4.5. Classification of power sector policies



Note: FIT = feed-in tariff, FIP = feed-in premium, RPO = renewable purchase obligations, RPS = renewable portfolio standards.

4.3. REGULATORY POLICIES FOR ALL STAKEHOLDERS

4.3.1 RENEWABLE ELECTRICITY QUOTAS AND MANDATES

Renewable energy electricity targets can be cascaded down to electricity suppliers, generators or consumers through electricity quota obligations, also referred to as **renewable portfolio standards** (RPSs, *e.g.* in the United States) or **renewable purchase obligations** (RPOs, *e.g.* in India) or **renewable obligations** (ROs, *e.g.* in the United Kingdom). By the end of 2016, 100 jurisdictions had adopted some variety of electricity quota obligations, including 29 US states (REN21, 2017).

Electricity quota obligations vary in their design according to the choice of design elements (type of quota, time frame, technology, obligated entities and compliance rules). The Republic of Korea, for example, adopted renewable energy standards to achieve 10% renewable energy generation by 2020. Key design elements included the differentiation of targets by technology and the establishment of a robust renewable energy certificate (REC) system and non-compliance mechanism (Cox and Esterly, 2016).

The effectiveness of quota obligations depends on the context in which they are applied and the presence of a solid framework to monitor and penalise non-compliance (the cost of non-compliance being higher than the cost of complying). In certain US states, for example, legislative mandates for renewable electricity standards include defined penalties for non-complying entities. This approach often places the responsibility of procuring renewable power on the electricity suppliers, often utilities (Cox and Esterly, 2016). Without penalties for non-compliance that are higher than the cost of compliance, renewable obligation policies may be ineffective. In India, solar RPOs have been introduced in 26 states, some of which are gradually incremented until 2021 (MNRE, 2016). However, implementation has been slow in India as the market for tradable certificates was not fully functional when the policy was implemented (see Box 4.1). In the United Arab Emirates, there are no compliance rules to penalise utilities in case of non-compliance.

4.3.2 TRADABLE CERTIFICATES

Most countries with quota obligations support the scheme with tradable RECs. A REC is typically awarded to a generator for each megawatt hour of renewable energy produced. Market participants, such as suppliers or generators, participate in receiving or buying a number of certificates to meet the mandatory quotas established for the year. Certificates can be accumulated to meet obligations and provide a tool for trading among participants. The number of countries to adopt RECs increased from 16 in 2005 to more than 30 by 2017, including the European Union and Australia (REN21, 2017). In Australia, for example, the REC market reached record highs, after the government's new targets for renewable energy, announced in June 2015, gave a boost to trading.

BOX 4.1 RENEWABLE PURCHASE OBLIGATIONS (RPOS) IN INDIA

In India, an assessment of state-level RPOs found that the instrument has not been effective. In 2016, RPO targets were achieved in only six out of 24 states despite being set at relatively low levels. Obligated entities did not make use of the renewable energy certificates (REC) mechanism for compliance and only six states reported purchasing RECs towards fulfilling RPO targets.

The failure to achieve RPO targets was due to a lack of effective monitoring and enforcement of compliance. Although regulations require regular reporting by designated nodal agencies on compliance by obligated entities, monitoring of compliance by central and state regulators has been lax. Only 10 out of 29 state electricity regulatory commissions (SERCs) have procedures to review RPO compliance. Moreover, as of early 2016, RPO compliance reporting had been done only up to financial year 2014, or, in some cases, 2012. Most states had failed to track RPO compliance by obligated entities. Some states allowed obligated entities to carry forward shortfalls in their RPO targets in a particular year to subsequent years, or, in some cases, sought waivers from fulfilling RPO targets. In 17 of the 24 states that reported shortfalls, penalties were not collected from obligated entities. It was estimated that an amount of approximately INR 42.34 billion (USD 617 million)[2] in penalties was subject to levies on defaulting obligated entities. As a consequence, RECs for fulfilling RPO targets were purchased in only six states. In addition, the mechanism did not allow for inter-state sale of RECs. This affected the cash flows of, and corresponding investment into, REC generators. The REC mechanism, which could have spurred investment in new renewable energy projects and added much required renewable energy capacity eventually lost its appeal, leading to a decline in the accreditation and registration of renewable energy projects under the REC mechanism. In the Indian context, if the REC mechanism is to survive, strict RPO compliance is will be required.

Source: Adebare, 2016.

2 USD 1 = INR 68.6072 in November 2016.

While these new targets have helped revitalise investment in renewables, a forecasted shortfall in supply caused the price of large-scale generation certificates to rise steadily in 2016, from AUD 65 (USD 48)[3]/MWh to AUD 90 (USD 66)/MWh (Environmental Finance, 2016).

As shown in the case of India, the effectiveness of tradable RECs is highly dependent on the definition of subnational binding targets aligned to national targets and supported by adequate compliance and enforcement. In addition, the availability of a dynamic and efficient market for trading certificates is important in enabling positive outcomes. Furthermore, in the absence of a penalty for entities that fall short of the legally required number of certificates each year, certificates will not have value on the market and will not drive greater deployment. To ensure a demand for certificates, the penalties should be higher than the market price of certificates, otherwise entities may choose to pay the penalties and ignore targets altogether. Owing to these design considerations, and to the fact that RECs cannot be applied in a single-buyer/one-supplier model, tradable RECs have not been implemented in many developing markets.

Even in some more mature markets, such as those of Italy and Poland, quota systems have been replaced by other instruments such as feed-in policies. In 2012, Italy gradually phased out its RPS in favour of feed-in policies (mix of feed-in tariffs and auctions depending on project size) although the scheme was successful in deploying large-scale renewables – with a total of 6 700 MW of wind capacity installed by the end of 2011. The feed-in policies enabled differentiated pricing according to project size, limiting the cost of support (Gipe, 2012). In addition, feed-in policies were perceived to be more effective than tradable certificates in lowering investor risks and increasing incentives for innovation in countries – including Denmark, Germany and Spain – leading to higher deployment (Mahalingam and Reiner, 2016).

In addition to enabling the monitoring of project compliance, tradable RECs provide additional financial support to developers through the sale of certificates. They also help private companies achieve their renewable energy targets. Most countries with established REC markets have two trading schemes: compliance markets, where utilities and energy suppliers issue or purchase RECs to comply with quotas for renewable energy; and voluntary markets, where RECs are bought and sold primarily by companies aiming to meet corporate goals for renewable energy and to reduce greenhouse gas (GHG) emissions from electricity (Sustainability Roundtable, 2012).

In most cases, renewable electricity quotas and mandates and tradable certificates have been adopted together with other regulatory and pricing mechanisms.

4.4. REGULATORY AND PRICING POLICIES FOR LARGE-SCALE INSTALLATIONS

4.4.1 ADMINISTRATIVELY SET FEED-IN PRICING POLICIES (FITS AND FIPS)

Administratively set feed-in pricing policies, namely **feed-in tariffs (FITs)** and **feed-in premiums (FIPs)**, have been instrumental in encouraging renewable energy projects worldwide, since they provide a stable income to generators and help increase the bankability of projects. By 2017, FITs and FIPs had been adopted by more than 80 countries, up from just 34 in 2005 (Figure 4.6). Their main challenge involves getting the tariff or premium level just right, and adjusting it as needed (methods to set the premium in a FIP are discussed in Box 4.2). For example, an inefficient tariff can result in a price that is too low to attract developers or one that is too high – leading to windfall profits, potentially high consumer tariffs or a strain on the government budget. Where deployment rates are high, the effects of an inefficiently set tariff level increase. Also, tariff schemes are subject to the information asymmetry common to the power sector: regulators and policy makers may not have access to the industry information they need to make informed decisions. As new information comes to light, tariffs must be adjusted accordingly (NREL, 2016a). Revisions must also reflect market developments and technological advancements (IRENA, 2015a). These are among the reasons why the use of feed-in policies with competitively set tariffs or auctions has increased in the past decade.

BOX 4.2 METHODS OF DETERMINING THE FEED-IN PREMIUM

Feed-in premiums (FIPs) have been increasingly adopted in liberalised electricity markets (such as those opened to private sector participation). Premiums are generally of two types: a fixed premium set on top of the market price, usually combined with a floor and cap to reduce risks, or a floating (sliding) premium where a reference value ("strike price") is set and the premium is calculated as the difference between the reference value and the reference market price. Caps and floors can be introduced to limit excessive profits or limit risks for generators when the electricity market price rises too high or falls too low. A variation of the FIP is the contract for difference: if the wholesale market price exceeds the strike price, the generators return the difference.

One key benefit of the FIP is that it makes the spot market more relevant, giving it an essential role in providing price signals that may guide investors in where and when renewables may be most efficiently used to produce electricity. Such a market often develops over years, and so a move from a FIT (fixed) to a FIP (first variable and then fixed) can be a way to accompany this development. It should be noted, however, that FIPs may impose additional costs on producers, including transaction, balancing, forecasting and scheduling costs.

Source: CEER, 2016.

3 USD 1 = AUD 1.35 in November 2016.

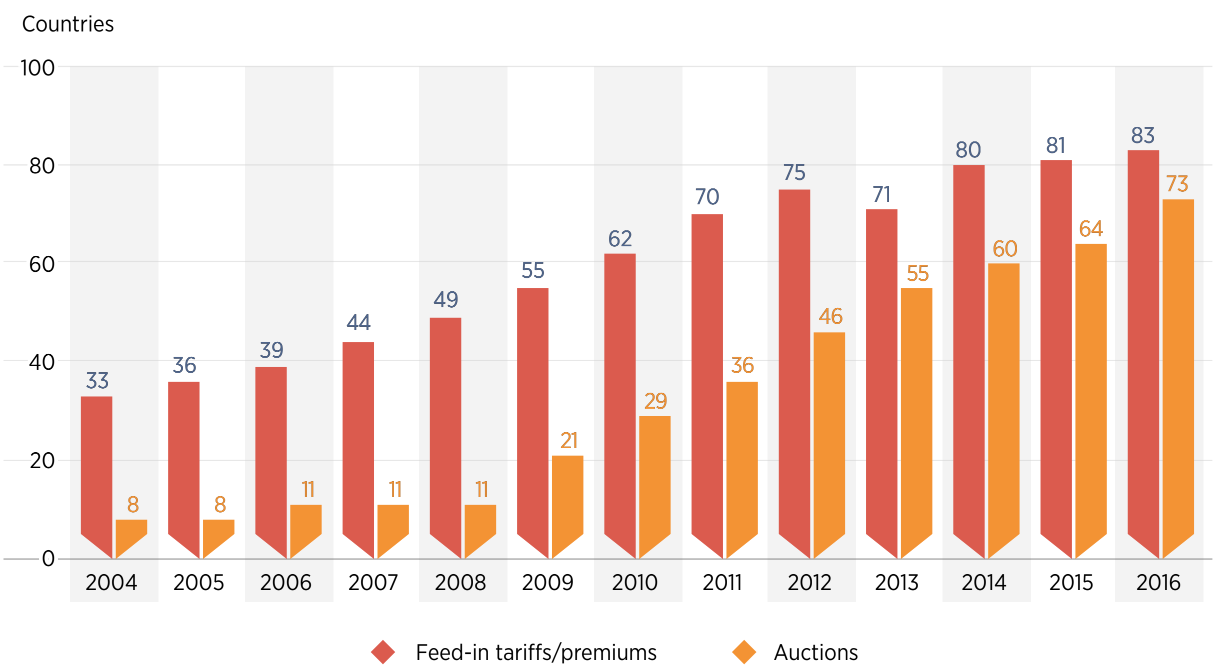
4.4.2 COMPETITIVELY SET FEED-IN PRICING POLICIES (AUCTIONS)

With the increasing cost-competitiveness of renewables, mainly solar PV and onshore wind, and the need for more sophisticated deployment policies that can contribute to other objectives, countries have increasingly moved to **auctions**. More than 70 countries had adopted auctions by the end of 2016 (Figure 4.6), and of these, 34 countries had held auctions in the year 2016 itself, more than double the previous year (REN21, 2017).

Auctions have gained popularity in different contexts in recent years, owing to their flexibility of design. In other words, they can be tailored to the country-specific context and objectives.[4] Moreover, in the presence of a suitable legal framework, auctions can ensure transparency and commitment. Auctions have often been implemented in parallel with other support instruments, such as those that aim to facilitate access to finance or maximise socio-economic benefits. In Argentina and Zambia, for example, auctions have been coupled with financial guarantees backing the contracts, to increase investor confidence. In South Africa, auctions have been coupled with local content requirements to support the development of a local industry. In Mexico, auctions were coupled with electricity quotas and tradeable certificate schemes, which require a solid regulatory framework and relatively advanced market.

Most important, auctions have been increasingly adopted given their potential for real price discovery. In China, solar and wind auctions conducted in 2011 served as price-discovery mechanisms used to set the FIT in various provinces (IRENA, 2013).

Figure 4.6. Trends in the adoption of FITs/FIPs and auctions, 2004-16



Source: REN21, 2005-17.
Note: FIT = feed-in tariff; FIP = feed-in premium.

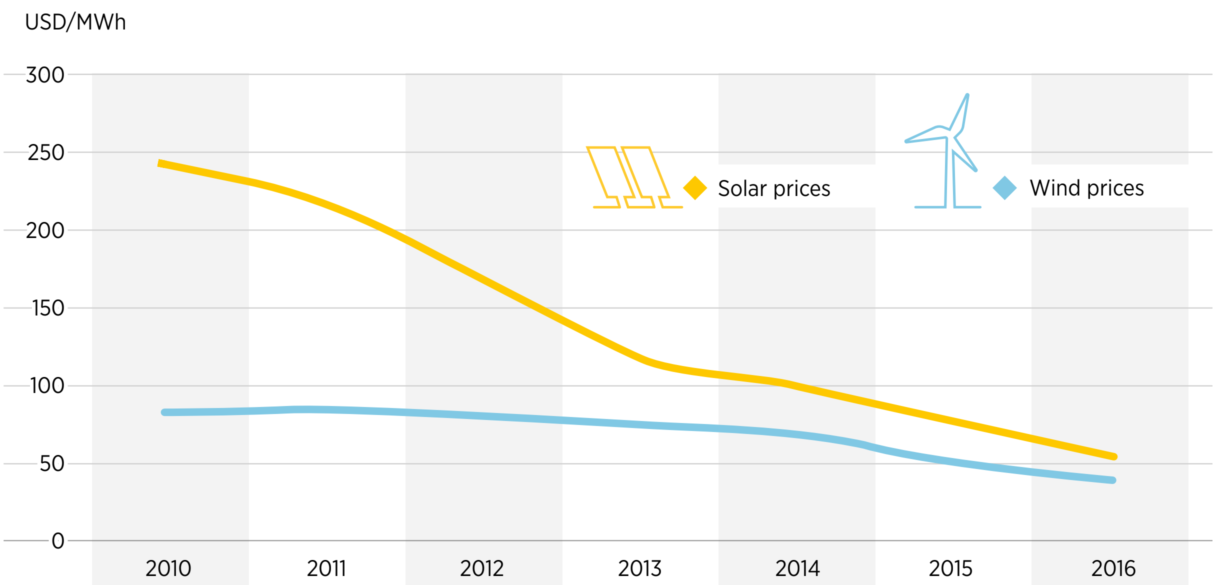
4 In the EU context, auctions are adopted as a support measure for renewable energy deployment in response to the updated European State Aid Guidelines.

The potential of auctions to discover real prices has been a major motivation for their adoption worldwide. As Figure 4.7 illustrates, the price results of solar and wind auctions have gradually decreased in recent years. In 2016, solar energy was contracted at a global average price of USD 50/megawatt hour (MWh), a striking difference from 2010's average price of almost USD 250/MWh. Wind prices also fell in the same period, albeit at a slower pace (since the technology was more mature than solar in 2010). The average price in 2016 was USD 40/MWh, down from USD 80/MWh in 2010. Even auctions for other renewable technologies attracted investment in 2016. Examples include auctions for offshore wind in Denmark, Germany and the Netherlands; for bioenergy capacity in Argentina and Peru; and for solar thermal power in Dubai (IRENA, 2017b).

It is important to highlight, however, that auctions reflect only the degree of competition that already exists in a market — and they must be designed appropriately to do even this. Moreover, they can lead to underbidding or limit the entry of small/new players in the market (IRENA, 2015b).

While many countries have moved from feed-in policies with administratively set support towards competitively set tariffs through auctions, some countries have chosen to implement both. For example, Germany (see Box 4.3), Italy and Malaysia are using auctions for large-scale projects and FITs/FIPs for smaller projects.

Figure 4.7. Average global prices resulting from solar PV and onshore wind auctions, 2010-16



Source: IRENA, 2017b.
Note: MWh = megawatt hours.

BOX 4.3 THE HYBRIDISATION OF AUCTIONS AND PREMIUMS IN GERMANY AND THE IMPACT ON CONSUMERS

In 2017, Germany held its first auction for offshore wind. Three of the four winning projects (1 380 MW out of the total 1 490 MW) offered a strike price of EUR 0/MWh for projects to be delivered in 2024. However, for projects won at a positive strike price, for offshore wind as well as other technologies, a continued fall in electricity market prices, with the increased penetration of renewables, may put pressure on residential consumers.

Germany funds renewable energy development through a consumer surcharge, based on the difference between the remuneration rate guaranteed to the developer and the wholesale market revenue of renewables. The latter has been falling in recent years. In the first half of 2016, the average power price on the exchange was CENT EUR 2.5/kWh, down from CENT EUR 3.2/kWh in 2015. The surcharge rose by about 8%, from CENT EUR 6.35/kWh to CENT EUR 6.79/kWh in 2017.

Moreover, because partial exemptions are given to more than 2 300 companies that are electricity intensive and subject to international competition (they pay only about 2% of the surcharge although they use about 25% of Germany's power), residential and small commercial customers pay the bulk of the support.

Sources: IRENA, 2017b; Lang and Lang, 2016.

4.5. REGULATORY AND PRICING POLICIES FOR DISTRIBUTED GENERATION

Renewable-based distributed generation (DG) technologies are expanding rapidly around the world. DG technologies, which allow for the production of energy near the point of use, can complement larger-scale power generation. The modular nature of DG systems allows for rapid deployment and, in many cases, is the most cost-effective energy option for rural off-grid locations (Section 4.6). Regulatory and pricing policies that can support DG include administratively set feed-in policies (Section 4.4) and net metering and billing schemes.

Administratively set feed-in policies for large-scale installations, discussed in section 4.4, are similar to those for distributed systems. A FIT/FIP can be designed to encourage distributed PV in buildings. In Malaysia, bonus rates are offered for PV installed in buildings or building structures or used as building materials (an additional MYR 0.1256/kWh on the FIT of MYR 0.4435/kWh for installations between 24 kW and 72 kW and an additional MYR 0.0848/kWh on the MYR 0.6682/kWh for installations up to 4 kW)[5] (SEDA, 2018).

Net metering and net billing are measures that promote the use of distributed generation for local consumption by providing compensation to DG owners. A self-consumption scheme usually allows DG system owners to reduce or eliminate the variable charge portion of their electricity bills. In a net metering scheme, the compensation is in energetic terms (*i.e.*, credit in kWh), and the credit can be applied to offset consumption of electricity within the current billing cycle (*e.g.*, one month) and often in future billing cycles as well. In net billing, the compensation is monetary (*i.e.* credit in monetary units) (IEA-PVPS, 2016). Under a net billing scheme, a DG system owner can consume electricity generated by its DG system in real time and export any generation in excess of on-site consumption to the utility's grid. In this way, net billing is akin to net metering. However, under net billing, banking of kilowatt-hours within a billing cycle to offset future consumption is not allowed. Rather, all net energy exports are metered and credited at a predetermined selling rate the moment they are injected into the grid (Zinaman et al., 2017).

The number of countries having adopted net metering and net billing increased from 9 in 2005 to 55 in 2017 (REN21, 2017). In the United States, net metering had been adopted in 41 states and several other jurisdictions in 2014, and the majority of solar installations across the country were operating under such a scheme (IRENA, 2017c). Regulators must decide on several key design features when setting up net metering or billing schemes. These include eligibility requirements, the value of excess electricity, the length of the self-consumption entitlement period, grid codes, additional taxes and fees applicable to self-consumption and third-party ownership, and geographical compensation (IEA PVPS, 2016).

Distributed generation enables local self-consumption, which can deliver savings both to the endconsumer and the system as a whole. For example, many commercial consumers have achieved electricity bill savings by installing solar PV panels. Distributed PV (DPV) has experienced significant growth in recent years, with investment reaching approximately USD 67.4 billion in 2015, up 12% from 2014 (Frankfurt School-UNEP Centre/BNEF, 2016). Much of this investment occurred in developing countries, largely attributed to the scale-up of effective finance, innovative business models and the continuing decline in DPV costs. DPV prices are competitive with electricity retail prices in many jurisdictions globally, and the DPV market is expected to continue to grow, particularly in developing countries (REN21, 2016).

5 USD 1 = MYR 3.89 in February 2018.

When local generation coincides in time with behind-the-meter consumption, self-consumption reduces the utilisation rate of network assets, both at the transmission and distribution level. This reduces power flows through the grid, decreasing energy losses, especially in the distribution network where most energy system losses occur. It can also enable reductions in peak demand, thus potentially postponing the need for network reinforcements and upgrades in areas with scarce spare grid capacity.

However, conventional tariff designs and net metering policies may jeopardise a system's cost recovery and create cross-subsidisation among those customers who self-consume and those who do not in cases where DG levels are high. End-consumers make their decisions based not on wholesale electricity prices but on the retail tariffs they pay, while the cost of generating electricity often accounts for less than half of the final electricity costs paid by the end-user. Moreover, with socket grid parity becoming increasingly widespread, there is a risk that retail tariffs will not accurately reflect the actual value of electricity at each location and time period (IEA PVPS, 2016). This, in turn, has implications for the efficiency of investment and consumption decisions.

Cost-reflective tariff structures should be deployed, which will require properly readjusting the balance between volumetric charges (USD/kWh), fixed charges (*e.g.*, USD/meter-month) and, where applicable, demand charges (USD/kW). Exposing consumers and prosumers to time-dependent pricing (time-of-use tariffs) would incentivise consumption at times (of the day and of the year) when variable renewable energy resources are abundant, thus contributing to system flexibility (IRENA, 2017c).

Implementing sharing economy approaches into tariff reformulation would facilitate the transition by partly eliminating the resistance from stakeholders that may feel threatened by the process, and simultaneously engaging other stakeholders currently lacking an active role in the system (prosumers empowerment).

Well-designed net metering schemes that encourage self-consumption can drive prosumers to a more system-friendly behaviour. Regulation should consider appropriate design elements, such as the length and timing of the netting period and the actual value of net excess generation. The key to appropriate incentives would be to strike the right balance between pushing the prosumer to consume as much energy as is generated and providing the appropriate economic signals to deploy distributed generation (IRENA, 2017c). In addition to regulations, other support measures can help the deployment of DG (*e.g.* fiscal and financial incentives can help reduce installation costs).

4.6. REGULATORY AND PRICING POLICIES FOR ELECTRICITY ACCESS FROM DECENTRALISED RENEWABLES

The Sustainable Development Goals (SDGs), which include achieving universal access to electricity by 2030, will not be achieved solely through the traditional approach of extending the grid. The deployment of decentralised solutions for electricity access is now at the forefront of the development agenda. With implications for other SDGs, these solutions offer opportunities to improve livelihoods, education and health services, food and water security, employment and gender equality. For instance, 4.13 million solar home systems had been installed in Bangladesh by 2018 (IDCOL, 2018) and the solar PV sector supported 140 000 jobs in 2016 (IRENA, 2016a). An improved watermills programme in Nepal created an estimated 8 500 jobs in operation and maintenance alone, feeding electricity into mini-grids to supply almost 900 households, while also providing motive power for agro-processing (IRENA, 2016b).

Where the goal is expanding energy access to rural communities, decentralised solutions feature lower costs and shorter wait times compared with grid extension. In this context, many countries are prioritising renewable decentralised technologies to meet energy access and broader goals. Energy access strategies can also be designed to address key barriers to successful renewable deployment in off-grid settings. Such barriers include financial constraints, lack of trust in renewable technologies and sustainability issues related to long-term operation and maintenance of renewable systems.

This section describes key regulatory and pricing policies and measures to enable electricity access via renewable-based mini-grids and stand-alone systems. It is structured along the policy categories laid out in Table 4.1, based on a classification developed by European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF), Energising Development (EnDev) and Practical Action (see Box 4.4).

Table 4.1. Policy instruments to support electricity access

Technology	Regulatory and pricing policies			Non-regulatory policies	
	Legal basis	**Price/tariff regulation**	**Main-grid arrival policies**	**Financial instruments**	**Non-financial instruments**
Mini-grids	Licensing, permitting procedures	Uniform or individual	Information on time frame for grid arrival and regulations for when the grid arrives	Grants/subsidies Tax reduction Guarantees Attractive financing	Quality/technical standards Technical assistance Capacity building Market information Energy efficiency
Stand-alone	Unrestricted	Unrestricted			

Sources: Based on EUEI PDF, EnDev and Practical Action, 2018; and IRENA, 2016c.

The instruments presented in Table 4.1 can be used to support both stand-alone and mini-grid solutions. While regulatory and pricing policies are mostly applicable to mini-grids only, stand-alone systems can be supported through financial and non-financial interventions (which also apply to minigrid solutions). The deployment of both mini-grid and stand-alone solutions requires clear policies regarding the arrival of the main grid.

BOX 4.4 CLASSIFYING NATIONAL APPROACHES TO ELECTRIFICATION

A national approach to electrification (NAE) can be defined as a coherent set of interventions supported by national authorities to increase electricity access in a given country. The main tool at the disposal of governmental agencies is policy; however, most NAEs also comprise non-policy elements.

Segregating NAEs into their constituent policy and non-policy elements was the target of a recent study by the EU Energy Initiative Partnership Dialogue Facility, Energising Development and Practical Action. The outcome is a tool, the “National Electrification Approaches – Review of Options,” that categorises the different elements of NAEs (see Table 4.2).

Table 4.2. Electricity access classification framework

Technology	Delivery model	Legal basis	Tariff regulation	Finance	Non-financial interventions
Grid extension	Public	Concession	Uniform	Private	Direct energy access provision
					Institutional restructuring
				User	Regulatory reform
Grid-connected mini-grid/ distribution system					Policy & target setting
	Private (non-Government)	License	Individual	Grants/ subsidies	Quality/technical standards
					Technical assistance
Isolated mini-grid				Cross-subsidies	Capacity building/ awareness raising
					Market information
	Public-private partnership	Unrestricted		Tax exemptions	Demand promotion
Standalone systems					Technology development/ adoption
				Guarantees	National energy planning

Source: EUEI PDF, EnDev and Practical Action, 2018.

The tool serves two main purposes. First, the classification framework goes beyond the established technology partition into grid, mini-grid and stand-alone and adds delivery model, legal basis, tariff regulation, and financial and non-financial interventions to the equation. A such, it can be used to compare and contrast different electrification approaches and to navigate the electrification policy landscape.

Second, the tool provides a review of 15 different electrification approaches. Examples that are covered range from the IDCOL model in Bangladesh to Mali’s Rural Electrification Programme and Peru’s concession model for stand-alone systems. Each approach is described alongside context, objectives, institutional setup, interventions and lessons learnt. As such, the study can serve as resource and inspiration for tailor-made electrification approaches worldwide.

Source: EUEI PDF, EnDev and Practical Action, 2018.

Regulatory and pricing policies should be customised to specific contexts, looking at the technology type, system size, energy demand, energy needs, business model and other characteristics that often vary from project to project. Regulatory and pricing policies include legal provisions that grant the private sector the legal right to generate, distribute and sell electricity to consumers with processes and procedures for obtaining the required licenses and permits, in addition to price/tariff regulation policies and policies related to arrival of the main grid.

4.6.1 LEGAL PROVISIONS

Permitting and licensing requirements for small-scale electricity providers should be streamlined to balance the cost of compliance with consumer protection. Some countries have chosen not to regulate projects or transactions below a certain threshold. The United Republic of Tanzania has completely deregulated small-scale energy projects below 100 kW, and mini-grids with a capacity of less than 1 MW need not apply for a generation license. These steps aim to promote projects' sustainability by reducing their administrative costs. Moreover, provisional licenses and concessions that grant exclusive rights to build, operate and maintain assets to supply electricity in a specific area for a defined time can be used to avoid a situation in which two or more developers carry out preparatory activities on the same site (IRENA, 2016c). This in turn can reduce risk and help spur energy access projects. However, safety and reliability standards should continue to be enforced, even for small-scale projects, to help protect consumers.

Additional regulation considerations for energy access include establishing a single-window clearance facility hosted at a rural electrification agency or similar body, such as the one-stop shop for mini-grid projects at the New and Renewable Energy Development Agency in the Indian state of Uttar Pradesh or by making information on processes and procedures easily accessible on an online information portal such as Tanzania's minigrids.go.tz (IRENA, 2016c).

4.6.2 PRICE/TARIFF REGULATION

Tariff regulation affects the viability and sustainability of installations, as it determines the operators' ability to set end-user tariffs, affecting project cash flows and the availability of funds for management, operation and maintenance, and cost recovery. While grant-financed systems typically require tariffs to cover at least the costs of management, operation and maintenance, private operators strive to also cover capital costs plus a risk-equivalent return.

To ensure equality and fairness between rural and urban consumers, some countries impose national uniform tariffs (or keep mini-grid tariffs lower and close to those of the main grid). However, such measures are sometimes opposed on the grounds that national tariffs are usually too low to allow sustainable system operation. For example, the Southern Africa Electricity Regulators Association emphasises that mini-grid tariffs must be high enough to cover costs (thus invariably higher than main grids), and structured to reflect current spending on energy. A tailored approach to tariff regulation is also an option: small-scale systems (under 100 kW in Nigeria and Tanzania) are increasingly exempted from tariff approvals, allowing operators to set tariffs in consultation with local communities. As systems expand, some form of official tariff approval can be used to mitigate the risk of future tariff disputes and regulators can standardise and define, to the greatest extent possible, the tariff-setting methodology (IRENA, 2016c).

Tariff caps and standardised tariff-calculation methodologies are design elements used to set tariffs. For tariff caps, operators are free to apply any tariff up to the cap that is set according to local conditions (*e.g.* the technology used, village area, capacity). In some cases, tariff caps are applied by financing institutions, as in Bangladesh. Standardised tariff-calculation methodologies (*e.g.* a cost-plus approach) allow regulators to systematically assess and approve tariffs, while also providing the basis for brief negotiations. Nigeria and Senegal apply the cost-plus approach to determine tariff caps (IRENA, 2016c).

Tariff structures should also be designed to allow for flexible financing or payment models, such as pay-as-you-go, power purchase agreements, business-to-business partnerships, lease or fee for service and community partnerships (Walters et al., 2015). Enabling these types of transactions allows the market to adapt to what users want and can afford, helping poorer customers gain access to energy.

4.6.3 POLICIES ON THE MAIN GRID'S ARRIVAL

Policies that govern how and when the main grid will arrive are used to mitigate major risks faced by off-grid and mini-grid operators: the main grid could siphon off customers and strand investments, especially in the years before the mini-grid is fully amortised. Rural electrification master plans and information – including the time frame for grid extension, population trends and productive loads – can inform decision making. For example, Kenya's National Energy and Petroleum Policy provides the basis for the development of a comprehensive electrification strategy toward universal access by 2020.

When the main grid reaches an area before renewable energy assets have been amortised, there are two options: 1) the system may be connected to the main grid, as in Cambodia, where 250 formerly isolated diesel mini-grids and small power distributors are now licensed by the Electricity Authority of Cambodia; and 2) the operator may be compensated for the residual value of the assets rendered uncompetitive by the main grid, as is the case in Rwanda and Tanzania, where regulators assign a depreciation scenario for fixed assets (IRENA, 2016c).

The successful deployment of systems that aim to increase electricity access requires additional measures such as financial and fiscal incentives, capacity building, awareness raising and technical assistance, market information and demand promotion, quality/technical standards and measures to promote the energy efficiency of appliances. The need for such measures is strongest in contexts where increasing energy access is a major priority.

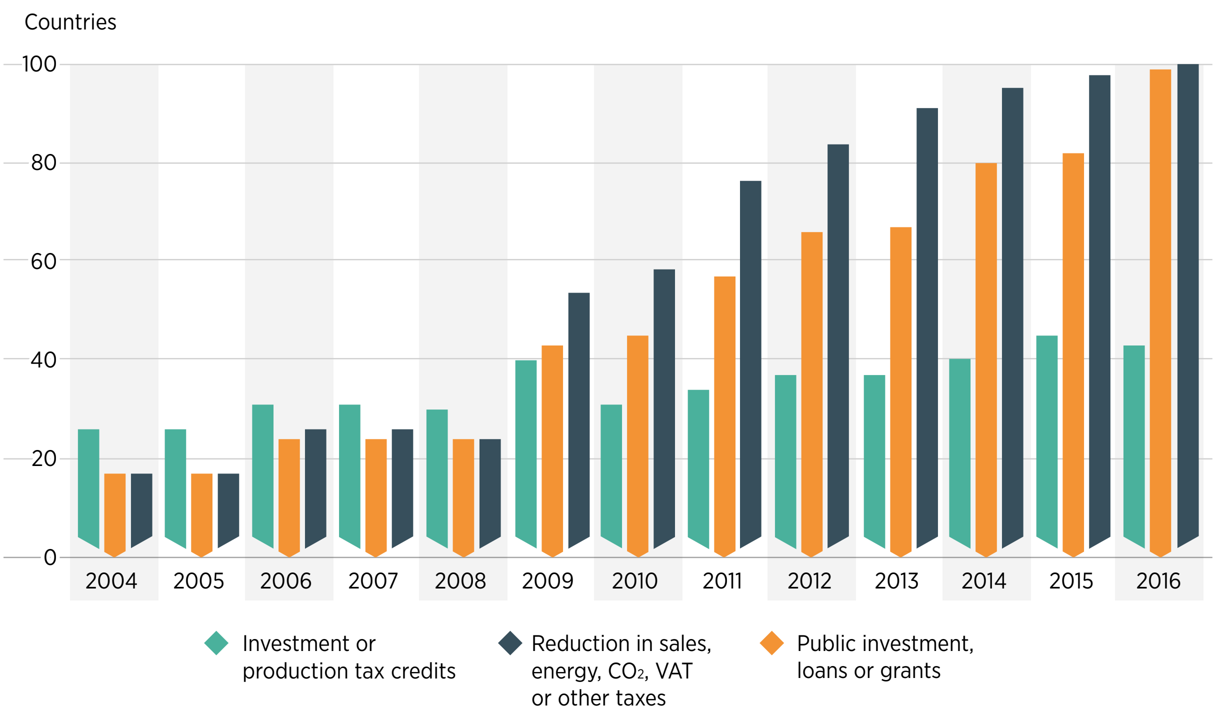
4.7. NON-REGULATORY POLICIES FOR ALL INSTALLATIONS

In addition to regulatory and pricing policies, non-regulatory instruments are also adopted to facilitate renewable energy investments through financial and fiscal incentives or to encourage the voluntary purchase of renewable electricity.

4.7.1 FINANCIAL AND FISCAL INCENTIVES

Financial and fiscal incentives are used (often in parallel with regulatory and pricing policies) to improve access to capital, lower financing costs, reduce the burden of high upfront costs or the production costs of large-scale renewable energy projects, and address split incentives associated with energy-efficient technologies. They can be introduced in the form of tax incentives, rebates, grants, performance-based incentives, concessional loans and guarantees, and measures to mitigate risk (NREL, 2016b). Figure 4.8 presents trends in the adoption of selected financial and fiscal incentives between 2004 and 2016 (REN21, 2005-17).

Figure 4.8. Trends in the adoption of financial and fiscal incentives, 2004-16



Source: REN21, 2005-17.
Note: CO_2 = carbon dioxide; VAT = value-added tax.

Tax incentives

Tax incentives are typically offered in the form of reductions in sales, energy, value-added or other taxes or in the form of investment tax credits, production tax credits or accelerated depreciation.

Reduction in sales, energy, value-added or other taxes reduce the cost of renewable energy systems for the installer/generator and increase their affordability and profitability. These are the most widespread policy instruments globally as they can be applied to projects and installations of all sizes, and in areas that are not connected to the grid. Tax reductions had been implemented in 100 countries by 2017 (Figure 4.8) and they have been the only instrument of choice in some countries in Southeast Asia and sub-Saharan Africa (*e.g.* Myanmar, Cameroon, Gambia, Guinea, Liberia, Madagascar, Niger and Togo) (REN21, 2017). In the remaining countries where they exist, they have been implemented alongside other instruments. In some countries where reduction in sales, energy, value-added or other taxes have supported kick-start deployment, policy revisions were strongly resisted for fear they would lead to higher electricity prices or pose a threat to the industry (see Box 4.5).

One of the weaknesses associated with reductions in sales, energy, value-added or other taxes is the lack of a mechanism to ensure the effectiveness of this instrument in promoting renewable electricity generation. Meanwhile, import tax breaks can hinder the development of local equipment manufacturers, especially in markets with high potential for leveraging local industries (IRENA, 2017d). In fact, the United States has already imposed import duties on solar equipment (see Box 4.6). India and other countries are considering such duties.

Production and investment tax credits (and accelerated depreciation) can support large-scale deployment, mainly in the form of production tax credits based on actual energy produced and investment tax credits that address potentially high upfront costs. Therefore, production tax credits can be more effective in incentivising the maximisation of energy production. Federal production and investment tax credits have been driving the deployment of solar and wind technologies in the United States but changes in policies have at times created uncertainty in the sector.

BOX 4.5 REVISIONS TO TAX INCENTIVES CONSIDERED IN THE PHILIPPINES AND SEVERAL COUNTRIES IN EAST AFRICA

In the Philippines, a tax reform package was put forward in May 2017 to amend the value-added tax (VAT) status of renewable energy developers from a VAT zero rating to a VAT exemption on the sale of electricity, with the risk of increasing electricity rates for consumers. Industry players who opposed this proposal argued that whereas, with a zero rating, all VAT is removed from zero-rated goods, activities or firms, exemption removes VAT only at one particular stage, thereby increasing taxes on the input goods and, as a result, raising the cost of production (Velasco, 2017).

In East Africa, a policy amendment on import duties was proposed by governments in June 2016, whereby solar-powered appliances were no longer eligible for tariff exemptions in Burundi, Kenya, Rwanda, Uganda and Tanzania. In particular, the removal of "spare parts and accessories" from the list of exempt items could negatively impact industry players across the board. In response, the Global Off-Grid Lighting Association (GOGLA) took a coordinated approach, bringing major stakeholders on board to support the reinstatement of the original wording of the tariff act (GOGLA, 2016).

BOX 4.6 IMPORT DUTIES ON SOLAR PV IN INDIA AND THE UNITED STATES

India is considering anti-dumping duties on solar cell imports from China, Taiwan and Malaysia. Such a move could increase the cost of achieving the solar target of 100 GW by 2022, and threaten the viability of the winning projects from recent auctions, some awarded at 2.65 INR/kWh (USD 40/MWh). But the move aims to support local manufacturing, and to reduce dependency on Chinese PV module imports, which now account for roughly 80% of the Indian market and are worth several billion dollars (PVmoduletech, 2017).

In the United States, about 30 solar manufacturers have gone bankrupt since 2012, including, most recently, Suniva and SolarWorld Americas. Solar manufacturers have asked for tariffs on solar modules and solar cells starting at 32 and 25 cents per watt, respectively, even as tariffs fell to 29 and 23.5 cents per watt over four years. However, the introduction of tariffs was opposed by the Solar Energy Industries Association, as it would also lead to the taxation of US-produced solar panels in foreign markets with an estimated damage of a USD 29 billion segment of the economy. Moreover, this would increase the cost of project development for nearly 9 000 US solar companies and the 260 000 Americans they employ (Silverstein, 2017).

Despite these concerns, in 2018 the United States introduced a 30% tariff, with a 5% declining rate per year over a four-year period, with an exemption for the first 2.5 GW of imported cells per year (SEIA, 2018a). It is estimated that the tariffs will reduce U.S. solar installations by 11% through 2022, with utility-scale solar hit the hardest (Pyper, 2018).

In fact, the production tax credit (PTC) was first enacted as part of the Energy Policy Act of 1992 and has since played a significant role in supporting wind energy. The PTC originally provided 1.5 cents USD for every kWh generated for wind and geothermal for ten years. It increased gradually until it reached around 2.3 cents USD for every kWh in 2016. The PTC is being phased out between 2016 and 2020, with a reduced incentive each year until it is eliminated. An investment tax credit (ITC) of 30% for solar projects was initially established in the Energy Policy Act of 2005. The ITC allowed for a tax deduction of 30% of a project's eligible tax basis by technology. Most recently the ITC was extended through 2021, with the tax credit decreasing to 10% by 2022. Since their initial inception, some federal renewable tax credits have expired, and been extended, modified or renewed numerous times. Both the PTC and ITC have had a significant impact on solar and wind deployment. Historically, changes to tax credits and uncertainty regarding their future levels have been highly correlated with year-to-year variations in annual renewable energy installations, particularly for wind. The US wind industry has experienced multiple boom-and-bust cycles that coincided with PTC expirations and renewals. Establishing long-term energy tax policies can help eliminate uncertainty and help increase the success and impact of policies.

Accelerated depreciation is an incentive that allows the owner of new assets to reduce taxable income by claiming a much-larger-than-usual depreciation allowance in the early years of the assets' operation. In India, accelerated depreciation has played a major role in the deployment of wind energy and indirectly promoted the development of the domestic wind industry, including equipment manufacturing and allied services. The instrument has also supported solar power, including smallscale rooftop installations. Accelerated depreciation was first introduced for wind in 1994 in India, with a depreciation rate of 100%, later reduced to 80% in 2002 (it was withdrawn completely in 2012 and then reintroduced in 2014). The benefit helped attract private investors in the sector for selfconsumption and also served to offset tax liabilities from their other businesses. Responding to persistent demand from various stakeholders, the depreciation benefit for the wind sector, and in August 2014 it was reinstated at the previous rate of 80% for plants installed on or after April 2014. It was withdrawn again in April 2017 (IISD and GSI, 2015).

Although accelerated depreciation supported the installation of wind capacity in India, it was perceived to be lacking focus on generation efficiencies as the incentive was linked to the project capital cost with no provision for penalising underperformance. As a result, generation was below its potential, with inefficient installations occupying some of the best sites in terms of resources. Moreover, the policy did not benefit large independent power producers and foreign investors, as the tax depreciation benefit could only be availed by entities with profits in the parent business and profits within India.

In order to diversify the developer base in the sector and promote the continued development of wind technology, a generation-based incentive (GBI) scheme was introduced in India for the period 2009-12 to: 1) support large independent power producers and foreign direct investors who could not avail the accelerated depreciation benefit, and 2) incentivise higher efficiencies through generation-/outcome-based incentives: the policy initially provided an incentive of USD cents 0.8 (INR 0.50)/kWh fed into the grid on top of the state-fixed feed-in tariff for a period of between four and ten years. Performance-based incentives are provided based on actual performance of an installed technology (*e.g.* cents per kilowatt hour payment). They are often provided by utilities and funded through utility customer payments.

Capital subsidies and grants

Capital subsidies can be used to help create a level playing field with conventional energy technologies and reduce upfront capital costs. They can be used to target very specific technologies, such as solar PV installations, as well as specific segments of the population. Whichever subsidies are employed, it is important that they be clear and free of confusion as to what technologies qualify or when they will be phased out (Walters et al., 2015). Capital subsidies are typically used in markets in the very early stages of deployment, after which they tend to be replaced by performance-based subsidies. In Nepal, for example, capital subsidies were offered in 2013 for projects of up to 1 MW, with the level of support dependent on the technology and remoteness of installation. The subsidy was assumed to cover 40% of the project capital cost; a soft loan covered another 40%, with the remainder covered by the owner/community. The subsidy policy was updated in 2016, introducing generation-based support rather than capital-only subsidies to increase the efficiency of systems (Climatescope, 2016).

Grants are normally provided by local governments, utilities or non-profit institutions to fund feasibility studies; research and development; system demonstration, installation and operation; andr business development. Through hybrid approaches, grants may also be combined with subsidised loans to support renewable energy and energy-efficiency deployment (NREL, 2016b). Unlike performance-based incentives, capital subsidies and grants do not directly offer operators the incentive to ensure efficient operation in the long term. In addition, such support for generating assets may lead to sharp increases in end-user tariffs when system capacity is expanded.

In the context of access, equity and grants can be attracted by improving access assessments and cooperating with regional and global funding facilities. In Rwanda, a USD 840 000 grant provided by the Sustainable Energy Fund for Africa helped co-finance feasibility studies of 20 micro-hydro sites. Easy repatriation of funds, low withholding tax and indexation of tariffs to key variables (*e.g.* diesel price, foreign exchange rate, inflation) helped attract investors for subsequent phases. To tackle specific financing gaps (*e.g.* access to debt), dedicated funds can be established that pool together public and donor finance; guarantee tools can be used to leverage private capital. Local commercial banks can be engaged to make available low-cost, local-currency loans. An example is the Inter-American Development Bank's USD 9.3 million programme implemented by Bancoldex, a commercial bank in Colombia that aims to deliver long-term concessional financing for private entities engaged in mini-grid development (IRENA, 2016c).

Attractive loans

Attractive financing is crucial to attract investments in renewable energy. Small and medium energy developers operating in the distributed energy sector, like most developing businesses, need different types of funding at different stages of the business cycle. For these developers, capital is critical to fund operations and scale up to profitability. Even where capital is generally available, it may be inaccessible to small companies in an unproven sector or serving low-income consumers. Examples of government support to improve access to capital could include grants or subsidies to reduce capital costs or provide equity; grants for start-up costs such as business plans, training and market development; direct financing through concessionary loans or lines of credit for capital purchases, working capital requirements, or consumer on-lending; or guarantees to encourage financial institutions to finance small and medium enterprises in the sector. Government programmes that establish or enable financial intermediaries to provide small-scale financial products can also be important in this regard. When addressing financing needs in the sector, policy makers should address the entire supply chain to ensure a sustainable market, including manufacturers, suppliers and service providers.

Microfinance institutions play multiple roles in some energy access markets. In some markets, they provide financing to consumers to allow the purchase of clean energy systems. In others, such as Ethiopia's, they have expanded to work with suppliers to provide or install energy systems directly. With the extensive rural networks of such institutions in Bangladesh, IDCOL has used them to assess household energy needs and install and service solar home and irrigations systems (IRENA, 2016c).

Risk mitigation

Governments can take risk-mitigation measures so as to catalyse private investments for renewable energy under constrained economic conditions, and a portfolio of innovative delivery models can facilitate access to equity, debt, as well as grant financing in the access context. A portfolio of measures, instruments and tools can be used to overcome investment barriers, mitigate investment risk such as in the case of geothermal presented in Box 4.7 and improve access to capital for renewables projects (IRENA, 2016d). Policies that facilitate the financing of renewable energy projects are only support measures. However, integral to the sustainability of renewable energy projects is that they generate long-term predictable and profitable revenue for the developers for small- and large-scale projects.

4.7.2 VOLUNTARY PROGRAMMES

Consumers and companies are being increasingly empowered to make choices about power consumption that align with specific preferences and goals. Key policies and approaches enabling this transformation include information awareness programmes on the benefits of renewable energy generation, community-based programmes, corporate procurement and supply chain greening, and voluntary REC markets (Section 4.3).

Information awareness programmes often lay the groundwork for community programmes and are aimed at educating electricity end-users on the benefits of renewable energy, such as local economic development, GHG emission reduction, air-quality improvements, climate resilience, and so on. These programmes can be supported through different forms of media and can be designed by utilities or local and national governments.

Building on awareness outreach, community-based programmes enable electricity consumers to either choose renewable energy sources for their electricity generation or invest directly in a community renewable energy project. Under the former approach, often called community choice aggregation, transmission and distribution services remain unchanged, and consumers are simply given options in relation to electricity generation supply (*e.g.* opting in for a certain percentage of electricity to be drawn from renewable sources). Under the investment-based approach, often

BOX 4.7 SUPPORTING GEOTHERMAL POWER BY REDUCING RISK

Global potential for geothermal energy is estimated at 70 to 80 GW. However, because of several barriers, only 15% of the potential capacity is being harnessed globally. One key challenge relates to the high risks and upfront costs associated with exploration, as well as overall project development costs, which occur over a relatively longer period of time.

To reduce the risks associated with geothermal development, several policy approaches and instruments have been successfully applied globally, including: full government development of the resource; cost-sharing between the government or donors and the private sector to mitigate risk; use of insurance instruments and loan guarantees; and application of other fiscal incentives (*e.g.* tax and import duty exemptions). Key features enabling successful implementation of geothermal projects under various policies include: sufficient capacity within the private sector to implement projects through a multistage (and time-consuming) process; development of transparent and clear criteria to select project development partners; and provision of clear information on risk capital to be mobilised.

Kenya, Turkey and Nicaragua have been successful in reducing risk through government-supported early-stage drilling with project development undertaken by the private sector. The Geothermal Risk Mitigation Funds for Africa and the Geothermal Development Facility for Latin America are supported by several donors and providing co-funding for early-stage exploration and certain project development costs. The facility also provides further risk mitigation through allowing for conversion of the co-funding into a full grant (with no further financial obligation) in cases where drilling is unsuccessful.

Source: ESMAP, 2016.

called community or shared wind or solar programmes, consumers can purchase a portion of a local wind or solar project (NREL, 2012). Under profit-sharing approaches for community wind or solar in the United States, the utilities or another third party owns the renewable energy project, while a share of the profits goes to local communities (*e.g.*, via electricity bill credits) (SEIA, 2018b). In Germany, communities and cooperatives have participated in solar and wind auctions to procure local generation directly.

On the corporate side, the demand for renewable energy has grown exponentially during the last decade. Companies in a variety of sectors are committing to ambitious renewable energy targets. More than 120 companies have joined RE100, an initiative bringing together companies with a 100% renewable electricity target (CEM, n.d.). While the public demand for corporate social responsibility, including the mitigation of greenhouse gases, is a key driver for corporate renewable energy sourcing, significant cost declines have made renewables an attractive source of energy enabling corporations to hedge against volatility in electricity prices. Based on these drivers, many companies are now working to incorporate an increased level of renewable energy sourcing across their supply chains. Although the bulk of corporate procurement of renewables takes place in the US and European markets, this practice is also experiencing growth in countries such as Argentina, Chile, China, Egypt, India, Japan, Mexico, Namibia and Thailand (IRENA, 2018c).

One of the more popular ways for corporations to source renewable energy is through virtual power purchase agreements, whereby fixed-priced contracts allow firms to receive credits for renewable energy that is deployed in various locations. The global cumulative capacity of corporate power purchase agreements is estimated to have reached 20 GW, with 5.4 GW of capacity signed in 2017 (BNEF, 2018). Other innovative options, such as utility green tariffs and other green premium products, are also emerging to support corporate procurement. As discussed in section 4.3.6, corporations can also purchase RECs/GOs through the voluntary certificate market to meet sustainability and climate goals. Certificate markets have been established in China, the European Union, India and the United States; they are emerging in other jurisdictions as well (IRENA, 2018c). To support the implementation of ambitious corporate targets, several successful platforms have been established, including the Renewable Energy Buyers Alliance now active in Australia, China, India, Mexico, the United States and Vietnam. The alliance supports corporate buyers in identifying barriers and streamlining solutions for the purchase of renewables (REBA, 2018).

Voluntary programmes can also enable expansion of distributed generation through the aggregation of smaller projects to reduce costs. In particular, on-site bulk purchasing of distributed generation can allow individuals or companies to aggregate their demand in order to reduce individual systems costs and simplify purchasing. This model has been implemented in many cities in the United States, including Portland, Oregon, and Madison, Wisconsin.

4.8. CONCLUSIONS

Renewable energy deployment in the power sector continues to expand significantly. The growth in renewable generation has surpassed generation from non-renewables. In 2015, renewables provided about 23.5% of all electricity generated, the bulk of which came from hydropower, wind, bioenergy and solar PV. Decentralised renewable energy solutions are increasingly deployed as a cost-effective means to increase energy access and enable development.

However, the deployment of renewables in the power sector still faces multiple barriers and policy support is needed to advance the transformation. Policies range from regulatory and pricing instruments to financial and fiscal incentives, quotas and obligations, and voluntary programmes, among others. Table 4.3 summarises the strengths and limitations of the policy instruments in the power sector.

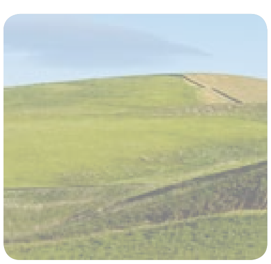
Table 4.3. Renewable power policy instruments – strengths and limitations

Technology	Strengths	Limitations
Targets for medium or long term	Provide clear direction and signals to consumers and industry	Highly dependent on continued political commitment Not effective on their own, need policy measures for implementation
Quotas and obligations (*e.g.* RPS, RPO, RO)	Help enforce mandatory and binding targets by assigning an entity responsible for achieving them. Can be scaled up by starting with a low percentage and then increasing year on year.	Require monitoring and compliance measures and a system for penalising shortfall. In most cases, must be tied to a system of tradable certificates and other mechanisms.
Tradable certificates	Market-based mechanisms that provide additional revenue to generators	Require compliance and enforcement mechanism for a functional market
Administratively set pricing instruments (FIT)	Limited risk for developers. Suitable for markets with low level of renewable energy development and for small-scale projects Hedge against energy and electricity price volatility by introducing fixed-price supply into the electricity supply mix	Complexity of tariff setting and adjustment, especially when cost structures change dynamically Challenges associated with market integration as share of variable renewables increases
Administratively set pricing instruments (FIP)	Enable market integration of renewable energy Provide incentive to produce electricity when supply is low	Risky for generators when electricity market price is low and risk of windfall profits when market price is high (without floor and cap) May impose additional costs on producers, including transaction, balancing, forecasting and scheduling
Competitively set pricing instruments (auctions)	Flexibility in design and potential for real price discovery	Risk of underbidding and driving small/new players out of the market
Net metering/billing	Can deliver savings both to the end-consumer and the system as a whole Help reduce transmission and distribution losses and congestion and peak demand of the system	May jeopardise a system's cost recovery and create cross-subsidisation among those customers who self-consume and those who do not in cases where distributed generation levels are high Risk that retail tariffs do not accurately reflect the actual value of electricity at each location and time period
Financial incentives (*e.g.* grants, tax credits, investment subsidies)	Increase the affordability of technology and can help address higher capital costs barrier	Support levels can be subject to frequent changes due to shifting political priorities Does not always relate to the quantity of electricity produced
Voluntary programmes	Enable deployment at no involuntary additional cost to government or consumers	Require awareness programmes Not necessarily factored in the planning

Note: FIP = feed-in premium; FIT = feed-in tariff; RO = renewable obligations; RPO = renewable purchase olbligation; RPS = renewable portfolio standards.

The key policy take-aways from this chapter are these:

- **Renewable energy targets** provide a critical high-level policy signal to utilities, investors and the private sector. Quotas and mandates help make the targets more binding by cascading them down to electricity producers and consumers. Quotas are generally supported by tradable renewable energy certificates. The effectiveness of quotas and certificates depends on the presence of a solid framework to monitor and penalise non-compliance and on specific market design considerations.
- **Regulatory and pricing policies** affecting renewable energy are evolving in several contexts. While many countries continue to introduce and implement administratively set feed-in policies, auctions are being increasingly adopted. When implemented thoughtfully, auctions can enable real-price discovery while also supporting other objectives such as socio-economic development. While some countries have switched from one to another, many continue to use both instruments, typically auctions for large-scale projects and feed-in tariffs and premiums for small-scale installations. The choice of instrument is context-specific and any policy chosen needs to continuously be adapted to changing market conditions in order to achieve greater cost-competitiveness and improved integration of variable renewable energy into the system.
- **Distributed generation** is expanding globally, supported by net metering/billing and financial and fiscal incentives. It can complement the grid and provide benefits and potential cost reductions to both the end-consumer and the overall system. Decentralised solutions can complement grid-based solutions, providing power to previously underserved areas. Supporting regulatory and pricing policies include the right to generate and sell electricity, tariff regulation and grid-arrival policies. They must be supported with measures to facilitate access to finance, develop local capacity, and standardise equipment.
- **Attractive financing and risk-mitigation** are crucial to attract investments in renewable energy. Governments can take measures to catalyse private investments for renewable energy under constrained economic conditions, combined with other steps to facilitate access to equity, debt and grant financing.
- **Voluntary and corporate purchase programmes** for renewable energy will be an important part of the energy transition going forward. They are often complemented by information awareness campaigns highlighting the benefits of renewable energy.



05

SYSTEM INTEGRATION OF RENEWABLES – TRANSFORMING POWER SYSTEMS

5.1 INTRODUCTION

Supportive policies and a dramatic fall in technology cost have led to the rapid growth of renewable energy technologies, in particular wind and solar photovoltaic (PV) – together referred to as variable renewable energy (VRE). Rapid growth in VRE capacity has become a global phenomenon. In 2016, the VRE share in electricity generation approached 45% in Denmark and exceeded 20% in Lithuania, Ireland, Spain and Germany; at least eight European and three South American countries had passed the 10% mark. By 2022, a wave of a wave of power systems - including some of the largest ones in the world, such as those of China, India and the United States – are expected to double their share of VRE to more than 10% of annual generation (IEA, 2017a).

VRE technologies have unique characteristics which, with increasing penetration, can affect the overall power system. In the absence of a systematic strategy to address those impacts, high shares of VRE risk driving up the cost of supplying electricity (IEA, 2014; Mills and Wiser, 2012; NREL, 2016; Ueckerdt *et al.*, 2013). Strategies for system integration of renewables (SIR), consisting of a coordinated sequence of measures, are crucial to minimise negative impacts, maximise benefits and improve cost-effectiveness of the power system. In an age of inexpensive VRE, the success of SIR strategies is crucial for high shares of VRE to translate indeed to low-cost electricity for consumers.

However, discussions of SIR frequently involve a very limited set of options, most often dedicated to electric batteries, giving short shrift to other valuable options that can be unlocked via appropriate policy, market and regulatory frameworks. This chapter introduces a range of policy, market and regulatory options useful in integrating VRE into the power system. Rather than providing extensive detail, the chapter aims to shed light on the most important aspects of available options.

5.1.1 VRE CHARACTERISTICS AND SYSTEM FLEXIBILITY

Six characteristics shape the impact of VRE on the power system:

- **Low short-run costs**. Once built, VRE generators produce energy with very little additional cost. When the resource (wind or sun) is available, they will be among the first plants that are called upon (dispatched) to meet demand, frequently reducing the market share for generators with higher short-run costs and reducing marginal generation costs.[1]
- **Variability**. Available power output from VRE fluctuates according to the instantaneous availability of the resource. The power system is designed to manage the variability in load, but VRE increase the magnitude of variation thereby increasing the stress on systems to maintain power quality. As a result, net load[2] fluctuations where VRE shares are higher are more frequent, larger and less predictable. Absolute net load levels can become very low, leading to more frequent use at minimum output cycling of dispatchable generators. Conversely, VRE production may be low at times of high demand, which calls for rapid increase in output of dispatchable generators or alternative options to meet demand at these times.
- **Uncertainty**. The availability and intensity of wind and solar resources can be predicted with high accuracy only in the short term and if adequate forecast tools are in place. The uncertainty stemming from wind and solar thus affects the definition and use of the power system's operational reserve requirements.
- **Location-constrained**. VRE resources are not equally good in all locations and cannot be transported like fossil fuels or biomass. Linking resource-rich areas with demand may require new grid infrastructure at an additional cost. This change also calls for updated transmission planning and operating practices.

1 This statement applies in areas that apply economic dispatch; in many countries where economic dispatch is not applied, RE generators enjoy priority dispatch, which leads to the same effect.

2 Net load is defined as power demand minus the generation of wind and solar.

- **Modularity**. Wind and solar plants consist of individual wind turbines and solar panels that can be deployed in different sizes, from offshore parks to individual turbines or solar home systems. Small plants connect to lower voltage levels in distribution grids, mandating changes in the way these are planned and operated.
- **Non-synchronous technology**. Synchronous generators enjoy a direct, electro-mechanical link to the power system and have a considerable amount of spinning mass (inertia). VRE plants are linked to the power system via power electronics and have less or no spinning mass, ***i.e.*** non-synchronous generators. This may require changes to how system stability is managed, especially during periods of high shares of VRE in power generation.

The degree to which these properties pose challenges depends on the amount of VRE in the system and on the system's flexibility. System flexibility, in this report, represents the extent to which the system can adapt the pattern of electricity generation and consumption to keep supply and demand in constant balance.[3] All power systems have some inherent level of flexibility available to deal with the variability of power demand, which often has seasonal and diurnal patterns, and with unpredictable failures of conventional generators and transmission lines.

Resources to improve overall system flexibility fall into four main categories: dispatchable generators, grid infrastructure, load shaping and energy storage (see Box 5.1).[4]

BOX 5.1. FLEXIBLE RESOURCES

Dispatchable generators are power plants that can be dispatched at the request of power grid operators or of the plant owners according to market needs. Flexible dispatchable generators (*e.g.*: gas plants) are the dominant source of system flexibility in most power systems, accommodating the variability of output of variable renewable energy (VRE) and demand. They provide flexibility by reducing power output or shutting down completely when VRE output is high. Similarly, they ramp up or start up rapidly during periods of low VRE output. Retrofits of power plants may be required to improve fleet flexibility. VRE plants themselves can also provide flexibility to the system, if market rules and forecasting quality allow them to be dispatched. In contrast to other flexibility options, non-renewable dispatchable generators are accompanied by externalities including carbon dioxide (CO_2).

Grid infrastructure encompasses all assets that connect generation to demand, high voltage/ultra high voltage (HV/UHV) transmission lines, distribution network lines, additional devices such as transformers and sophisticated HV/UHV components. Larger and more meshed networks are better able to integrate VRE generation. Aggregating distant VRE plants and flexible resources smooths overall VRE output and allows cost-effective utilisation of flexibility options.

Load shaping encompasses all systematic measures to better match electricity demand to variable supply. These may include managing the load (activity usually called demand side management) or creating new electricity demand at these times through electrification or "sector coupling". Load shaping is needed to absorb high VRE output, accommodate times of low VRE output, and to provide system services. Many technologies are suitable for load shaping purposes. Their common property is the ability to shift or adjust power consumption for a certain amount of time, to interrupt electricity consumption in exceptional circumstances at short notice. New sources of demand can absorb low-cost electricity or use it to produce another energy carrier (hydrogen, synthetic fuels[5], heat, etc.). The electrification of thermal energy services and transport thus increases the ability to perform load shaping.

Electricity storage describes all technologies that accept electrical energy and return it later as electrical energy. Opportunities for arbitrage (the practice of taking advantage of a price difference for financial gain) have driven storage deployment in the last 40 years, specifically pumped hydro storage. However, electricity storage technologies can provide multiple services, ranging from fast frequency response to seasonal bulk energy storage, helping to meet new challenges related to VRE variability. A detailed description of costs, challenges and capabilities of flexible resources can be found in IEA (2014).

3 The definition of flexibility may differ in other publications. IRENA (2017) provides a literature overview of the definitions. VRE integration will require also addressing those technical challenges (ensuring sufficient capacity, system stability, and compliance with the physical limits of the network, among other things) that are already part of sound system management (IRENA, 2018a).

4 The IRENA's FlexTool is being developed to assist policy makers in making a quick assessment of potential flexibility gaps, as well as pointing to a possible cost-effective mix of solutions (IRENA, 2018b).

5 Synthetic fuels are fuels produced combining such hydrogen (*e.g.* from electrolysis) with carbon or nitrogen.

5.1.2 SYSTEM FLEXIBILITY FROM A POLICY PERSPECTIVE

SIR measures are designed to support the reliable, cost-effective deployment of VRE, reducing negative effects from VRE deployment while improving system flexibility. Specific instruments exist to encourage the uptake of flexible resources, but good SIR policy making depends on building flexibility into the entire power system.

Policies promoting VRE have not always been accompanied by a robust policy framework for integrating VRE technologies in the larger power system. Improving system flexibility and deploying flexible resources in a timely manner can help save costs and improve system reliability at increasing shares of VRE. Policy makers pursuing wider deployment of VRE should therefore ensure the timely enactment of SIR measures. Synchronizing their adoption with VRE deployment is crucial.

Flexibility is a property of the whole power system rather than its components and mobilising power system flexibility depends on technology factors, economic incentives and regulations as well as the roles and responsibilities of different power system actors, *e.g.* owners of power plants, grid owners and operators, government agencies, large or potential consumers, and so on. Hence, involving all relevant parties during the early phase of policy drafting is helpful to ensure SIR measures' effectiveness, to align policies and to identify possible weak points of the system.

Chile provides an example of good practice for the engagement of energy sector stakeholders. In 2014, the Government of Chile released the "Energy Agenda" as a foundation for reform of national energy policy. Among the goals was strengthening of renewable energy. The process incorporated stakeholders' participation at key points in drafting the reform. In 2016, following the tasks identified by the "Energy Agenda", the government of Chile launched the nation's new energy strategy, "Energy 2050", which targets generating 70% of electricity from renewables by 2050.

The system-wide nature of SIR policies can make them appear challenging to tackle. However, experience demonstrates that system integration challenges emerge gradually. This is good news: in the early phases of integration a focus on the right set of issues will allow continued progress, while allowing more time to adopt comprehensive approaches needed to meet upcoming challenges (IEA, 2017b).

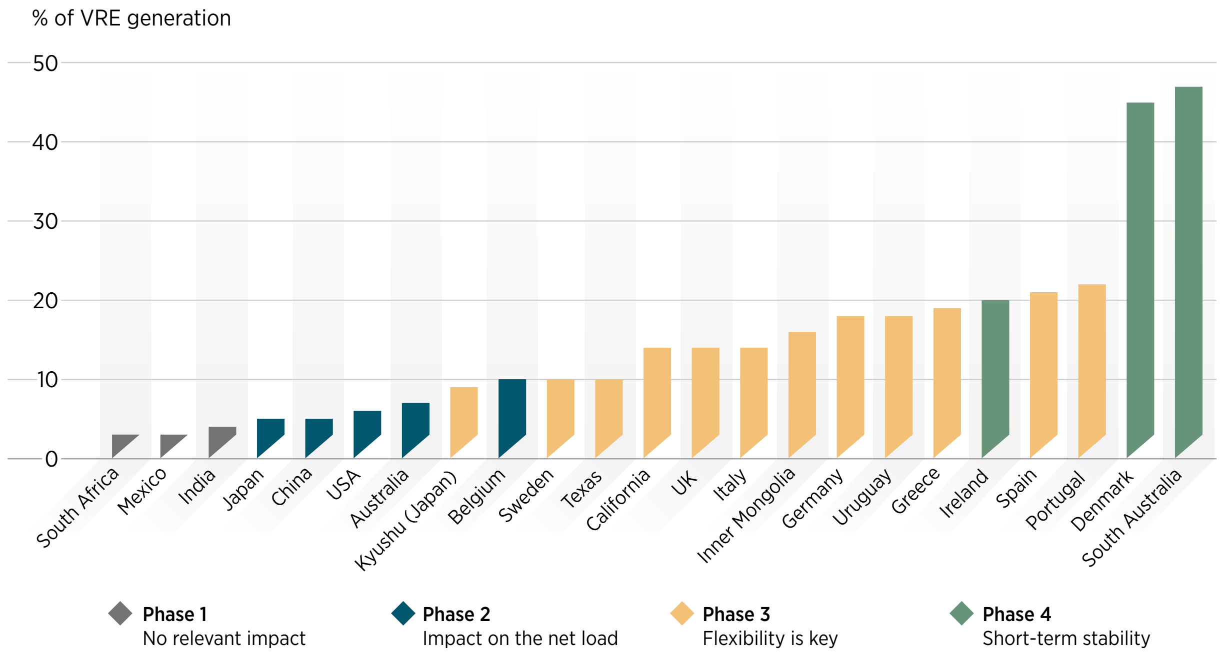
5.1.3 THE PHASES OF SYSTEM INTEGRATION OF RENEWABLES

The increasing impact of VRE on the power system can be categorised by phases, which can help identify the main challenges related to VRE integration and select appropriate measures to enhance flexibility (IEA, 2017b). This simple categorisation allows the segmentation of possible SIR challenges and provides a useful framework for the prioritisation of tasks:

- **Phase 1**. The first set of VRE plants are insignificant at the system level; their effects are very localised, *e.g.* at plants' grid connection points.
- **Phase 2**. As more VRE plants are added, changes between load and net load become noticeable. Upgrading operating practices and making better use of existing system resources usually suffice to achieve system integration of renewables.
- **Phase 3**. Greater swings in the net load prompt the need for a systematic increase in power system flexibility that goes beyond what can be easily supplied by existing assets.
- **Phase 4**. VRE output is sufficient to provide a large majority of demand at certain periods. This requires changes in how the power system responds to unexpected disruptions. This phase thus concerns power system stability.
- **Phase 5**. Without additional measures, adding more VRE plants will mean that their output frequently exceeds power demand. Structural surpluses of VRE would lead to an increased risk of curtailment. Moving demand to periods of high VRE output and creating new demand via electrification of other end uses can mitigate this issue. Use of electricity in industrial processes and transportation or for the production of synthetic fuels may become a viable option.
- **Phase 6**. The main obstacle to achieving even higher shares of VRE now becomes meeting demand during periods of low wind and sun availability as well as supplying uses that cannot be easily electrified. This phase is thus characterised by the potential need for seasonal storage and the use of synthetic fuels for power generation.

The vast majority of countries in the world are in phases 1 and 2. It is possible for a large system to be in an earlier phase, while a certain region/sub-system in the same system has already reached a later phase. For example, despite the generally low share of VRE in Australia, South Australia has a very high penetration and faces Phase 4 issues (Figure 5.1). Also, the speed at which a system experiences issues corresponding to different phases depends not only on the share of VRE generation, but also on several other power systems factors, such as system size, transmission and distribution infrastructure, operational practices, and existing levels of flexibility. Moreover, all else being equal, smaller systems (*e.g.* Ireland) tend to fall into a higher phase than large systems, since few VRE facilities may represent a significant proportion of generation. To date even the most advanced countries are primarily dealing with issues related to Phase 4 (Figure 5.1).

Figure 5.1. Selected countries and regions by phase of system integration, 2016



Source: IEA (2017a).

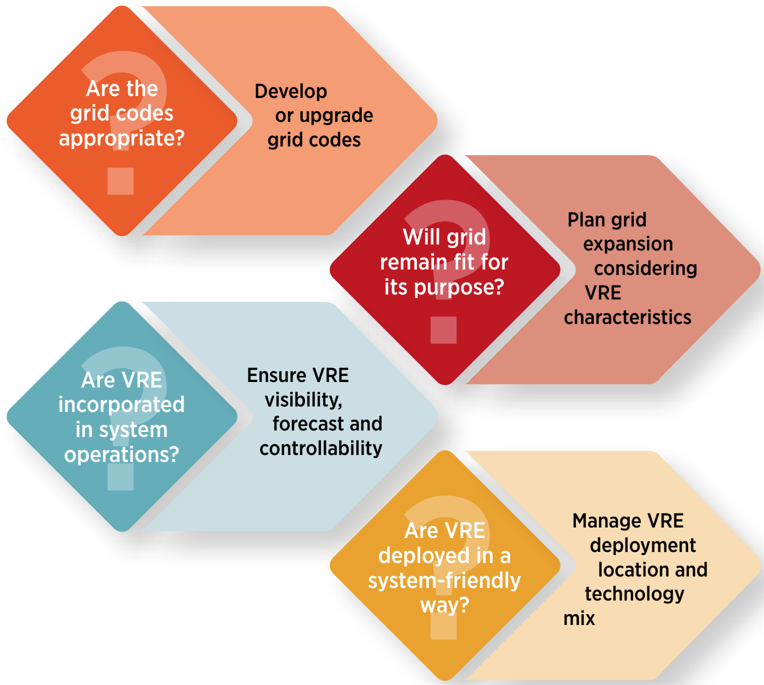
5.2 PHASES 1 AND 2: TARGETED MEASURES AT THE ONSET OF VRE DEPLOYMENT

During Phases 1 and 2, a few targeted interventions are typically sufficient to achieve SIR. The main objective in Phase 1 is to ensure that VRE plants maintain local power quality. This can be done via a standard technical study of the point of connection to the grid. Furthermore, certain minimum technical standards should be enforced for VRE plants, aimed chiefly at ensuring security of supply during later phases (IEA, 2017b).

Phase 2 requires the first set of specific SIR interventions, with three main objectives: laying the foundations for reliability for later phases, mobilising existing flexibility (relying mainly on existing power plants and grids) and minimising challenges by optimising VRE deployment. Achieving these objectives requires answers to four main questions (Figure 5.2): Is the grid code appropriate for VRE? Is VRE incorporated in system operation? Will grid infrastructure remain fit to its purpose? Is VRE deployed in a system-friendly way?

Responding to these issues generally requires changes to existing procedures rather than dedicated investments in new technology. The cost of implementing these solutions is generally relatively low, and likely to have little impact on customers' bills beyond any difference in the cost of VRE generation relative to conventional sources of supply.

Figure 5.2. Measures to integrate VRE in at the onset of VRE deployment



Source: adapted from IEA (2017b).

5.2.1 DEVELOP OR UPGRADE GRID CODES

Modern wind and solar power plants use so-called power electronics to connect to the grid. Their behaviour on the system – including during times of system stress – is the result of settings in their digital control software. These settings need to be aligned with local system conditions and be forward looking, *i.e.* able to accommodate future changes to the power system.

Grid codes – or, more precisely, technical connection standards – specify how plants should behave on the system. Although they are highly technical, managing the process of their development does require policy maker intervention (IRENA, 2016). The following points are critical:

- Responsibility for grid code development should not be in the hands of an entity that owns generation assets. VRE plants often compete with existing generation assets. By imposing overly demanding grid codes, incumbents may try to keep VRE competition out of the market. In systems dominated by a vertically integrated utility, technical knowledge may be centralised in the utility, which can make it challenging to develop a fair grid code. In this case, policy makers should seek an independent review of the proposed grid code. For example, an appropriate regulatory body could be mandated to review the proposed code, possibly relying on independent technical consultants.
- Countries should avoid imposing non-standard requirements. State-of-the-art wind turbines are designed to comply with international grid code requirements, including demanding grid codes in countries that already have high shares of VRE. Countries should aim to adopt standards that are consistent with these requirements. Failure to do so may increase deployment costs without bringing any real benefit for system reliability, because manufacturers would need to tailor technology to a single, small market.
- Grid-code development should be organised as an inclusive process, led by technically competent experts, adopting state-of-the art energy modelling and incorporating feedback from RE manufacturers and developers. Incorporating industry feedback in the development process avoids overly burdensome requirements. A technically competent but neutral entity should lead the process to make sure requirements are sufficiently stringent.
- Grid codes are living documents that should be updated as new international experience is gained. A regular review process can help to ensure risks are discovered on time and corrected appropriately.

Technical requirements in grid codes should strike a balance between obtaining high-performance equipment that can meet also the challenges of higher shares of VRE without driving up equipment cost excessively.

Compliance with overly demanding grid codes may raise costs, in particular if retrofits are required (IRENA, 2016a). Forward looking grid code development with broad stakeholder participation can help prevent this. The development of harmonised European Network Codes is an example of good practice, both in terms of process and outcome. The results provide a guide to developing a country-specific grid code (EC, 2018a).

5.2.2 INCORPORATE VRE IN SYSTEM OPERATIONS

When VRE generation starts to affect the power system, improving operation of VRE plants and of the system as a whole becomes a priority. Improving operations to accommodate more VRE will generally modernise and improve the efficiency of system operations in general, regardless of the actual rate of VRE penetration.

System operation practices are highly technical and require time and effort to change. Existing protocols are often based on long-standing experience and operators may be reluctant to change. However, failure to upgrade operations will increase the cost of integrating renewables and can result in unnecessary curtailment or even reduced reliability at higher shares. The role of policy makers is to monitor the system operator's activities and to mandate change as it becomes necessary. A wide range of experience is now available from systems that have already reached double-digit shares of VRE. System operators in countries that are experiencing growth in VRE can start by reviewing this experience to develop their own strategies. Some relevant objectives to improve system operations are (IEA, 2017b):

- Guarantee visibility (adequate real-time information) of a sufficient number of power plants, including VRE plants, to the system operator.
- Implement and use VRE production forecasts.
- Improve the scheduling of plants, the management of interconnections with other balancing areas, and the management of operating reserves according to load and VRE forecasts. In systems that have undergone market liberalisation this will likely require changes to market design.
- Give system operators the ability to control a sufficient number of plants close to and during real-time operations.

Facing increasing VRE shares, many European Transmission System Operators (TSOs) have, in different ways, improved their system operation to incorporate VRE. For example, Red Eléctrica de España, Spain's TSO, established a control centre within its main system operation centre dedicated to better manage renewable energy resources. The centre helps maximise VRE production while ensuring system reliability.

5.2.3 USE AND EXPANSION OF THE GRID

The grid infrastructure is usually managed by regulated entities, either TSOs or vertically integrated companies. These entities schedule the expansion of the grid through long-term plans that identify the grid's main weak points and future needs for optimisation, expansion and reinforcement. The exact route of a new power line is then decided through a planning approval procedure. Such processes frequently incorporate analyses of wider impacts of new infrastructure, such as impacts on local communities or policy objectives. Policy makers may require the adoption of appropriate provisions in the statutes of the regulated entities to facilitate renewable deployments. For example, they may introduce the mission of reducing the environmental impact of the power sector (IRENA, 2017).

The commissioning of a VRE plant requires relatively little time (from six months for a utility scale PV plant to two years for a wind farm) compared with the several years that may be required to build new transmission infrastructure. Consideration should be given to how to synchronise both. Establishing dedicated renewable energy zones as part of the grid planning process may help (see Box 5.2).

At growing shares of VRE, the grid may experience congestion at its weaker points. In some cases, options such as dynamic line rating, Flexible AC Transmission Systems, line repowering can defer or even avoid the need for a dedicated new power line. Granting regulatory approval for such options, after appropriate cost-benefit analysis, can thus help improve SIR. There may be the additional need for developing best practices and guidelines for regulators in performing cost-benefit analysis.

Another frequent grid-related integration issue is the cost of connecting new plants to the main grid. For VRE, it may be that resource-rich areas are far from the existing grid. If all plants build their own connecting line, costs rise unnecessarily. Two solutions have been found to allow multiple projects to share the same line: developers share costs (in which case, the TSO and/or policy makers can be in charge of arrangement design) or the connection costs are recovered from taxpayers or electricity users, depending on policy makers' decisions. The application of renewable energy zones may reduce connection costs.

BOX 5.2. RENEWABLE ENERGY ZONES AND TRANSMISSION PLANNING

High-quality VRE resources may be located in areas that lack the network to integrate them. Therefore, identification of suitable areas for VRE deployment (zoning) and their integration in transmission planning can have multiple advantages. Integrated planning may assist in identifying new lines to connect resource-rich areas to the neediest load centres and in increasing the confidence of VRE developers that their assets will be put to full use, thus reducing the cost of VRE deployment (IRENA, 2015; IRENA, 2017; NREL, 2017).

One approach to zoning is to incentivise VRE deployment in specific areas. In South Africa, the first VRE plants were deployed through a competitive auction that induced independent power producers to identify sites that would minimise tariffs under power purchase agreements. However, the geographical concentration of projects increased pressure on the overall system owing to delays and rising grid connection costs. CSIR (Council for Scientific and Industrial Research) then identified eight Renewable Energy Development Zones (REDZs) where VRE development was considered most desirable strategically.

By anticipating grid expansion needs, REDZ signal areas with lower connection costs. South Africa government has also simplified the procedure for assessing the environmental impact of utility-scale VRE projects sited in the REDZs, and for related lines and substations (IEA, 2016a; IRENA, 2018c).

Another option is to use transmission planning to signal to developers the most suitable areas for VRE projects. In the United States, the Midcontinent Independent System Operator (MISO)[6] established a value-based planning process, called Multi Value Project (MVP) Portfolio Analysis, to identify grid-expansion projects that can provide economic value, increase reliability or contribute to state policy. Since its inception, the MVP analysis has been used to expand the grid to accommodate the generation of 41 TWh of wind energy to meet renewable power mandates and state goals. By identifying a set of zones suitable for wind generation, more than 2.5 GW of new wind farms were developed close to newly built transmission lines. Developers preferred siting the new wind farms in locations where transmission lines were planned, rather than in the windiest areas (MISO, 2017).

5.2.4 DEPLOY SYSTEM-FRIENDLY VRE DURING THE EARLY PHASES

VRE plants can be deployed in a manner that facilitates their integration, but encouraging such deployment requires appropriate VRE remuneration schemes, such as feed-in policies (see Chapter 4). In most cases, these schemes centre on the levelised cost of electricity (LCOE), a measure of cost for a particular generating technology at the plant level. This cost approach, however, does not consider when, where and how energy is produced, and its impact on the wider system, which can be assessed by considering the system value of the power plant in addition to its cost. In this context, system value is defined as the as the net benefit arising from the addition of a power generation source to the power system.[7]

The objective of the value-based approach is to minimise overall power system costs, not just VRE generation costs alone. The many ways to do this have been explained in detail by the IEA (2016a). Elements of the value-based approach can be used with administratively set tariffs and auction schemes alike. Typically, administratively set tariffs can incorporate a bonus or other price signal to steer investment; in auction schemes, the value-based approach can be implemented by including specific requirements at the qualification stage or by applying weighted criteria to the evaluation of bids.

To summarise, in the early stages of VRE deployment, optimising the geographic location of VRE plants and deploying a mix of wind and solar – as resources allow – are most relevant.

- **Location**. There may be a trade-off between the sunniest or windiest sites and the cost of connecting them to the grid. Siting VRE assets in locations where electricity is needed (or where the VRE production profile best fits the system load profile) and transmission infrastructure is available has a positive impact on system costs. Similarly, the aggregated output variability of a distributed fleet may vary depending on size and geographic distribution. Locational signals can be included in support policies to favour certain areas over others. For example, the feed-in schemes in several countries draw distinctions according to resource quality, providing higher remuneration per unit of energy for areas with lower wind speeds or less sunlight. China feed in tariffs have such a design. Moreover, since 2011, the allocation of new wind and solar power projects in China is co-ordinated at the national level. China's FITs were determined following auctions that provided a signal of the appropriate prices in each area according to resource availability.
- **Technology mix**. The availability of wind and sun is complementary in many parts of the world: when it is windy it tends to be less sunny and vice versa. Thus, deploying both technologies in the right mix can reduce variability (from minutes to months) and impacts on the grid. Based on long-term modelling studies, it is possible to determine an optimised mix of VRE technologies. This information can then be used when putting in place and adjusting remuneration schemes for VRE plants. Technology-specific auctions can be designed to achieve an optimal balance for the system. This is the case in South Africa, where VRE is procured through auctions, with the allocation of specific technologies determined on the basis of long-term system planning.

6 MISO is the Independent System Operator providing transmission services in the U.S. Midwest, plus Arkansas, Mississippi, Louisiana and Manitoba (Canada).

7 The definition of "value" for society or for the system may vary among countries; the literature provides different definitions of value (LBNL/ANL, 2017).

5.3 PHASES 3 AND 4: A SYSTEM-WIDE APPROACH

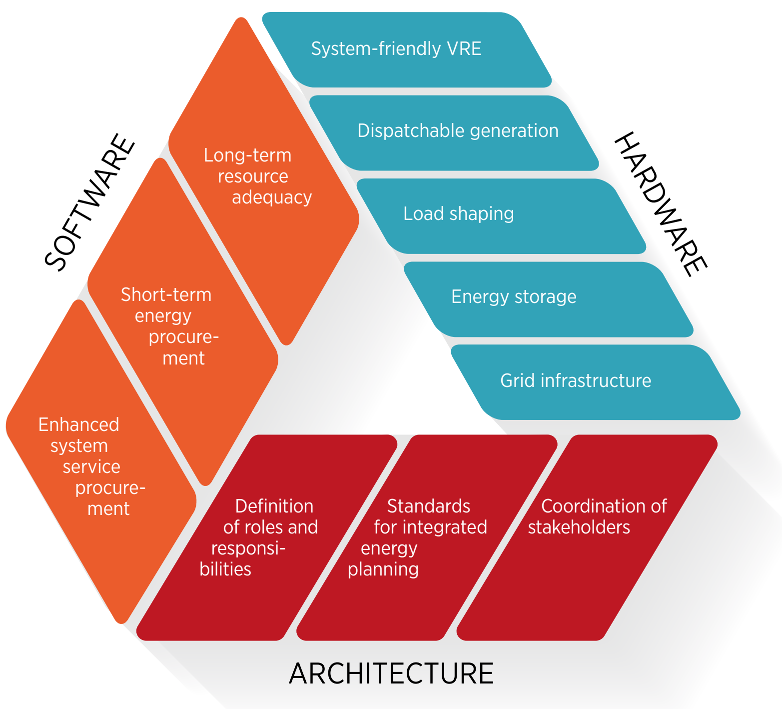
The task of integrating high shares of VRE becomes significantly more complex as the system moves to Phases 3 and 4. Electricity supply comes to be characterised by higher levels of uncertainty and variability, and by periods of low net load, particularly during periods of low demand and high VRE generation, such as sunny or windy weekends.

A successful integration of VRE is one that holistically considers three levels of the system: technical, institutional and economic. Making the required flexibility available for the power system depends on the system's technical capabilities (its "hardware"), the roles and responsibilities of different actors (its institutional "architecture") and the system operation and market rules in use (its "software").

For example, in order to make the demand side more flexible, special devices for the remote control of loads are needed (hardware); electricity prices should vary across time (software); and new players, such as aggregators, may need to be defined (architecture). Only if all three aspects work well together can demand-side flexibility be maximised (Figure 5.3).

Effective policy-making considers these interplays, identifying the technical, institutional and economic links and barriers. SIR measures, at high shares of VRE, should not be adopted separately, but in "policy packages" that address these three levels of the power system.

Figure 5.3. Different layers of system integration of VRE



5.3.1 THE HARDWARE: UPTAKE OF INNOVATIVE TECHNOLOGY

Ensuring secure and effective system operation at higher shares of VRE imposes new priorities for utilities and system operators. Depending on the level of policy ambition, additional investment in flexible resources can also become necessary. Securing such investment becomes an important aspect of the overall policy, regulatory and market frameworks. Sufficient flexibility can usually be achieved by combining system friendly VRE with an appropriate mix of the four flexibility resources introduced in Box 5.1 and explored in the subsections below.

Some promising technologies may not be market-ready; in such cases, additional research and development could accelerate the reduction of technology cost. Capital grants and dedicated loans for first developers or demonstration projects can enrich the experience of system operators with new technologies, helping them identify relevant barriers. Conversely, the power system may be tipped in favour of one player or technology, raising entrance barriers for new technologies. The role of policy makers is to preserve a level playing field and ensure fair competition.

Advanced power plant flexibility

Dispatchable generation currently provides the bulk of the electricity in most power systems, but, as the share of VRE in a system increases, its contribution to the generation mix diminishes, while it continues to be a valuable source of flexibility. Dispatchable generation technologies will need to be able to respond rapidly to VRE generation by reducing output to very low levels or shutting down completely, and being able to ramp up and down or start up and shut down quickly.

This topic has commanded substantial attention in recent years. For example, in 2017, the Clean Energy Ministerial[8] launched the Advanced Power Plant Flexibility campaign. The Campaign seeks to build strong momentum and commitment from governments and industry to solutions that make power generation more flexible and better able to accommodate growing shares of VRE. Its main objectives are to facilitate VRE integration, highlight current success stories with power plant flexibility, unlock latent flexibility potential and optimize the utilisation of generation assets.

Several technical measures, which vary by plant design and fuel, can improve inflexible thermal power plants towards more flexible operations. These include improving combustion conditions and integrating digital controls to enable real-time monitoring. Existing generation assets can offer a large amount of flexibility. The Chinese government has identified improvements in the flexibility of its existing fleet of coal-fired power plants as key to the successful integration of increasing shares of VRE to meet its long-term climate goals. In its 13th Five-Year Plan, China commits to retrofit by 2020 133 GW combined heat and power and 86 GW condensing coal-fired plants to enhance their operational flexibility and environmental performance. This represents about one-fifth of the installed coal-fired capacity in China. Making such options economically attractive, often requires changes to market, policy and regulatory frameworks.

Load shaping: demand-side management

Load shaping consists of a number of different activities and technologies that make it possible to adjust demand to better fit with system needs. Their common property is the ability to shift power consumption, to interrupt electricity consumption or to absorb low-cost electricity production.

Load shaping can be achieved through demand-side management (DSM), electrification of end uses and the adoption of strategies that transfer low-cost electricity from VRE to other energy carriers (sector coupling). This chapter focus on the DSM options; a dedicated box at the end of the chapter examines the sector coupling options.

DSM can be defined as a combination of two activities: the management of load through market mechanisms (explicit DSM), and the response of consumers to price signals (implicit DSM). Historically, explicit and implicit DSM programmes have been used to reduce peak loads (often in the interest of deferring investment), improve system reliability and save fuel costs. DSM can also improve market functioning, providing system services and shaping demand in a way that facilitates the integration of VRE.

Various explicit DSM programmes in place around the globe (mainly in US, Europe and Australia) allow large consumers (industries) and small consumer aggregators to participate in energy markets. Nevertheless, DSM has remained limited in scale and largely restricted to large industrial consumers. Today, about 40 GW of capacity globally is able to respond directly to shortages or excess supply (Navigant Research, 2017).

Large consumers that could implement DSM may be concerned about the risk of disrupting their core business , due to a lack of understanding of the DSM options. (The energyst, 2017). Policy makers should address these concerns, by engaging consumers, disseminating information, and simplifying energy products and market access rules in order to facilitate participation in the market.

Implicit DSM can be used to shape the average demand profile of small consumers to better fit with system needs. For implicit DSM, dynamic pricing (peak charges, time of use tariffs, etc.) is the key to trimming peaks and shaping demand in a cost-effective way. Dynamic pricing is applied in several countries across the globe, both in stable (Denmark, U.S.) and dynamic (China, South Africa) systems.

Consumers may tend to resist change keep pre-set options, even where alternatives may yield better (*e.g.* more financially rewarding or materially advantageous) personal outcomes. Policy makers may need to address consumers' behavioural inertia with mandates, awareness programmes or by supporting the deployment of enabling technologies.

DSM is made possible by advanced digital metering, which tracks the time of energy consumption. To promote digital metering and benefit from economies of scale, policy makers may opt for a large-scale or selective rollout – examples of which can be found in the European Union, California and Australia – that imposes a policy mandate on distribution companies or suppliers, specifying minimum

8 The CEM is a high-level forum to promote policies and programs that advance clean energy technology, to share lessons learned and best practices, and to encourage the transition to a global clean energy economy. The IEA supports the implementation of the campaign as operating agent.

technical requirements. Such programmes should include a cost-benefit analysis including future, VRE-rich scenarios. A potential drawback of a mandated rollout is that consumers may object on grounds of privacy. Opt-out clauses and proper informational campaigns may then be included.

The Brazilian energy regulator ANEEL passed a norm in mandating distribution companies to offer customers the choice of installing a smart meter. The offer must highlight the benefits of access to enhanced information, more tariff options and remote connection management (IRENA, 2016b)

Energy storage

The ability of energy storage technologies to offset demand and absorb excess generation makes them in principle an ideal complement to variability in VRE output and energy demand. Storage options span a large array of technologies with different cost and performance characteristics. This makes them suited differently to the range of services electricity storage can provide (see Table 5.1). Currently, the vast majority of electricity storage deployed globally is pumped hydro storage, but battery technologies such as lithium-ion or flow batteries are also increasingly common.

Table 5.1. Qualitative description of energy storage services in the power system

	Application	Description
Generation	RE integration, bulk	Time-shift RE output to optimise for grid integration and minimise curtailment
	RE integration, ramp	Optimise short-term RE output to improve power quality and avoid imbalances
Network operation	Frequency control	Maintain supply and demand balance via power increases/ decreases with different response patterns
	T&D deferral	Defer upgrades to network infrastructure
	T&D congestion	Avoid re-dispatch and local price differences due to risk of overloading existing infrastructure
	Black start	Restore power plant operations after network outage without external power supply
	Voltage support	Maintain voltage levels across networks via reactive power supply/reduction
Behind-the-meter storage	Peak power supply	Reduce demand supplied by the network during peak hours to reduce network charges
	Back-up power	Provide power during network failure to ensure power quality and availability
	RE self-consumption	Maximise usage of self-generated power and minimise exports to the network
	Bill management	Shift energy consumption from high-tariff to low-tariff periods to reduce energy charges
Market	Energy arbitrage	Purchase power in low-price periods and sell in high price periods on wholesale or retail market

Note: RE = renewable energy; T&D = transmission and distribution.

No single application would require the entire storage capacity continuously. Therefore, storage can provide additional services at the same time. This would increase the profitability of such investment option, if there is an appropriate regulatory framework. To enable that, policy makers need to remove existing barriers, for example adjusting minimum bidding size in reserve markets, where batteries are often excluded due to small size (Stephan, 2017). Energy markets should allow companies to supply services that cut across multiple, independently regulated markets (long-term, short-term, balancing, etc.). This is supported by establishing pricing mechanisms that reflect the value of a given service to the electricity system and each stakeholder's contribution to providing it (Carbon Trust, 2016). In recent years, batteries have fallen in cost. Prices for lithium-ion battery packs for electric transport fell on average by 19% per year – from USD 1 000 per kWh in 2010 to USD 209 in 2017 (BNEF, 2017). This also affected stationary systems, with the installed cost of residential lithium-ion systems in Germany falling from EUR 2 000 per kWh in 2013 to EUR 1 200 in 2016 (Schmidt *et al.*, 2016). Costs for utility-scale application are expected to decline from USD 200-1260 per kWh in 2016 to USD 77-574 in 2030 (IRENA, 2017b).

High investment costs are a barrier to residential storage deployment. The German support programme for residential storage is based on low-interest loans and investment grants for PV-battery systems or PVretrofits with residential batteries.

Grid infrastructure

Grid infrastructure encompasses all assets that connect generation to demand, most importantly highvoltage transmission lines, the lines of the distribution system and additional devices (*e.g.* transformers). Grid infrastructure aggregates distant resources and in doing so brings important portfolio and scaling benefits to the entire power system. Both the transmission and distribution grid are complex networks that often make use of very sophisticated additional control and management equipment.

In an energy system undergoing transformation, grids must manage electricity flows from a growing number of renewable energy plants, some or many of which are located in remote regions or offshore. These changes increase the complexity of grid infrastructure and require specific interventions to manage the flow of electricity.

Grids are generally considered natural monopolies, with some projects standing as exceptions to this rule. Grid owners do not face competition and revenues are guaranteed within the limits of applicable regulation. Depending on the regulatory framework in place, grid owners may have a tendency to overinvest in standard assets and are not naturally incentivised towards innovation.

Policy makers should aim to guarantee the best investments for the network, at a fair price, involving all stakeholders in the process and while meeting policy objectives. One example of a recent attempt to improve regulation of grid assets and provide incentives for innovation is the RIIO programme in the United Kingdom (see Box 5.3).

BOX 5.3. THE UNITED KINGDOM'S RIIO PROGRAMME

The RIIO ("Revenue=Incentives+Innovation+Outputs") is a programme to promote the selection of the most appropriate investments in the gas and power transmission and distribution grids, while limiting the costs to consumers. It contains different aspects that assist the deployment of the most innovative solutions. The programme applies to England, Scotland and Wales.

The RIIO model opens network innovation to competition. Ofgem, the power sector regulator for Great Britain, has the authority to involve third parties in new projects through competitive procurement. To attract efficient investments, the RIIO model rewards companies that offer solutions that improve the system's performance – from customer satisfaction to reliability. Moreover, specific projects in the distribution grid can apply to receive specific funds, in particular when the innovation meets environmental criteria but does not bring enough financial benefits.

RIIO sets clear performance targets for operators, with a focus on social obligations. Such targets are set after a consultation process with grid users and involve financial penalties for failure and incentives for overachieving.

The RIIO model relies on the TOTEX parameter, *i.e.* sum of capital and operation costs over the project lifetime. Previously, Ofgem allocated funds for capital and operational costs separately. Using the TOTEX parameter, the RIIO model aims to limit costs over the lifetime of the asset. This approach recently gained international attention and similar projects are in various stages of implementation in other jurisdictions (Pöyry, 2017; IRENA, 2016).

Grid development projects may be time consuming due to local opposition and the challenges of minimising impacts on nature and communities. Policy makers should implement a constructive public engagement aiming at improving public acceptance for grid development processes while addressing or even surpassing environmental protection standards. The European Commission BESTGRID projects tested the best practices on this regard, and new approaches to achieving public acceptance for new power lines for the integration of renewables have been developed, tested and applied (EC, 2015).

System-friendly VRE deployment at higher shares

VRE plants can facilitate their own integration by incorporating certain design elements. While location and the technology mix are the aspects to be considered at the early stages of VRE deployment, other options may become relevant as the share of VRE grows:

- **Optimising the generation time profile**. VRE plants can be designed to produce energy more smoothly, for example by using "low wind" turbines or mounting PV panels to face towards east or west to move the peak production away from midday (IEA, 2016a). Support schemes can incorporate a time signal, for example, through partial exposure to market prices (*e.g.* fixed feed-in premiums) or by adjusting remuneration according to time of delivery (TOD). In California, for example, TOD factors have been used in power purchase agreement (PPA) prices, favouring solar PV production in the late afternoon (IEA, 2017c)
- **Increasing self-consumption**. Reducing the amount of energy exported from residential and commercial PV plants reduces stress on the grid. Self-consumption is incentivised implicitly when remuneration for grid injection is lower than the cost of procuring grid energy. Net metering schemes can also encourage self-consumption by modifying the "netting period": for example, in Denmark, net metering is calculated on an hourly basis, *i.e.* solar PV generation in one hour is counted against electricity consumed during the same hour. There is no compensation for excess exported electricity to the grid after netting. This implicitly incentivises household consumption to match better with solar PV production.
- **System services from VRE**. Forecast technology enables system operators to know how much wind and sun they can reliably expect hours in advance, permitting VRE to be used to provide system services such as operating reserves. For example, through blade pitching, wind turbines can provide upward and downward reserve. When system services can be obtained from VRE in addition to dispatchable power plants, the power system can accommodate more VRE. But obtaining system services from VRE requires various policy measures, such as specific grid codes and upgrades to the system services procurement mechanism. In Spain, since February 2016, wind energy can provide ancillary services, providing balancing with closer to delivery time allowing wind energy management optimisation.

Assessing the optimal mix of different flexible resources

The previous sections provided examples of technological options to enhance system flexibility. A natural next step is to assess how different options can be combined into a strategic approach.

In assessing how best to combine flexible resources, modelling simulations are appropriate. For example, Chalmers University conducted a study (Göransson and Johnsson, 2017), supported by the Swedish Energy Agency (SEA), to investigate how different flexibility strategies (called "variation management strategies" in the study) can facilitate efficient integration of wind power in Europe. The study was carried out for the European electricity system (EU27+Norway+Switzerland), assuming a cap on CO_2 emissions and continued growth of renewable energy in line with 2020 National Renewable Energy Action Plans (NREAPs) extrapolated to 2050 as well as continued ambitions on energy efficiency (see Box 5.4).

BOX 5.4. CHALMERS UNIVERSITY STUDY: THE EFFECTS OF FLEXIBILITY STRATEGIES

At the onset of deployment, when its share is low, variable renewable energy (VRE) as solar PV often generates at times of high demand. This translates into a high market value. as long as its share is low. However, all PV systems will tend to generate at the same time. This means that when PV capacity is generating, as more PV capacity is added to the system, there is an increasing abundance of electricity, aggravated by the fact that solar photovoltaic systems tend to generate at the same time. The effect is similar for wind, though not as pronounced. The exact magnitude of the decline in value is highly system specific. For example, regions with hydropower may experience a slower drop in the value of wind, compared to isolated regions or with no access to hydropower.

Göransson and Johnsson (2017) assessed through modelling tools how flexible resources and related flexibility strategies can mitigate the decrease in wind value (applying the modelling to the European context), reducing the need for investments in base load and peak capacity. Their modelling illustrates that the decrease in wind's value as its share increases can be mitigated if measures are taken to increase flexibility.

The study identified three types of flexibility strategies, each requiring a specific investment option. "Complementing strategies" use dispatchable generation to complement VRE output. "Shifting strategies" change how energy is consumed over time through energy storage and demand-side management. "Absorbing strategies" convert power to some other energy carrier such as heat or fuel (sector coupling), thereby introducing additional demand for electricity.

Grid infrastructure and system friendly VRE are options that enable greater system flexibility under any strategy.

Complementing strategies are usually the first used by system operators to balance the changes in net load introduced by the output of VRE resources. In the form of flexible generators (such as reservoir hydropower), complementing strategies increase cost-optimal investments in wind plants at the early stage of wind deployment. Reservoir hydropower plants, in particular, are a carbon-free, pre-existing source of flexibility that can reduce the drop in value of wind. In regions with reservoir hydropower, the value of wind is higher for low to medium wind shares, compared to other regions.

Shifting strategies move electricity demand in time, through DSM and batteries. The Chalmers' study concluded that shifting strategies reduce average generation costs (mainly in regions without access to hydropower) by lowering the need for peak capacity. Shaping strategies also increase the value of wind power by 1-3 EUR/MWh in the EU context.

Absorbing strategies – notably the electrification of heating and cooling and transport and the production of synthetic fuels – can effectively reduce the number of zero price hours, by increasing power demand, effectively increasing the value of wind at medium and high wind shares, where the zero-price events would otherwise occur.

Chalmers' study assessed the role of chemical storage: with fixed annual hydrogen demand (*e.g.* for use in industry), the presence of a hydrogen weekly storage can reduce average generation cost and increase wind revenues, by more than 10 EUR/MWh in the EU context. This benefit should be compared to the cost of a hydrogen production and storage system.

In the EU context, the flexibility strategies consistently reduce base load investments and there is a general reduction in investments in peak capacity. These strategies are not mutually exclusive, nor are their effects independent of each other. Combining strategies can have synergistic effects on cost-optimal investments in VRE. The synergies obtainable from combinations of strategies should be the subject of analysis for any power system transitioning towards high VRE shares, to find the best mix of flexibility investments (Göransson and Johnsson, 2017).

Table 5.2. Flexibility strategies and related flexibility investment options

Strategy	**Complementing**	**Shifting**	**Absorbing**
Flexibility investment options	Dispatchable generation	Demand-side management Electricity storage	Sector coupling Power-to-X
	Grid infrastructure – System friendly VRE		

5.3.2. THE ARCHITECTURE: CHANGE IN ROLES, RESPONSIBILITIES AND PLANNING PROCEDURES

Proper economic incentives and technology deployment policies cannot function effectively in the absence of an appropriate institutional framework. Successful power system transformation is thus likely to require structural changes in power sector governance. This may include changes to roles and responsibilities, adoption of integrated planning processes and improved coordination of the system's parts.

Change in roles and responsibilities

Over the past decade, a number of new drivers have emerged to change the way the power system is managed. These drivers include VRE, distributed generation, smart grids, energy storage, and energy efficiency, all available at increasingly competitive prices. Others are business models and institutional approaches that further encourage or leverage changes to power systems. In many regions of the world, these changes challenge traditional sector structure and institutional arrangements (Kind, 2013).

A crucial element of defining roles and responsibilities is the proper regulation of those institutions authorised by statute to regulate the power system. The role of the policy makers in the face of such changes is to provide clarity about the roles of the various regulators and governmental bodies, and to ensure that political objectives are clearly articulated.

Role clarity is essential for an entity to understand and fulfil its role effectively and depends on the proper definition of each entity's objectives, functions and scope – in other words, a mandate that does not conflict with those of other entities, a defined policy role and the power to cooperate transparently with other bodies (OECD, 2014). Broader changes to roles and responsibilities may be necessary, such as unbundling roles formerly held by a single entity, to avoid conflicts of interest.

Mexico recently implemented a comprehensive reform of its energy sector. The reform aimed to resolve a number of structural challenges, opening the sector to competition and unbundling the state-owned electric utility, CFE. This reform was conducive to the cost-effective uptake of VRE, thanks to defining roles and responsibilities that avoided conflicts of interest, for example by the establishment of a new planning process developed by the Secretariat of Energy, or the establishment of an independent system operator (IEA, 2017c).

Standards for integrated energy planning

Electricity system planning may involve a large number of stakeholders whose respective responsibilities may be unclear, leading to unclear results. Further complexity may result from multiple jurisdictions undertaking planning for a given system.

With the growing presence of VRE, it is crucial that VRE characteristics are taken into consideration in longterm energy planning so that investments are appropriate and timely. A large-scale rollout of VRE and flexible resources should set responsibilities, time frames, technical requirements and economic conditions for cost recovery.

Integrated long-term power sector planning can also provide clear guidance to market players to align their own plans with overall system change. For example, the presence of a long-term plan enables operators of large, inflexible power plants to better determine when retrofits or decommissioning may be required.

The role of policy makers is to make sure that policy objectives are well-considered in the planning procedure, that the characteristics and impacts of VRE are appropriately taken into consideration with in-depth analysis of data and that relevant stakeholders are consulted in the development of the energy sector's long-term plans (IRENA, 2017; Leisch and Cochran, 2016; NREL, 2017).

In Denmark, integrated energy system planning has a long, well-established tradition. This long-term planning has been developed by the Danish Energy Agency and has solid support in parliament. The Danish approach to energy policy is characterised by holistic planning, emphasising flexible resources and crosssectoral electrification. The grid and market structures are continuously reshaped to handle increasing VRE production. All these factors are important tools to trigger relevant investment in the Danish energy system (IEA, 2016a).

Enhanced co-operation between system stakeholders

The power sector's evolution toward more VRE also calls for a change in the way its players interact. The characteristics of VRE, notably its modularity and uncertainty, require enhanced co-operation and data exchange among operators on a variety of issues, including grid congestion management, balancing and operating reserves. Timely and comprehensive data exchange is needed for secure and cost-effective system operations. Policy makers should assure the creation of a framework to ensure appropriate data exchange, which may require a redefinition of rules regulating data sharing and ownership.

The interface between the transmission system and local grids provides a good example. Historically, the interface was managed from the top down, but this is sub-optimal in systems with large shares of VRE connected on the distribution grids. For example, a TSO may obtain operating reserves from aggregators of small-scale resources connected to the distribution grid. If the TSO issues a request for increased output, this electricity needs to be fed upwards to higher voltage levels to take effect. However, this may not be possible if there is local congestion in the distribution grid at that time. This highlights the need for improved coordination under the new paradigm (IEA, 2017c; IRENA, 2017b).

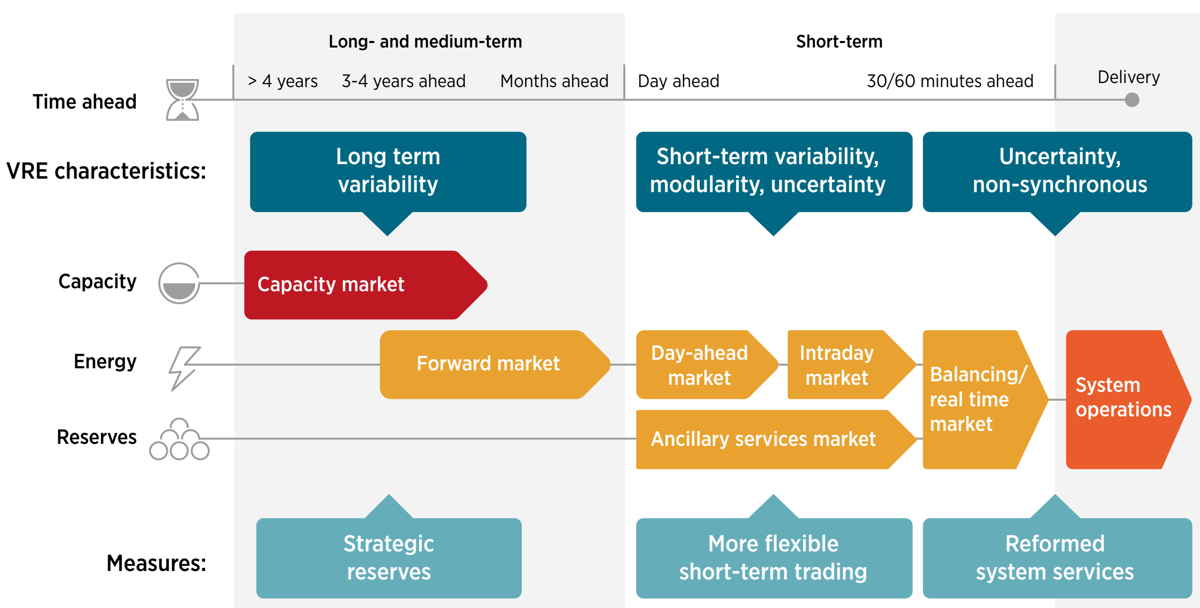
Solutions to improve TSO/DSO cooperation are currently under study in many institutions. The Council of European Energy Regulators, for example, has published principles of cooperation and related regulatory arrangements in the areas of governance, network planning and system operations (CEER, 2016)

5.3.3. THE SOFTWARE: DESIGN OF POWER MARKETS AND REMUNERATION MECHANISMS

The design of power markets, including their remuneration mechanisms, has a critical role in guiding operational and investment decisions. But the large-scale uptake of VRE challenges traditional design frameworks. This is true for nearly all market structures, whether they lean towards competitive markets with extensive private sector participation or vertically integrated utility models. The required adaptations will be different in each circumstance, though some convergence between the different models can be observed. Where vertically integrated models have prevailed so far, a push can be detected towards competitive mechanisms to improve the efficiency of power system operation. For example, the ongoing power market reform in China aims for the introduction of a market mechanism to coordinate the dispatch of power plants in a more cost-efficient manner from a system perspective. In turn, countries that have pioneered power market liberalisation have seen a tendency to implement supplementary mechanisms to ensure security of electricity supply. For example, the United Kingdom has combined centralised forward capacity markets with a long term contracts-for-differences mechanism for low-carbon generation (IEA, 2017c).

It is possible to establish a connection between the properties of VRE (and how they affect electricity markets) and relevant price signals at the wholesale level (Figure 5.4).

Figure 5.4. Electricity markets and VRE characteristics



Source: Adapted from IEA (2016b).

Broadly speaking, it is possible to distinguish between long-term and short-term markets. Within short-term markets one can differentiate between standard trading of energy (such as day-ahead, intraday) and specialised arrangements for the procurement of system services. Unlocking flexibility depends on proper design along all of these time scales.

Resource-adequacy instruments

In systems where growth in VRE generation outpaces the need for new investments, wholesale prices can become very low, potentially undermining the economics of resources that are needed for long-term resource adequacy. These issues have been addressed by putting in place capacity remuneration mechanisms, instruments that provide additional revenues to relevant system resources (such as power plants) to compensate them for their contribution to the adequacy and stability of the system.

At a minimum, policy makers should ensure that a monitoring system for resource adequacy is in place. If a capacity remuneration mechanism is adopted, it should be proportionate to system needs and designed in such a way as to be technology neutral, to accommodate demand responses, and to minimise distortions in short-term market signals.

Forms of capacity remuneration mechanisms have begun operations in the United Kingdom (2015) and France (2017). Other European countries, as well as Japan, are implementing or considering such instruments. In France, the price set in the first capacity remuneration mechanism was EUR 10 per kilowatt (kW) and the regulator estimated that this would represent EUR 1.44/MWh in 2017 for residential consumers (CRE, 2017).

In Germany, after the identification and quantification of the security of supply risks, a strategic reserve mechanism has been put in place to ensure security of supply during the ongoing reform of the German electricity market and the phase-out of nuclear power plants. As such, the mechanism is temporary. The reserve is procured through auctions open to all types of capacity providers, including DSM resources (EC, 2018b).

More flexible short-term trading

Short-term markets are the foundation of all market-based electricity systems and have been proven to be a good way to integrate electricity dispatching with high shares of VRE. Although there is no standard design for electricity markets, short-term markets fall into two broad categories depending on the degree of their geographical and temporal resolution of electricity prices (IEA, 2016):

- Low-resolution market designs have been implemented in Europe, where the primary objective was to enable cross-border trade in electricity. Each country has had relatively little internal network congestion and a single country price has been considered sufficient. Within each price zone, power exchanges, not system operators, calculate prices as if congestion and network constraints did not exist. System operators handle congestion by redispatching power plants. The primary market is the day-ahead market. Participation is not mandatory.
- High-resolution market designs provide an accurate economic representation of the physical reality and operation of power systems. These have become common in parts of the North America, for example in Texas (Alaywan, Wu and Papalexopoulos, 2004). System operators directly manage the market platform using sophisticated software to perform security-constrained economic dispatch.

High-resolution market design constitutes the benchmark for short-term markets and can reduce the overall costs of operating power markets (Green, 2007; Neuhoff and Boyd, 2011). Market design with a high geographic and temporal resolution is better suited to integrating increasing shares of VRE. But lowresolution designs can be improved by dedicated policies (IEA, 2014; 2017c). For example, the German government recently passed a regulatory package for the country's "Energy Market 2.0" which aims, among other measures, to ensure efficient power system operations by improving the temporal accuracy of price signals, to ensure security of supply, and to open the market to DSM, electric vehicles and storage.

Improved procurement of system services

System operators are required to balance the power system in case of unexpected deviations in energy supply or demand. System operators procure system services to offset these deviations and maintain grid stability. To date, dispatchable generators have provided many of these services.

As the penetration of VRE increases, the need for such services and their economic value are bound to change. Generally, state-of-the-art VRE generators are technically sophisticated and capable of providing a range of relevant system services to stabilise the grid. However, few jurisdictions require or allow VRE operators to provide them and, until this changes, it is unlikely that they will do so. Hence, it becomes a priority to reform system services market, updating the definitions and deployment of system services.

The role of policy makers, as in the previous cases, is to make sure the system services procurement mechanism is monitored and updated to comply with the needs of a system with high shares of VRE. For example, the products traded on system services markets may need to be redefined. In the process, new system service products may become relevant, such as fast frequency response to deal with reduced system inertia or ramping reserves to deal with ramping events. All potential resources should be allowed to bid in the system services market, including VRE and flexible resources, since dispatchable generation may not be available when VRE generation is high.

An example is the UK National Grid's Enhanced Frequency Response (EFR). The power system in Great Britain is losing inertia as thermal generators are shutting down with increasing penetration of VRE. Thus, the enhanced ability of the system to respond to sudden power losses or surges has become more important. The National Grid established EFR, a service requiring full power output within 1 second compared to 10 seconds for the previously fastest frequency response service. A technology-neutral auction in summer 2016 for four-year contracts rewarded eight battery storage projects totalling 201 MW of capacity at a price range between USD 9.4 and 16 per megawatt per hour (National Grid, 2016). The successful bids were significantly lower than average bid prices for conventional frequency response services (Miller, 2016).

IN FOCUS: POLICY ON THE FRONTIER – SECTOR COUPLING

The concept of "sector coupling" encompasses co-production, combined use, conversion and substitution of different energy supply and demand forms - electricity, heat and fuels.

Sector coupling is not a new concept, but it is currently gaining more attention as the costs of variable renewable energy (VRE) fall and VRE comes to occupy a larger share of power generation around the world. Electrification and synthetic fuels are critical elements of any effort to address the system integration challenges to be faced in Phases 5 and 6. Both elements are being applied to a certain extent today. However, irrespective of grid integration challenges, the simple fact that VRE electricity is becoming low cost and is available abundantly in areas with little land use competition (windy deserts, for example) may create new opportunities to replace fossil fuels.

Abundance, or even surplus, of VRE generation might become recurrent in power systems with high shares of VRE. In the absence of other efforts to mitigate them, these surpluses might prompt large-scale curtailment of VRE output, and thus lower the value of VRE, reducing investment attractiveness. To maintain its value, VRE electricity should be expanded into more end uses and supply sectors.

Sector coupling, in this context, involves two aspects of energy system planning and operation. First, an energy source is linked to a type of service (*e.g.* the electrification of heat and transport). Second, new links are created between energy carriers (*e.g.* electricity is used to create a synthetic fuel that can be then be used to provide a service). This second type of coupling allows the indirect electrification of processes that cannot be electrified directly (*e.g.* industrial processes).

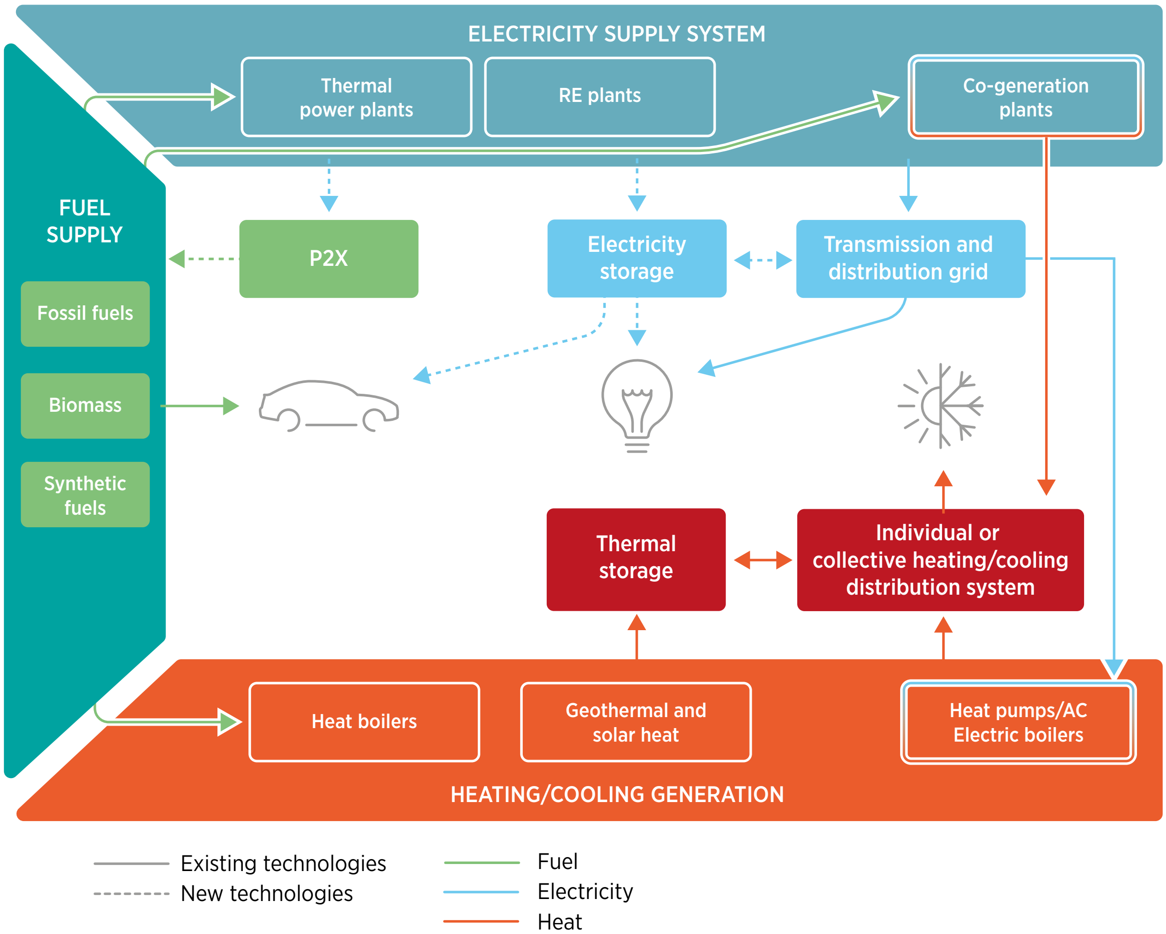
Sector coupling may better align demand with VRE production periods if proper strategies for shaping the demand profile are adopted. These would reduce the volume of curtailed VRE, reduce conventional power plants' need to provide system services, and reduce system-wide fuel use. This would maintain the high market value of VRE since it would facilitate load shifting when VRE production peaks.

These new options raise new questions, related to the design of the energy sector and system costs. Without strategies to manage the new loads, the electrification of new end uses can become a long-term challenge for the power system. For example, in a scenario with high EV penetration, unmanaged charging could result in a sizeable increase (over 30%) in peak power draw (IEA, 2017d). Electricity price structure can become a barrier to appropriate sector coupling: if fixed and inelastic charges form a large share of the electric bill, consumers are less likely to adopt behaviours good for the entire system (*e.g.* taking advantage of periods of VRE abundance).

Policy makers in charge of energy sector planning should evaluate the most cost-effective mix of solutions to deal with the variability of energy production in systems with very high shares of VRE. The options span grid infrastructure (fuel, electricity, district heating grids), stationary long- and short-term energy storage, sector coupling options (electric vehicles, synthetic fuels, electric heating, etc.) and energy efficiency measures. Policies should evaluate technologies based on their real environmental benefits and costs.

Cost-efficient sector coupling would require better monitoring and control of where, when and how electricity is being used. Digitalisation is essential in managing a more complex system with a higher penetration of VRE. Aggregated electric heat options and vehicles could participate in the wholesale and system services markets. To promote digitally-enabled aggregate smart charging, regulators and policy makers would have to enable business models that deliver some combination of time-based price signals, control signals and aggregation enabled by data analytics and controls for large numbers of users.

Figure 5.5. Sector coupling



P2X = Power-to-X.

Electricity is already commonly used for heat (especially for space and water heating, as well as electric cooking) and accounts for about 6% of global heat consumption. Most cooling demand (*e.g.* air conditioning and refrigeration) is also met through electricity.

The further electrification of heating is now being considered in many countries, mostly as a decarbonisation option in combination with a rising share of renewable generation. At the same time, demand for electricity for cooling is on the rise. Electrification options for space heating include electric boilers, electric radiators or heat pumps, either in individual or collective heating systems such as district heating (DH) networks. In industrial heat applications, many technologies can be used, including induction, micro-waves, Foucault currents, arc furnaces or plasma torches.

This rising demand for electricity for heating and cooling could strain the power sector at times of peak demand. Seasonal imbalances in the net load may be aggravated by the electrification of space and water heating in particular. However, electrification also has the potential to provide enhanced flexibility to the system. For example, electric boilers (in some cases combined with thermal storage) are already used in Denmark in district heating schemes during times of wind surplus to avoid curtailment. It is therefore important that policy makers consider how electrification can be accomplished in a system-friendly way.

Heat pumps (which can also be used for cooling purposes) provide a particularly efficient option, both for individual applications and in industry and district heating. However, they have higher capital costs than electric or fossil fuel boilers. The purchase and installation of heat pumps is therefore incentivised in a number of European countries under policies such as Germany's market incentive programme, the United Kingdom's renewable heat incentive and France's heat funds. As a result of these and similar policies, in 2016 heat pump sales in Europe grew by nearly 1 million, a 12% increase from 2015 levels (IEA, 2017a).

However, at present these policies are focused on growing the heat pump market in general rather than ensuring that heat pumps provide system services. In particular, more incentives may be needed to combine heat pumps (*e.g.* in district heating) with large thermal storage – both to store surplus VRE electricity to subsequently elevate its temperature for end-use purposes. Thermal storage is a cheap and flexible demandside resource, allowing a shift between grid energy consumption and use of hours, days and even months. Cold storage (*e.g.* via ice or chilled water) can also help air conditioning systems operate in a system-friendly way.

Transport

The sales of electric vehicles (EVs) hit a new record in 2016. Of 750 000 plug-in EV sold, 60% were batteryelectric (the remaining were plug-in hybrid EVs). The global stock of electric cars has reached 2 million units in circulation (IEA, 2017d). While their deployment is still at an early phase, they are projected to have a larger role in the future, with more than 157 million vehicles circulating in 2030, for a total electricity consumption of 165 TWh (1.5% of total electricity demand) (IEA, 2017d).

To ensure the grid is well-prepared for EV charging, careful system planning is crucial. For example, it is important to install electric vehicle supply equipment (EVSE) in areas where both the projected impact is low (due, for example, to a robust distribution grid) and utilisation throughout the day is expected to be high. With rising shares of residential solar PV and falling stationary battery costs, solutions to incentivise selfconsumption may help to reduce the impact of sector coupling on distribution grids.

EVs can assist their own integration by providing valuable system services. Managed charging of EVs can help increase VRE value, for example, by ensuring that energy is consumed at times of high VRE production. Vehicle to Grid (V2G) enabling technologies allow vehicles to provide system services to the grid. To study this option, the UK government has awarded almost USD 42 million (GBP 30 million) to 21 projects aimed at using electric vehicles to feed energy back to the grid. In one of these projects, electric equivalents will replace Royal Mail vans and Addison Lee taxis in Oxford (Gov.uk, 2017).

Use of electricity in industrial processes and synthetic fuels

Electricity can replace fossil fuels in industry and help reduce its energy-related – and, in some cases, processrelated – greenhouse gas emissions, while providing enhanced flexibility to the system. Low-cost electricity at times of VRE abundance could make this solution attractive, but would depend on the level of taxes and levies.

While some industrial loads are easily interruptible, others are not and create inflexible loads. However, flexibility can be introduced through innovative interventions, as shown by an aluminium smelter conversion in Essen, Germany. Insulation and active heat management allow the aluminium production process to adjust to fluctuating amounts of electricity from VRE. The output can be varied by 25% (up and down) with no risks to production.

Sector coupling can be achieved through the production of hydrogen or hydrogen-rich chemicals serving as feedstock, process agents or fuels (see absorbing strategies in Box 5.4). The rapid cost reductions of solar and wind today make the production of hydrogen through water electrolysis cost-competitive with its production from fossil fuels (IEA, 2017e).

An important example of such technology development, supported by government, is the Swedish Hydrogen Breakthrough Steel Making (HYBRIT) project, a joint venture of the Swedish iron-ore mining company, LKAB; the steel manufacturer, SSAB; and Vattenfall. The project aims to develop fossil-free steel making, utilising low-cost VRE to produce hydrogen for use in steel making for reducing iron ores, replacing almost all coal and natural gas in the process. A pre-feasibility study, conducted between 2016 and 2017, gave the clearance for the next phase of the project. In 2018, a pilot plant for fossil-free steel production will be designed. The pilot phase is planned to last until 2024, while the demonstration phase will end in 2035 (SSAB, 2018). Such innovative approaches can be part of a cohesive strategy to enhance system flexibility.

Power-to-gas or Power-to-liquids (commonly named Power-to-X [P2X]) technologies combine hydrogen with carbon or nitrogen to produce fuels for end-use sectors. Producing storable energy carriers such as hydrogen or, better, synthetic fuels can increase the long-term value of VRE. Interest in P2X technologies has emerged primarily from polices that mandate the decline of the carbon intensity of fuels, and opportunities are being strengthened for production pathways based on renewable energy and carbon sources. Fuels produced via P2X are not yet in commercial use and are still subject to ongoing research and development. These technologies may be a solution to decarbonize sub-sectors where direct electrification may be challenging, as with airplanes and ships (IEA, 2017f).

5.4 CONCLUSION

The characteristics of variable renewables from other sources of electricity call for changes to traditional ways of operating and planning the power system. These changes will come in the form of policies and measures to integrate a growing share of VRE into the power system, a process known as system integration of renewables (SIR).

In recent years, VRE penetration has increased in many countries, thanks to decreasing costs, enabling policy frameworks, and political objectives. Their experiences display the impacts of VRE in the power system. The first lesson learnt in this process has been that integration challenges appear progressively as the VRE share grows, suggesting that policy makers and regulators should adopt SIR policies gradually. The increasing impact of VRE on the power system can be categorised by phases to identify the main challenges related to VRE integration (Section 5.1.3). At the same time, SIR policies should be linked to VRE policies, to reap the benefits of a coordinated progress.

The rising share of VRE affects the power system in its technical, institutional, and economic aspects. Policy makers should consider these interplays, identifying links and barriers between the three realms. SIR measures, at high shares of VRE, should not be adopted separately, but in policy packages that address the three levels of the power system.

Table 5.3 shows the area of policy intervention, disaggregated by phase and layer of the power system, with relevant examples.

Table 5.3. Areas of policy intervention relevant to system integration of renewables

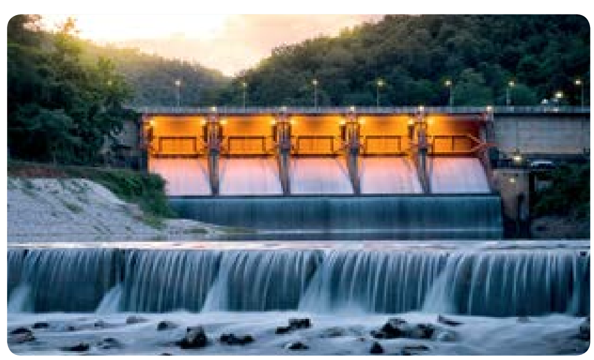
Area of policy intervention	Example
PHASE 1 & 2	
Development or upgrading of grid codes	The development of harmonised European Network Codes is a good-practice example of forward-looking grid-code development with broad stakeholder participation, which can minimize costs from grid codes compliance
Incorporation of VRE in system operations	Red Eléctrica de España, Spain's TSO, established a new control centre to improve management of renewable energy resources. The centre helps maximise VRE production while ensuring system reliability.
Optimised expansion of the grid	South Africa Government simplified the procedure of environmental impact assessment for VRE projects sited in Renewable Energy Development Zones where VRE development is considered most appropriate strategically.
System-friendly VRE – Location	China's FiT scheme differentiates according to resources quality, providing higher remuneration per unit of energy for areas with lower wind speeds or less sunlight.
System-friendly VRE – Technology mix.	Technology-specific auctions can be designed to achieve an optimal balance for the system. In South Africa, the volume of VRE procured in technology-specific auctions is set based on long-term system planning.
PHASE 3 & 4	
Hardware	
Advanced power plant flexibility	In its 13th Five-Year Plan, China commits to retrofit 133 GW combined heat and power and 86 GW condensing coal-fired plants to enhance their operational flexibility and environmental performance by 2020. This represents about one-fifth of the installed coal-fired capacity in China.
Demand-side management	The Brazilian energy regulator ANEEL has mandated distribution companies to offer customers the choice of installing a smart meter. The offer must highlight the benefits of access to enhanced information, more tariff options and remote connection management.
Energy storage	High investment costs are a barrier to residential storage deployment. Germany's support program for residential storage is based on low-interest loans and investment grants for PV-battery systems or PV-retrofits equipped with residential batteries.
Grid infrastructure	The RIIO programme, adopted in the UK, aims to guarantee the best investments for the network, at a fair price, setting clear performance targets for operators.
System friendly VRE - Optimising the generation time profile	Support mechanisms incorporate a time signal through partial exposure to market prices (*e.g.* fixed feed in premiums) or by adjusting remuneration according to time of delivery. One example is the adoption of time-of-delivery tariffs in power purchase agreements in California.
System friendly VRE - Increasing self-consumption	In Denmark, net metering is calculated on an hourly basis. This implicitly incentivises household consumption to match solar PV production.
System friendly VRE – System services	In Spain, since February 2016, wind energy can provide ancillary services, providing balancing through close negotiations to delivery time.

Key takeaways:

- New challenges arise for the power system as the share of VRE increases. Policies for system integration of renewables (SIR) policies encompass those measures that are needed to ensure a sound and cost-effective integration of wind and solar power.
- Because system integration challenges emerge gradually as VRE grows in the power system, it is advisable to meet those challenges gradually. Co-ordination of VRE deployment and system integration measures is crucial to operate the system in a cost-effective, reliable and safe manner.
- The very first VRE plants usually do not have a significant effect on the system (depending on its size). But as the presence of VRE begins to change the shape of the net load, new or revised grid codes, improved system operations, and coordination of grid and VRE deployments may become necessary.
- A set of targeted measures is sufficient at first but at higher shares of VRE a systematic overhaul is needed (Phase 3). Flexibility becomes increasingly valuable to the power system. The complexity of power systems requires technical capacity, a properly tuned market and an institutional framework in which roles and responsibilities are clearly and rationally defined, in order to make technical feasible, financially attractive and system-wide recognized the deployment of flexible resources, which allow the deployment of higher shares of VRE.

Table 5.3. Areas of policy intervention relevant to system integration of renewables (continued)

Area of policy intervention	Example
PHASE 3 & 4	
Architecture	
Change in roles and responsibilities	Mexico recently implemented a comprehensive reform of its energy sector and state-owned electric utility, CFE. This reform was conducive to the cost-effective uptake of VRE, thanks to the definition of roles and responsibilities that avoided conflicts of interest.
Integrated planning	The Danish approach to energy policy is characterised by holistic planning, emphasising flexible resources and cross-sectoral electrification. The grid and market structures are reshaped continuously to handle increasing VRE production.
Enhanced co-operation between system stakeholders	The Council of European Energy Regulators has published principles for cooperation among transmission and distribution system operators, as well as related regulatory arrangements in the areas of governance, network planning and system operations.
Software	
Resource adequacy instruments	Capacity remuneration mechanisms have recently begun to function in the United Kingdom (2015) and France (2017). Other European countries, as well as Japan, are currently implementing or considering such instruments.
More flexible short-term trading	The German government passed a regulatory package for the country's "Energy Market 2.0" which aims, among other measures, to ensure efficient power system operations (by improving the temporal accuracy of price signals), to ensure security of supply, and to open the market to demand-side management, electric vehicles and storage.
Improved system services procurement	National Grid in the United Kingdom has established Enhanced Frequency Response (EFR), a service requiring full power output within one second. A technology-neutral auction for four-year contracts in summer 2016 rewarded eight battery storage projects totalling 201 MW of capacity at a price of USD 9.4-16/MW/h.



06

THE WAY FORWARD

THE WAY FORWARD

Impressive progress has been made globally in the development and deployment of renewable energy, especially in the power sector, where, in the past five years, renewables have accounted for well over half of new power capacity. Policy has played a key role in creating markets for renewable energy and in driving growth in deployment. Nearly all countries have at least one renewable energy target and the number of countries adopting related policies tripled to almost 150 between 2004 and 2017.

A wide range of policies has been adopted to support the growth of renewable energy. The specific nature of those policies in a given country depends on the maturity of the sector, the particularities of the market segment, and wider socio-economic conditions. As deployment of renewable energy has grown and the sector has matured, policies must adapt and become more sophisticated to ensure the smooth integration of renewables into the wider energy system - including the end-use sectors - and a cost-effective and sustainable energy transition. A wider mix of policies has also become relevant as countries look to the socio-economic dimension of the energy transition. Besides deployment, an enabling policy mix covers policies related to education and training, industry, labour, investment promotion and R&D, among others.

As governments consider the right mix of policies for their specific context, this report offers insights on recent developments and trends, which are summed up in this concluding chapter. Recognising the need for a holistic approach to policy making for the energy transition, the chapter also presents a new classification of policies that captures the multitude of policy measures needed for the energy transition, an array that extends well beyond the energy sector itself.

RENEWABLE ENERGY POLICIES MUST FOCUS ON END-USE SECTORS

Policy support for renewables has historically focused primarily on power generation, while support for renewables in the heating and cooling and transport sectors has been less dynamic. Dedicated policies and measures to support renewable energy deployment in all sectors will be crucial to achieve an energy transition that is in alignment with the national and climate objectives.

THE USE OF RENEWABLE ENERGY FOR HEATING AND COOLING REQUIRES GREATER POLICY ATTENTION

Renewables can play a key role in the decarbonisation of heat supply. But to achieve this, dedicated policies and measures are needed on the national and sub-national levels. Those policies must reflect local conditions (*e.g.* building stock, industrial heat demand, resource potentials) and context-specific barriers. Measures to support renewable heat include:

- *Dedicated targets* for renewables in heating and cooling and strategies to achieve the set targets.
- *Mandates and obligations* (*e.g.* for solar water heaters) to offer greater certainty of increased deployment. Building codes that set energy performance requirements can also support renewable heating and cooling and be used to align energy efficiency with renewable heat requirements.
- *Fiscal and financial incentives* to reduce the capital costs of renewable-based heat technologies, and to create a level playing field with fossil fuels. These can also be used to support district energy infrastructure, which then allows the integration of multiple renewable heat options.
- *Heat generation–based incentives*, a more recent addition to the array of policy tools, to provide support over long periods of time.
- *Carbon/energy taxes* to provide important price signals and reduce externalities, recognising that these may be politically difficult to implement, especially given that energy-intensive industries often benefit from exemptions.

POLICIES IN THE TRANSPORT SECTOR REQUIRE FURTHER DEVELOPMENT

Decarbonising the transport sector is key to decarbonising the energy sector as a whole. Successful decarbonisation will depend on fundamental changes in the nature and structure of transport demand, efficiency improvements, and changes in the energy mix. Not only does the transport segment of the broader energy transition require technology developments, but also behavioural change and a major policy push. Policy considerations include:

- *A need of integrated policies that address three dimensions of renewable transport:* the availability of energy carriers and fuels produced from renewable energy sources; the deployment of vehicles capable of running on renewable energy fuels; and the development of infrastructure for the distribution of energy and fuel.
- *Policies to level the playing field* for renewable energy transport options, notably by reforming fossil fuel subsidies and putting a price on carbon. Fuel standards that encompass life-cycle reductions in emissions of greenhouse gases and sustainability criteria are other technology-neutral measures that can facilitate decarbonisation of transport.
- *Blending mandates* to provide guaranteed demand for biofuels and thereby encourage investment. For blending mandates to increase, fleet standards may have to be adapted to accommodate higher blends.
- *Financial instruments* to encourage research and development as well as demonstration of less mature renewable fuels (*e.g.* advanced biofuels, power-to-X) that are critical in certain transport sub-sectors (long-haul transport, aviation and shipping). Low-carbon fuel targets and sub-targets will be needed to ensure at least minimum shares for these fuels.
- *Closer collaboration* among decision makers in energy and transport to align goals and facilitate integrated planning and policy design.

POLICIES IN THE POWER SECTOR WILL HAVE TO CONTINUE TO EVOLVE TO ADDRESS NEW CHALLENGES

Targets for renewable electricity provide a critical policy signal for investment, but for them to be effective, they need to be supported by dedicated policies and measures. The strong correlation between policy and investment flows demonstrates the necessity of maintaining a stable, predictable, yet adaptable policy environment that underpins the vitality and sustainability of the renewable energy sector. Policy considerations include:

- *Administratively set pricing policies* (feed-in tariffs and premiums), continuously adapted to changing market conditions and accompanied by regular tariff adjustments to reflect the falling cost of technology.
- *Auctions* are being increasingly adopted, given their ability for real-price discovery. Auction prices in 2016 for electricity generated from solar PV were a fifth of what they were in 2010. Prices for onshore wind fell by nearly half in the same period. However, the success of an auction in achieving deployment and development objectives depends on its design and proper implementation.
- In the choice between an administratively set or a competitively set pricing policy, an important consideration is that no one policy can serve as the preferred approach in all contexts. The proper choice of policy instrument must depend on specific country conditions, the state of the energy market, technology, and the objectives to be achieved. The design of the policy instrument selected and its proper implementation are key to its success.
- *Quotas and mandates*, generally supported by tradable renewable energy certificates, to enable targets to cascade down to electricity producers and consumers. To ensure the effectiveness of quotas and certificates, a robust framework to monitor and penalise non-compliance is needed.
- *Net metering and net billing* to support distributed generation. Careful consideration is needed to avoid jeopardising the ability of the wider power system to recover costs and creating cross-incentivisation among customers who self-consume and those who do not.
- *Fiscal and financial incentives* to support regulatory measures, such as subsidies, grants and tax incentives. Such measures are especially important in the access context where they complement regulations governing the right to generate and sell electricity, tariff-setting and grid-connection. Equally important are *quality-assurance frameworks, measures to facilitate access to finance, capacity building and linking energy services to livelihoods*.
- *Voluntary and corporate purchase programmes* for renewable energy. These increasingly important parts of the energy transition are often complemented by awareness campaigns highlighting the benefits of renewable energy.

MEASURES ARE NEEDED TO SUPPORT THE INTEGRATION OF VARIABLE RENEWABLE ENERGY

As growing amounts of electricity are generated from variable renewable energy (VRE) sources, action must be taken to ensure that the power system will be able to fully benefit the newly generated electricity, a process known as system integration of renewables.

- Successful system integration of VRE requires policies and strategies that take into account the unique characteristics of VRE technologies in order to minimise negative effects, to maximise the benefits they confer and to improve the cost-effectiveness of the power system.
- Integration challenges emerge gradually as the role of VRE within the power system grows, pointing to the advisability of a graduated approach to integrating VRE. Co-ordination of VRE deployment and SIR measures is crucial to operate the system in a cost-effective, reliable and safe manner.
- A set of targeted measures is sufficient at first. At higher shares of VRE, flexibility becomes a valuable characteristic in power systems. Eventually, significant changes in the power system may be needed to enhance system flexibility, the technical capability of the system, system operations, market design and institutional architecture.
- As the transport, heating and cooling, and power sectors become increasingly integrated, cross-sectoral decision making and policy design will be crucial to leverage synergies and accelerate the energy transition.

ACHIEVING THE ENERGY TRANSITION REQUIRES POLICIES THAT ARE MORE COMPREHENSIVE THAN THOSE DEVISED FOR THE ENERGY SECTOR ALONE

Rapid change in the energy field calls for a new way of classifying policies. The energy transition involves the transformation of the energy system and the socio-economic structure upon which it is built. Policies to support the transition need to adopt a holistic approach that accounts for both these dimensions. As renewables have transitioned from niche to mainstream, the policies that drive the transition must cover not just the deployment of renewables, but also their integration into the broader energy system and economy-wide policies that affect the sustainability and pace of the transition. Table 6.1 presents an updated classification of renewable energy policies based on three major categories[1]:

Direct policies and instruments are used to support the development and deployment of renewable energy technology and products, both in the general sense and in the context of expanding access to electricity and other forms of clean energy. These are typically classified as *push, pull,* and *fiscal* and *financial*. Push policies mandate certain actions such as electricity quotas, use of solar water heaters or biofuels mandates, rural electrification, and the popularisation of clean cookstoves or biogas. Pull policies incentivise certain actions, *e.g.* through pricing or regulation. Fiscal and financial policies and instruments include tax incentives, grants, and subsidies.

Integrating policies incorporate the use of renewables and energy efficiency in the heating and cooling, transport, and power sub-sectors into the larger energy and economic system and into consumers' daily lives. This category includes policies to ensure the development of the infrastructure needed (*e.g.*, transmission and distribution networks, charging stations for electric vehicles, district heating infrastructure), policies to enhance system flexibility (*e.g.*, support for energy storage deployment), to promote sector coupling and to support research, development and demonstration. Measures to encourage the economy to take full advantage of successive steps in the energy transition are also needed to ensure a smooth and sustainable energy transition for all.

Enabling policies contribute to a wider environment for renewable energy development. These include policies that issue clear signals to stakeholders, level the playing field for renewables (*e.g.*, fossil fuel subsidy reforms, carbon pricing policies), manage land use, ensure the reliability of technology (*e.g.*, quality and technical standards, certificates), facilitate access to affordable financing at multiple levels and support labour-market needs (through direct measures and through education and training). The development of a local industry can be supported through industrial policy (*e.g.*, leveraging local capacity) and trade policies (*e.g.*, trade agreements, export promotion). Finally, renewables can be supported through environmental and climate policies and regulations.

Some measures can aid in both enabling and integrating renewable energy. These include the establishment of a supportive governance and institutional architecture (*e.g.*, streamlined permitting procedures, dedicated institutions for renewables), awareness programmes to induce behavioural change, and the coupling of renewable energy policies with livelihood development. Social protection policies to address disruptions are also needed for a sustainable energy transition.

This classification attempts to capture renewable energy policy in the context of energy sector policies, and link them to broader growth and development objectives. The classification is presented to facilitate a harmonised mechanism for policy tracking. Table 6.1 contains a non-exhaustive list of examples to clarify the classification. Continued research on the topic, inspired by policy implementation and development in the sector, would further refine the classification to inform holistic policy-making in support of an accelerated energy transition.

1 The table presents examples of policies and measures in each category of policies but it is not exhaustive.

Table 6.1. Updated classification of policies

<table>
<tr><th colspan="2">Policies to achieve the energy transition</th><th>Deployment (installation and generation) of renewables in the general context</th><th>Deployment (installation and generation) of renewables in the access context (including energy services)</th><th>Maximisation of socio-economic development from renewable energy deployment</th></tr>
<tr><td rowspan="3">Direct policies</td><td>Push</td><td>■ Binding targets for use of renewable energy
■ Electricity quotas and obligations
■ Building codes
■ Mandates (e.g., solar water heaters, renewables in district heating)
■ Blending mandates</td><td>■ Rural electrification targets, strategies, programmes
■ Clean cooking strategies, programmes
■ Biogas digester programmes</td><td rowspan="3">Deployment policies designed to maximise benefits and ensure a sustainable transition (e.g., communities, gender) including requirements, preferential treatment and financial incentives provided to installations and projects that help deliver socio-economic objectives</td></tr>
<tr><td>Pull</td><td>■ Regulatory and pricing policies (e.g., feed-in tariffs and premiums, auctions)
■ Tradable certificates
■ Instruments for self-consumption (e.g., net billing and net metering)
■ Measures to support voluntary programmes</td><td>■ Regulatory and pricing policies (e.g. legal provisions, price/tariff regulation)</td></tr>
<tr><td>Fiscal and financial</td><td>■ Tax incentives (e.g., investment and production tax credits, accelerated depreciation, tax reductions)
■ Subsidies
■ Grants</td><td>■ Tax incentives (e.g., reduction)
■ Subsidies
■ Grants
■ Concessional financing
■ Support for financial intermediaries</td></tr>
<tr><td colspan="2" rowspan="3">Integrating policies</td><td>■ Measures to enhance system flexibility (e.g., promotion of flexible resources such as storage, dispatchable supply, load shaping)</td><td colspan="2">■ Policies for integration of off-grid systems with main-grid
■ Policies for mini-grids and smart distributed energy systems
■ Coupling renewable energy policies with efficient appliances and energy services</td></tr>
<tr><td colspan="3">■ Policies to ensure the presence of needed infrastructure (e.g., transmission and distribution networks, electric vehicles charging stations, district heating infrastructure, road access)
■ Policies for sector coupling
■ RD&D support for technology development (e.g., storage)</td></tr>
<tr><td colspan="3">■ Better alignment of energy efficiency and renewable energy policies
■ Incorporation of decarbonisation objectives into national energy plans
■ Adaptation measures of socio-economic structure to the energy transition</td></tr>
<tr><td colspan="2" rowspan="3">Enabling policies</td><td>■ Policies to level the playing field (e.g., fossil fuel subsidy reforms, carbon pricing policies)
■ Measures to adapt design of energy markets (e.g., flexible short-term trading, long term price signal)
■ Policies to ensure the reliability of technology (e.g., quality and technical standards, certificates)</td><td colspan="2">■ Industrial policy (e.g., leveraging local capacity)
■ Trade policies (e.g., trade agreements, export promotion)
■ Environmental and climate policies (e.g., environmental regulations)</td></tr>
<tr><td colspan="3">■ National renewable energy policy (e.g., objectives, targets)
■ Policies to facilitate access to affordable financing for all stakeholders
■ Education policies (e.g., inclusion of renewable energy in curricula, coordination of education and training with assessments of actual and needed skills
■ Labour policies (e.g., labour-market policies, training and retraining programmes)</td></tr>
<tr><td colspan="3">■ Land-use policies
■ RD&D and innovation policies (e.g., grants and funds, partnerships, facilitation of entrepreneurship, industry cluster formation)
■ Urban policies (e.g., local mandates on fuel use)
■ Public health policies</td></tr>
<tr><td colspan="2">Enabling and integrating policies</td><td colspan="3">■ Supportive governance and institutional architecture (e.g., streamlined permitting procedures, dedicated institutions for renewables)
■ Awareness programmes on the importance and urgency of the energy transition geared toward awareness and behavioural change
■ Social protection policies to address disruptions
■ Measures for integrated resource management (e.g., the nexus of energy, food and water)</td></tr>
</table>

Note: RD&D = research, development and demonstration.

REFERENCES FOR CHAPTER 1

FERC (Federal Energy Regulatory Commission) (2018), US Department of Energy, "FERC Issues Final Rule on Electric Storage Participation in Regional Markets", press release, 15 February, FERC, Washington, DC, www.ferc.gov/media/news-releases/2018/2018-1/02-15-18-E-1.asp#.WrPTPmrwapo.

FERC (2017), Integration of Renewables (database), FERC, Washington, DC, www.ferc.gov/industries/electric/indus-act/integration-renew.asp.

Frankfurt School-UNEP Centre/BNEF (2018), Global Trends in Renewable Energy Investment 2018, www.fs-unep-centre.org.

González, Ana María, Harrison Sandoval, Pilar Acosta, & Felipe Henao (2016), "On the Acceptance and Sustainability of Renewable Energy Projects – A Systems Thinking Perspective," *Sustainability, Vol. 8,* MDPI, p. 1171, www.mdpi.com/journal/sustainability.

Government of Fiji (2015), "Government Encourages Investment in Renewable Energy", press release, 4 September, Ministry of Communications, www.fiji.gov.fj/Media-Center/Press-Releases/GOVERNMENT-ENCOURAGES--INVESTMENT-IN-RENEWABLE-ENE.aspx.

Government of Jamaica (2009), *Jamaica's National Energy Policy 2009-2030*, Ministry of Energy and Mining, mstem.gov.jm/sites/default/files/National%20Energy%20Policy.pdf.

Government of Singapore (2017), National Climate Change Secretariat, "Singapore's Approach to Alternative Energy", www.nccs.gov.sg/climate-change-and-singapore/national-circumstances/singapore's-approach-to-alternative-energy.

IEA (International Energy Agency) (2017a), *Energy Efficiency Market Report 2017*, OECD/IEA, Paris, www.iea.org/publications/freepublications/publication/Energy_Efficiency_2017.pdf.

IEA (2017b), *Digitalization & Energy*, OECD/IEA, Paris, www.iea.org/publications/freepublications/publication/DigitalizationandEnergy3.pdf.

IEA (2017c), *Status of Power System Transformation: System Integration and Local Grids* , OECD/IEA, Paris.

IEA (2016), *Medium-Term Renewable Energy Market Report 2016*, OECD/IEA, Paris, www.iea.org/publications/freepublications/publication/MTRMR2016.pdf.

IEA (2011), *Renewable Energy: Policy Considerations for Deploying Renewables*, OECD/IEA, Paris, www.iea.org/publications/freepublications/publication/Renew_Policies.pdf.

IRENA (International Renewable Energy Agency) (2018), *Renewable Power Generation Costs in 2017*, IRENA, Abu Dhabi.

IRENA (2017a), "IRENA Expands Effort to Drive Corporate Renewable Energy Use", press release, 7 June, IRENA, Abu Dhabi, www.irena.org/newsroom/pressreleases/2017/Jun/IRENA-Expands-Effort-to-Drive-Corporate-Renewable-Energy-Use.

IRENA (2017b), *REthinking Energy 2017*, IRENA, Abu Dhabi, www.irena.org/DocumentDownloads/Publications/IRENA_REthinking_Energy_2017.pdf.

IRENA (2017c), *Renewable Energy and Jobs – Annual Review 2017*, IRENA, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/May/IRENA_RE_Jobs_Annual_Review_2017.pdf.

IRENA (2017d), *Untapped potential for climate action: Renewable energy in Nationally Determined Contributions*, IRENA, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Nov/IRENA_Untapped_potential_NDCs_2017.pdf.

IRENA (2016), *Renewable Energy in Cities*, IRENA, Abu Dhabi, www.irena.org/menu/index.aspx?mnu=Subcat&PriMenuID=36&CatID=141&SubcatID=3748.

IRENA (2016a), Renewable Energy Benefits: Measuring the Economics, IRENA, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_Measuring-the-Economics_2016.pdf.

IRENA (2016b), Unlocking renewable energy investment: The role of risk mitigation and structured finance, IRENA, Abu Dhabi, www.irena.org/publications/2016/Jun/Unlocking-Renewable-Energy-Investment-The-role-of-risk-mitigation-and-structured-finance.

IRENA (2015), *The Republic of Marshall Islands: Renewables Readiness Assessment*, 2015, IRENA, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_RRA_Marshall-Islands_2015.pdf.

IRENA (2012), *Financial Mechanisms and Investment Frameworks for Renewables in Developing Countries*, 2012, IRENA, Abu Dhabi, www.irena.org/publications/2013/Jan/Financial-Mechanisms-and-Investment-Frameworks-for-Renewables-in-Developing-Countries.

MIT (MIT Energy Initiative) (2016), *The Value of Aggregators in Electricity Systems*, MIT Center for Energy and Environmental Policy Research, Cambridge, MA, energy.mit.edu/publication/the-value-of-aggregators-in-electricity-systems/.

NLC (National League of Cities) (2016), *Trends in Smart City Development*, National League of Cities, Washington, DC, www.nlc.org/sites/default/files/2017-01/Trends%20in%20Smart%20City%20Development.pdf.

OFGEM (Office of Gas and Electricity Markets) (2017), "Electricity storage under the Renewables Obligation", blog, 13 September, OFGEM, London, www.ofgem.gov.uk/news-blog/our-blog/electricity-storage-under-renewables-obligation (accessed 19 January 2018).

Power for All (2017), "News Release: Power for All Report Pinpoints Policies to Accelerate Energy Access for 1 Billion Rural Poor", press release, 4 April, Power for All, www.powerforall.org/blog/2017/4/4/power-for-all-news-release-policy-call-to-action-from-promise-to-progress (accessed 22 March 2018).

RE100 (2018), Companies, The Climate Group, there100.org/companies (accessed 19 January 2018).

REN21 (2017a), *Advancing the Global Renewable Energy Transition: Highlights of the REN21 Renewables 2017 Global Status Report*, REN21, Paris, www.ren21.net/gsr.

REN21 (2017b), *Renewables 2017 Global Status Report*, REN21, Paris, www.ren21.net/gsr.

REN21 (2016), *Renewables 2016 Global Status Report*, REN21, Paris, www.ren21.net/resources/publications.

REN21 (2015), *Renewables 2015 Global Status Report*, REN21, Paris, www.ren21.net/resources/publications/.

WHO (World Health Organization) (2018), Air Pollution, WHO, Geneva, www.who.int/airpollution/en/ (Accessed 14 February 2018).

REFERENCES FOR CHAPTER 2

Alliance for Green Heat (2017), *State and local Incentives*, Alliance for Green Heat, www.forgreenheat.org/incentives/state.html.

ASEAN Shine (2017), ASEAN regional policy roadmap for harmonization of energy performance standards for air conditioners, ASEAN Shine, Bangkok www.aseanshine.org/asean-shine-task-force/d/asean-regionalpolicy-roadmap-for-harmonization-of-energy-performance-standards-for-air-conditioners.

CEEW (2015), *Clean, Affordable and Sustainable Cooking Energy for India*, CEEW, New Delhi, http://ceew.in/pdf/ceew-clean-affordable-and-sustainable-cooking.pdf.

Energy Transitions Commission (2017), *Better Energy, Greater Prosperity*, energy-transitions.org/sites/default/files/BetterEnergy_fullReport_DIGITAL.PDF.

Euroheat and Power (2017), *Statistics overview country by country 2015 survey*, Euroheat, Brussels, www.euroheat.org/wp-content/uploads/2016/03/2015-Country-by-country-Statistics-Overview.pdf (accessed 16 May 2017).

Eurostat (2017a), *Renewables shares*, Eurostat, Brussels, ec.europa.eu/eurostat/web/energy/data/shares (accessed 16 May 2017).

Eurostat (2017b), *Heating degree days*, Eurostat, Brussels, ec.europa.eu/eurostat/web/energy/data (accessed 16 May 2017).

GIZ (2016), *Meeting Energy Needs with Biogas Technology*, Deutsche Gesellschaft für Internationale Zusammenarbeit, Bonn and Eschborn, Germany, www.giz.de/en/downloads/giz2016-en-biogas-technology.pdf.

Hannon, M. (2015), "Raising the temperature of the UK heat pump market: Learning lessons from Finland", *Energy Policy*, Vol 85/2015, Elsevier, Amsterdam, pp. 369-375.

IEA (International Energy Agency) (2017a), *Renewables 2017 Market Report*, OECD/IEA, Paris, www.iea.org/publications/renewables2017/.

IEA (2017b), *District Energy Systems in China: Options for Optimisation and Diversification*, OECD/IEA, Paris, www.iea.org/publications/freepublications/publication/DistrictEnergySystemsinChina.pdf.

IEA (2017c), *Energy Access Outlook 2017*, OECD/IEA, Paris, www.iea.org/publications/freepublications/publication/WEO2017SpecialReport_EnergyAccessOutlook.pdf.

IEA (2018), *Renewable Heat Policies: Delivering Clean Heat Solutions for the Energy Transition*, IEA Insights Series, OECD/IEA, Paris, www.iea.org/publications/insights/insightpublications/Renewable_Heat_Policies.pdf.

IRENA (International Renewable Energy Agency) (2017), *Renewable Energy in District Heating and Cooling*, IRENA, Abu Dhabi.

IRENA (2016), Renewable Energy Benefits – Decentralised Solutions in the Agri-food Chain, IRENA, Abu Dhabi, www.irena.org/publications/2016/Sep/Renewable-Energy-Benefits-Decentralised-solutions-in-agri-food-chain.

IRENA (2015), *Renewable Energy Policy Brief Brazil*, IRENA, Abu Dhabi, www.irena.org/DocumentDownloads/Publications/IRENA_RE_Latin_America_Policies_2015_Country_Brazil.pdf.

New York State (2017), "Clean Heating fuel credit", www.tax.ny.gov/pit/credits/clean_heating_fuel_credit.htm (accessed 28 June 2017).

Niebling, C. (2017), "Adding Thermal Energy to State Renewable Energy Standards: Opportunity, Status, and Challenges", presentation at REV 2017, 2 October 2017, www.inrsllc.com/REV%202017%20Niebling%20Oct%202%202017.pdf.

NITI Aayog (National Institution for Transforming India) (2017), Draft National Energy Policy, Government of India, New Delhi, niti.gov.in/writereaddata/files/new_initiatives/NEPID_27.06.2017.pdf.

REN21 (2017) *Global Status Report 2017*, REN21, Paris, www.ren21.net/gsr-2017/.

Rycroft, M. (2016), "Solar water heater rollout programme gains momentum", EE Publishers www.ee.co.za/article/solar-water-heater-rollout-programme-gains-momentum.html.

Statistics Sweden (2017), "Consumption of fuels for steam and hot water production, by type of fuel and type of production type. Yearly 1990 – 2016", www.scb.se/en/finding-statistics/statistics-by-subject-area/energy/energy-supply-and-use/annual-energy-statistics-electricity-gas-and-district-heating/ (accessed 4 December 2017).

Solarthermalworld (2017a), *Tunisia: National Subsidy Scheme Prosol Extended to 2020*, Solarthermalworld, www.solarthermalworld.org/content/tunisia-national-subsidy-scheme-prosol-extended-2020 (accessed 7 December 2017).

Solarthermalworld (2017b), *Brazil: Energy Ministry with Big Plans for Solar*, Solarthermalworld, www.solarthermalworld.org/content/brazil-energy-ministry-big-plans-solar (accessed 8 December 2017).

Stori, V. (2017), "Overview of Renewable Heating and Cooling Policy Drivers in the U.S.", presentation at the IEA Renewable Heat Workshop, 7 February 2017, www.iea.org/media/workshops/2017/heatingcooling/Stori_US.pdf.

World Future Council (2016), *Beyond Fire: how to achieve sustainable cooking*, World Future Council, Hamburg, www.worldfuturecouncil.org/file/2016/10/WFC_BeyondFire_web-version.pdf.

WWF (2017), Industrial scale solar heat in South Africa: opportunities in agri-processing and textiles, WWF South Africa, Cape Town, www.wwf.org.za/what_we_do/energy/?21621/Industrialscale-solar-heat-in-SA#.

REFERENCES FOR CHAPTER 3

AFDC (Alternative Fuels Data Center) (2018a), *Fuels and Vehicles*, www.afdc.energy.gov/.

AFDC (2018b), *Flexible Fuel Vehicles*, www.afdc.energy.gov/vehicles/flexible_fuel.html.

BAV (Bundesanstalt für Verwaltungsdienstleistungen) (2017), *Charging infrastructure for electric vehicles in Germany* (Federal funding program, Federal Ministry of Transport and Digital Infrastructure), www.bav.bund.de/SharedDocs/Downloads/DE/Foerderung_Ladeinfrastruktur/Foerderrichtlinie.pdf?__blob=publicationFile&v=5.

EC (European Commission) (2018a), *Sustainability Criteria*, ec.europa.eu/energy/en/topics/renewable-energy/biofuels/sustainability-criteria.

EC (2018b), *Renewable Energy Directive*, ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive.

EC (2017), *Proposal for post-2020 CO_2 targets for cars and vans*, ec.europa.eu/clima/policies/transport/vehicles/proposal_en.

EEA (European Environment Agency) (2018), "Aviation and shipping – Impacts on Europe's environment", *Transport and Environment Reporting Mechanism* (TERM) report, www.eea.europa.eu/publications/term-report.

EPAct (Energy Policy Act) (2018), *Alternative Compliance*, epact.energy.gov/alternative-compliance.

GREET Model. (2017). *The Greenhouse gases, Regulated Emissions, and Energy use in Transportation Model*. greet.es.anl.gov/.

Hochfeld, C. (2016), Post-Fossil Carbon *Neutral Transport: Options by Transport Segments*, Deutsche Gesellschaft für Internationale Zusammenarbeit, Regional Cooperation on Renewable Energy and Energy Efficiency, Brainstorming Workshop REN21/UNIDO, Paris, sadc-energy.sardc.net/attachments/article/273/Post-Fossil-Carbon-Neutral-transport-Christian-Hochfeld.pdf.

Hockenos, P. (2018), "Europe Takes First Steps in Electrifying World's Shipping Fleets", *Yale Environment 360*, e360.yale.edu/features/europe-takes-first-steps-in-electrifying-worlds-shipping-fleets.

IATA (International Air Transport Association) (n.d.), *Climate Change*, www.iata.org/policy/environment/Pages/climate-change.aspx.

IATA (2018), *Sustainable Aviation Fuels – Fact and Figures at a Glance*, www.iata.org/pressroom/Documents/SAF-stats-sheet.pdf.

ICAO (International Civil Aviation Organization) (2018), *Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)*, www.icao.int/environmental-protection/Pages/market-based-measures.aspx.

ICCT (International Council on Clean Transportation) (2017a), *Expanding the Electric Vehicle Market in U.S Cities*, www.theicct.org/publications/expanding-electric-vehicle-market-us-cities.

ICCT (2017b), *Emerging best practices for electric vehicle charging infrastructure*, www.theicct.org/publications/emerging-best-practices-electric-vehicle-charging-infrastructure.

IEA (International Energy Agency) (2018). *Nordic EV Outlook 2018. Insights from leaders in electric mobility. OECD/IEA, Paris,* www.iea.org/publications/freepublications/publication/NordicEVOutlook2018.pdf.

IEA (2017a), *World Energy Balances 2017*, OECD/IEA, Paris, www.iea.org/publications/freepublications/publication/WorldEnergyBalances2017Overview.pdf.

IEA (2017b), *Energy Technology Perspectives – Tracking Clean Energy Progress*, OECD/IEA, Paris, www.iea.org/etp/tracking2017/.

IEA (2017c), *Renewables 2017 – Analysis and Forecasts to 2022*, OECD/IEA, Paris, www.iea.org/publications/renewables2017/.

IEA. (2017d). *Global EV Outlook 2017*. OECD/IEA, Paris, www.iea.org/publications/freepublications/publication/global-ev-outlook-2017.html.

IEA (2017e), *The Future of Trucks – Implications for Energy and the Environment*, OECD/IEA, Paris, www.iea.org/publications/freepublications/publication/TheFutureofTrucksImplicationsforEnergyandtheEnvironment.pdf.

IEA. (2017f). *Market Report Series: Oil 2017*. OECD/IEA, Paris, www.iea.org/publications/freepublications/publication/Market_Report_Series_Oil2017.pdf.

IEA (2017g), *Key World Energy Statistics 2017*, OECD/IEA, Paris, www.iea.org/publications/freepublications/publication/KeyWorld2017.pdf.

IEA (2016), *Life in the Fast Lane: Evolving Paradigms for Mobility and Transportation Systems of the Future*, OECD/IEA, Paris, www.iea.org/media/workshops/2016/egrdtransportsystemsofthefuture/EGRDMtgRationale.

IEA-RETD. (2016). *Non-individual transport – Paving the way for renewable power-to-gas* (RE-P2G). IEA Implementing Agreement for Renewable Energy Technology Deployment (IEA-RETD), Utrecht, iea-retd.org/archives/publications/re-p2g.

IEA-RETD. (2015). *Driving renewable energy for transport – Next generation policy instruments for renewable transport* IEA-RETD, Utrecht, iea-retd.org/wp-content/uploads/2015/12/IEA-RETD-RES-T-NEXT-201511.pdf.

IEA/UIC. (2013). *Railway Handbook 2013 – Energy consumption and CO2 emissions*, OECD/IEA, Paris, uic.org/IMG/pdf/2013_uic-iea_railway_handbook_web_high.pdf.

INL (Idaho National Laboratory) (2012), Vehicle-to-Grid (V2G) *Power Flow Regulations and Building Codes Review by the AVTA*, energy.gov/sites/prod/files/2014/02/f8/v2g_power_flow_rpt.pdf.

IRENA (International Renewable Energy Agency) (Forthcoming). *New Delhi Metro Rail: Turning an entire urban metro system green*, Abu Dhabi, IRENA.

IRENA (2017a), *Renewable Energy and Jobs – Annual Review 2017*, IRENA, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/May/IRENA_RE_Jobs_Annual_Review_2017.pdf.

IRENA. (2017b). *Biofuels for aviation: Technology brief, Abu Dhabi: IRENA*. IRENA, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/IRENA_Biofuels_for_Aviation_2017.pdf.

IRENA (2016a), *The Renewable Route to Sustainable Transport: A working paper based on REmap*, IRENA, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_REmap_Transport_working_paper_2016.pdf.

IRENA. (2016b). *Innovation Outlook: Advanced Liquid Biofuels, Abu Dhabi*: IRENA, Abu Dhabi, www.irena.org/DocumentDownloads/Publications/IRENA_Innovation_Outlook_Advanced_Liquid_Biofuels_2016.pdf.

IRENA. (2015). *Renewable Energy Options for Shipping: Technology Brief. Abu Dhabi: International Renewable Energy Agency (IRENA)*, IRENA, Abu Dhabi, www.irena.org/menu/index.aspx?mnu=Subcat&PriMenuID=36&CatID=141&SubcatID=517.

ITF (International Transport Forum) (2017), ITF Transport Outlook 2017, OECD/ITF, Oslo, read.oecd-ilibrary.org/transport/itf-transport-outlook-2017_9789282108000-en#page1.

ITF (2015), *Policy Strategies for Vehicle Electrification*, OECD/ITF, Oslo, www.itf-oecd.org/sites/default/files/docs/dp201516.pdf.

Kamsvag, N.R. (2018). "Ripple to tidal wave: Norway is currently the world's demonstration project for green transport solutions", *The Times of India*, blogs.timesofindia.indiatimes.com/toi-edit-page/ripple-to-tidal-wave-norway-is-currently-the-worldsdemonstration-project-for-green-transport-solutions/.

Kempton et al. (2017). "Public Policy for Electric Vehicles and for Vehicle to Grid Power", *OpenEdition*, journals.openedition.org/rei/5999?lang=en#tocto2n6.

Klimafonds. (2017) *Leitfaden E-Mibilität für Private*. www.klimafonds.gv.at/assets/Uploads/Downloads-Frderungen/E-Mobilitaet/Private-E-PKW/LF-Emobilitaet-fuerPrivate-2017.pdf.

Lambert, F. (2018). "Large 'Tesla ships' all-electric container barges are launching this autumn", *Electrek*, electrek.co/2018/01/12/large-tesla-ships-all-electric-barges/.

Lasek, M. (2017), "What Does IMO's 0.50% Sulphur Cap Decision Mean for the Bunker Supply Chain?", *Ship & Bunker*, shipandbunker.com/news/features/industry-insight/174369-what-does-imos-050-sulphur-cap-decision-mean-for-the-bunker-supply-chain.

Lloyds-UMAS (Lloyd's Register and University Maritime Advisory Services) (2017), *Zero-Emission Vessels 2030*, www.lr.org/en/insights/global-marine-trends-2030/zero-emission-vessels-2030/.

Low Carbon Technology Partnerships initiative. (2015). *Brazil Low-carbon Country Case Study*, openknowledge.worldbank.org/handle/10986/19286.

Merk, O. (2017). "Climate change: What about shipping", *Medium*, medium.com/@OECD/climatechange-what-about-shipping-471a13444fdd.

OECD (Organisation for Economic Co-operation and Development) (2014), *The Cost of Air Pollution: Health Impacts of Road Transport*, OECD, Paris, www.oecd.org/env/the-cost-of-air-pollution-9789264210448-en.htm.

OECD Observer. (2018). *Climate change: Is shipping finally on board?* www.hellenicshippingnews.com/climate-change-is-shipping-finally-on-board/.

PPMC Paris Process on Mobility and Climate (2017), *A Global Macro Roadmap Outlining An Actionable Vision of Transport Decarbonization*, www.ppmc-transport.org/wp-content/uploads/2017/02/An-actionable-Vision-of-Transport-Decarbonization_03172017_web.pdf.

REN21. (Forthcoming). Global Status Report 2018, Paris: REN21 Secretariat.

REN21. (Continuous) REN21 Policy Database.

REN21. (2017). Global Status Report 2017, Paris, REN21 Secretariat. www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf.

Richardsen, P.W. (2016). "Developing A Roadmap for Green Coastal Shipping", *DNV GL*, www.dnvgl.com/news/developing-a-roadmap-for-green-coastal-shipping-75090.

Robinson, Aaron, U.A. (2017). Personal communication with REN21, United Airlines.

SLoCaT (2017), SLoCaT (Partnership on Sustainable, Low Carbon Transport) (Forthcoming). *E-Mobility Trends and Target. Transport Knowledge Base (TraKB) Version 0.1*, www.slocat.net/docs/1916.

TransportPolicy.net. (2018). *BRAZIL: FUELS: BIOFUELS* www.transportpolicy.net/standard/brazil-fuels-biofuels/.

UIC (International Union of Railways) (2017), *Railway Handbook 2017*, uic.org/IMG/pdf/handbook_iea-uic_2017_web2-2.pdf.

UN (United Nations) (2017), *New Urban Agenda, Nairobi: United Nations*.

UN (2016), *Mobilizing Sustainable Transport for Development*, sustainabledevelopment.un.org/content/documents/2375Mobilizing%20Sustainable%20Transport.pdf.

UNICA (The Brazilian Sugarcane Industry Association) (2018), *Motor Vehicles, Automobiles – Annual Sales and Fleet Statistics*, www.unicadata.com.br/listagem.php?idMn=55.

USDA Foreign Agricultural Service. (2017). *Biofuel Mandates in the EU by Member State in 2017*, Gain Publication, Berlin, gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuel%20Mandates%20in%20the%20EU%20by%20Member%20State%20in%202017_Berlin_EU-28_6-1-2017.pdf.

Voegele, E. (2018), "Brazil establishes national biofuels policy", biomass magazine, biomassmagazine.com/articles/14948/brazil-establishes-national-biofuels-policy.

VTPI (Victoria Transport Policy Institute) (2017), *Transportation Cost and Benefit Analysis II – Congestion Costs*, www.vtpi.org/tca/tca0505.pdf.

Waltz, M. (2017). *Atmosphärische Spannungen*. www.deutschlandfunk.de/flugverkehr-contra-klimaschutzatmosphaerische-spannungen.724.de.html?dram:article_id=390693.

WHO (World Health Organization) (2018), Road Traffic Injuries, www.who.int/mediacentre/factsheets/fs358/en/.

WSDOT (Washington State Department of Transportation) (2018), *Washington State Ferries Environmental Program*, www.wsdot.wa.gov/Ferries/Environment/.

REFERENCES FOR CHAPTER 4

Adebare, A. (2016), *Assessment of Renewable Power Purchase Obligations In India*, Mondaq, www.mondaq.com/india/x/546712/Renewables/Assessment+Of+Renewable+Power+Purchase+Oblgatons+In+Inda.

BNEF (Bloomberg New Energy Finance) (2018), Global Corporate Database, Accessed 4 February 2018.

BP (British Petroleum) (2018), *Electricity*, www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/electricity.html.

CEER (Council of European Energy Regulators) (2016), *Key Support Elements of RES in Europe: Moving Towards Market Integration, CEER*.

CEM (Clean Energy Ministerial) (n.d.), *Corporate Sourcing of Renewables,* CEM.

Climatescope (2016), *Nepal Renewable Energy Subsidy Policy,* Climatescope, global-climatescope.org/en/policies/#/policy/3959.

Cox and Esterly (2016), *Renewable Electricity Standards: Good Practices and Design Considerations*, NREL, Golden, CO, www.nrel.gov/docs/fy16osti/65507.pdf.

Environmental Finance (2016), RECs in Reverse, Environmental Finance, www.environmental-finance.com/content/analysis/recs-in-reverse.html.

ESMAP (Energy Sector Management Assistance Programme) (2016), *Comparative Analysis of Approaches to Geothermal Resource Risk Mitigation*, documents.worldbank.org/curated/en/621131468180534369/pdf/105172-ESM-P144569-PUBLIC-FINAL-ESMAP-GeoRiskMitigation-KS024-16-web.pdf.

EUEI PDF, EnDev and Practical Action (2018), National Electrification Approaches – Review of Options, endev.info/content/File:National_Approaches_to_Electrification_-_Review_of_Options.zip.

Frankfurt School UNEP Centre/BNEF (2016), *Global Trends in Renewable Energy Investment 2016*, Frankfurt School UNEP Centre/BNEF, fs-unep-centre.org/sites/default/files/publications/globaltrendsinrenewableenergyinvestment2016lowres_0.pdf.

Gipe, P. (2012), "Italy Abandons RPS, Adopots System of Feed-in Tariffs", Renewable Energy World, 6 December, www.renewableenergyworld.com/articles/2012/12/italy-abandons-rps-adopts-system-of-feed-in-tariffs.html.

GOGLA (2016), "GOGLA and partners take first step to address tariff exemption confusion in EAC"*, Gogla.org*, www.gogla.org/news/gogla-and-partners-take-first-step-to-address-tariff-exemption-confusion-in-eac.

IDCOL (Infrastructure Development Company Limited) (2018), IDCOL SHS Installation Under RE Program, IDCOL, www.idcol.org/old/bd-map/bangladesh_map/.

IEA (International Energy Agency) (2015), *World: Electricity and Heat for 2015*, OECD/IEA, Paris, www.iea.org/statistics/statisticssearch/report/?year=2015&country=WORLD&product=ElectricityandHeat.

IEA-PVPS (2016), *Review and Analysis of PV Self-Consumption Policies*, IEA-PVPS, nachhaltigwirtschaften.at/resources/iea_pdf/reports/iea_pvps_task1_review_and_analysis_of_pv_self_consumption_policies_2016.pdf.

IISD and GSI (2015), *Case Study: India's Accelerated Depreciation Policy for Wind Energy*, IISD and GSI, www.iisd.org/sites/default/files/publications/india-accelerated-depreciation-policy-wind-energy-case-study.pdf.

IRENA (International Renewable Energy Agency) (2018a), *IRENA REsource: capacity and generation*, resourceirena.irena.org/gateway/dashboard/?topic=4&subTopic=16.

IRENA (2018b), *Renewable Power Generation Costs in 2017*, IRENA, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf.

IRENA (2018c), REmade Index.

IRENA (2017a), *REthinking Energy 2017*, IRENA, Abu Dhabi, www.irena.org/documentdownloads/publications/irena_rethinking_energy_2017.pdf.

IRENA (2017b), *Renewable Energy Auctions: Analysing 2016*, IRENA, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Jun/IRENA_Renewable_Energy_Auctions_2017.pdf.

IRENA (2017c), *Adapting Market Design to High Shares of Variable Renewable Energy*, IRENA, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/May/IRENA_Adapting_Market_Design_VRE_2017.pdf.

IRENA. (2017d). *Renewable Energy Benefits: Leveraging Local Capacity for Onshore Wind*, IRENA, Abu Dhabi, www.irena.org/publications/2017/Jun/Renewable-Energy-Benefits-Leveraging-Local-Capacity-for-Onshore-Wind.

IRENA (2016a), *Renewable Energy Jobs: Annual Review 2016*, IRENA, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_RE_Jobs_Annual_Review_2016.pdf.

IRENA (2016b), *Renewable Energy Benefits: Decentralised solutions in the agri-food chain*, IRENA, Abu Dhabi, www.irena.org/publications/2016/Sep/Renewable-Energy-Benefits-Decentralised-solutions-in-agri-food-chain.

IRENA (2016c), *Policies and regulation for private sector renewable energy mini-grids*, IRENA, Abu Dhabi, www.irena.org/DocumentDownloads/Publications/IRENA_Policies_Regulations_minigrids_2016.pdf.

IRENA (2016d), *Unlocking Renewable Energy Investment: The Role of Risk Mitigation and Structured Finance*, IRENA, Abu Dhabi, www.irena.org/publications/2016/Jun/Unlocking-Renewable-Energy-Investment-The-role-of-risk-mitigation-and-structured-finance.

IRENA (2015a), *Adapting Renewable Energy Policies To Dynamic Market Conditions*, IRENA, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2014/policy_adaptation.pdf.

IRENA (2015b), *Renewable Energy Auctions: A Guide to Design*, IRENA, Abu Dhabi, www.irena.org/publications/2015/Jun/Renewable-Energy-Auctions-A-Guide-to-Design.

IRENA (2013), *Renewable Energy Auctions in Developing Countries*, IRENA, Abu Dhabi, www.irena.org/publications/2013/Jun/Renewable-Energy-Auctions-in-Developing-Countries.

Lang and Lang (2016), *EEG Surcharge Up to 6.354 ct/kWh for 2016 – 7.6% Increase for Core Surcharge, German Energy Blog,* www.germanenergyblog.de/?p=19487.

Mahalingam, A. and Reiner, D. (2016), *Energy subsidies at times of economic crisis: A comparative study and scenario analysis of Italy and Spain*, Energy Policy Research Group, Cambridge, United Kingdom, www.eprg.group.cam.ac.uk/wp-content/uploads/2016/02/1603-PDF.pdf.

MNRE (Ministry of New and Renewable Energy) (2016), *State-wise Solar RPO targets*, MNRE, mnre.gov.in/file-manager/UserFiles/Solar%20RPO/state-wise-solar-RPO-targets.pdf.

NREL (National Renewable Energy Laboratory) (2016a), *Feed-in Tariffs: Good Practices and Design Considerations*, NREL, Golden, CO, www.nrel.gov/docs/fy16osti/65503.pdf.

NREL (2016b), *Financial incentives to enable clean energy Deployment*, NREL, Golden, CO, www.nrel.gov/docs/fy16osti/65541.pdf.

NREL (2012), *Innovations in Voluntary Renewable Energy Procurement: Methods for Expanding Access and Lowering Cost for Communities, Governments, and Businesses,* NREL, Golden, CO, www.nrel.gov/docs/fy12osti/54991.pdf.

PVmoduletech (2017), *India's Solar Anti-dumping Saga: The Industry Anticipates,* PVmoduletech, moduletech.solarenergyevents.com/2017/09/27/indias-solar-anti-dumping-saga-the-industry-anticipates/.

Pyper, J. (2018), *New Tariffs to Curb US Solar Installations by 11% through 2022*, Greentech Media, www.greentechmedia.com/articles/read/tariffs-to-curb-solar-installations-by-11-through-2022.

REBA (2018), *We Power the Large Buyer Movement Toward Renewable Energy*, REBA, rebuyers.org/

REN21 (Renewable Energy Policy Network for the 21st Century) (2017), *Renewables 2017 Global Status Report* (Paris, REN21, 2017), www.ren21.net/gsr-2017/.

REN21 (2016), *Renewables 2016 Global Status Report* (Paris, REN21, 2016), www.ren21.net/wp-content/uploads/2016/10/REN21_GSR2016_FullReport_en_11.pdf.

REN21 (2015), *Renewable 2015 Global Status Report* (Paris, REN21, 2015), www.ren21.net/wp-content/uploads/2015/07/REN12-GSR2015_Onlinebook_low1.pdf.

REN21 (2014), *Renewables 2014 Global Status Report* (Paris, REN21, 2014), www.ren21.net/Portals/0/documents/Resources/GSR/2014/GSR2014_full%20report_low%20res.pdf.

REN21 (2013), *Renewables 2013 Global Status Report* (Paris, REN21, 2013), www.ren21.net/Portals/0/documents/Resources/GSR/2013/GSR2013_lowres.pdf.

REN21 (2012), *Renewables 2012 Global Status Report* (Paris, REN21, 2012), www.ren21.net/Portals/0/documents/Resources/GSR2012_low%20res_FINAL.pdf.

REN21 (2011), *Renewables 2011 Global Status Report* (Paris, REN21, 2011), www.ren21.net/Portals/0/documents/Resources/GSR2011_FINAL.pdf.

REN21 (2010), *Renewables 2010 Global Status Report* (Paris, REN21, 2010), www.ren21.net/Portals/0/documents/activities/gsr/REN21_GSR_2010_full_revised%20Sept2010.pdf.

REN21 (2009), *Renewables 2009 Global Status Report* (Paris, REN21, 2009), www.ren21.net/Portals/0/documents/activities/gsr/RE_GSR_2009_Update.pdf.

REN21 (2008), *Renewables 2008 Global Status Report* (Paris, REN21, 2008), www.ren21.net/gsr.

REN21 (2007), *Renewables 2007 Global Status,* www.ren21.net/Portals/0/documents/activities/gsr/RE2007_Global_Status_Report.pdf.

REN21 (2006), *Renewables 2006 Global Status Report* (Paris, REN21, 2006), www.ren21.net/Portals/0/documents/activities/gsr/RE_GSR_2006_Update.pdf.

REN21 (2005), *Renewables 2005 Global Status Report* (Paris, REN21, 2005), www.ren21.net/Portals/0/documents/activities/gsr/RE2005_Global_Status_Report.pdf.

SEDA (Sustainable Energy Development Authority) (2018), *FiT Rates Dashboard*, SEDA, seda.gov.my/.

SEIA (Solar Energy Industries Association) (2018a), *Section 201 Solar Tariffs*, www.seia.org/research-resources/section-201-solar-tariffs.

SEIA (2018b), *Community Solar*, www.seia.org/initiatives/community-solar.

Silverstein, K. (2017), *Will The U.S Solar Industry Survive Import Tariffs? Trump Holds The cards, Forbes* www.forbes.com/#245d28f52254.

Sustainability Roundtable (2012), *International Markets for Renewable Energy Certificates*, Sustainability Roundtable, sustainround.com/library/sites/default/files/SRER_Member%20Briefing_International%20Markets%20for%20Renewable%20Energy%20Certificates_2012-07-16.pdf.

Velasco, M. (2017), "*Scrapping of zero VAT RE to drive up electricity rates*", Manila Bulletin, business.mb.com.ph/2017/05/14/scrapping-of-zero-vat-re-to-drive-up-electricity-rates/.

Walters et. al. (2015), *Policies to Spur Energy Access: Volume 1 Engaging the Private Sector in Expanding Access to Electricity*, NREL, Golden, CO, www.nrel.gov/docs/fy15osti/64460-1.pdf.

Zinaman et. al. (2017), *Grid-Connected Distributed Generation: Compensation Mechanism Basics*, NREL, Golden, CO, www.nrel.gov/docs/fy18osti/68469.pdf.

REFERENCES FOR CHAPTER 5

Alaywan, Z., T. Wu and A.D. Papalexopoulos (2004), "Transitioning the California Market from a Zonal to a Nodal Framework: An Operational Perspective", paper presented at the IEEE PES PSCE Meeting, New York.

Carbon Trust (2016), *Energy Storage Report: Can storage help reduce the cost of a future UK electricity system?*, www.carbontrust.com/resources/reports/technology/energy-storage-report/.

CEER (2016) "CEER Position Paper on the Future DSO and TSO Relationship." www.ceer.eu/documents/104400/3731907/C16-DS-26-04_DSO-TSO-relationship_PP_21-Sep-2016.pdf.

CRE (2017), "6 questions pour comprendre le mécanisme de capacité en France" [6 questions to understand the capacity mechanism in France], Décryptages, Vol. 51, p. 6, Commission de Régulation de l'Énergie, www.cre.fr/documents/publications/decryptages/decryptages-numero-51.

EC (European Commission) (2018a), Electricity network codes and guidelines, EC, Brussels, ec.europa.eu/energy/en/topics/wholesalemarket/electricity-network-codeshttps://ec.europa.eu/energy/en/topics/wholesale-market/electricitynetwork-codes.

EC (2018b), "State aid: Commission approves six electricity capacity mechanisms to ensure security of supply in Belgium, France, Germany, Greece, Italy and Poland", press release, EC, Brussels, europa.eu/rapid/press-release_IP-18-682_en.htm.

EC (2015), Renewables-Grid and Public Acceptance (BESTGRID), ec.europa.eu/energy/intelligent/projects/en/projects/bestgrid.

Göransson L. and F. Johnsson,(2017) "A comparison of variation management strategies for wind power integration in different electricity system contexts", submitted to *Wind Energy*.

Green (2007), "Nodal pricing of electricity: how much does it cost to get it wrong?", *Journal of Regulatory Economics*, Vol. 31, pp. 125-149.

Gov.uk(2018),"£30millioninvestmentinrevolutionaryV2Gtechnologies", news story, 12 February, Gov.uk., www.gov.uk/government/news/30-million-investment-in-revolutionary-v2g-technologies.

IEA (International Energy Agency) (2017a), *Renewables 2017*, OECD/IEA, Paris.

IEA (2017b), *Getting Wind and Solar into the grid*, OECD/IEA, Paris.

IEA (2017c), *Status of Power System Transformation 2017*, OECD/IEA, Paris.

IEA (2017d), *Global EV outlook*, OECD/IEA, Paris.

IEA (2017e), *Renewable Energy for Industry*, OECD/IEA, Paris.

IEA (2017f), *The Future of Trucks*, OECD/IEA, Paris.

IEA (2016a), *Next Generation Wind and solar Power*, OECD/IEA, Paris.

IEA (2016b), *Re-Powering Markets*, OECD/IEA, Paris.

IEA (2014), *The power of transformation*, OCD/IEA, Paris.

IRENA (International Renewable Energy Agency) (2018a, forthcoming), *Transforming small-island power systems technical planning studies for the integration of variable renewables*, IRENA, Abu Dhabi.

IRENA (2018b, forthcoming), *IRENA FlexTool*, IRENA, Abu Dhabi.

IRENA (2018c, forthcoming), *Renewable Energy Auctions: Cases from sub-Saharan Africa*, IRENA, Abu Dhabi.

IRENA (2017), *Planning for the Renewable Future: Long-term modelling and tools to expand variable renewable power in emerging economies*, IRENA, Abu Dhabi.

IRENA (2017c), *Electricity storage and renewables: Costs and markets to 2030*, IRENA, Abu Dhabi.

IRENA (2016), *Scaling up Variable Renewable Power: The Role of Grid Codes*, IRENA, Abu Dhabi.

IRENA (2017b), *Adapting market design to high shares of variable renewable energy*, IRENA, Abu Dhabi.

LBNL/ANL (2017), *Impacts of Variable Renewable Energy on Bulk Power System Assets, Pricing, and Costs*, Lawrence Berkeley National Laboratory, Washington DC and Argonne National Laboratory, DuPage County, Illinois.

Leisch J. and J. Cochran (2016), *The Evolution of Power System Planning with High Levels of Variable Renewable Generation, Greening the Grid,* www.greeningthegrid.org/resources/factsheets/the-evolution-of-power-system-planning-with-high-levels-of-variable-renewable-generation.

Miller (2016), *Enhanced Frequency Response 2016*, National Grid Group, www.nationalgrid.com/sites/default/files/documents/8589937157-06_EFR.pdf.

Mills A. and R. Wiser (2012), *Changes in the Economic Value of Variable Generation at High Penetration Levels: A Pilot Case Study of California*, Lawrence Berkeley National Laboratory, Washington DC, emp.lbl.gov/sites/all/files/lbnl-5445e.pdf.

National Grid (2016), *Enhanced Frequency Response – Market Information Report*, National Grid Group, www.nationalgrid.com/sites/default/files/documents/EFR%20Market%20Information%20Report%20v1%20%281%29_1.pdf.

MISO (2017), *Multi Value Project Portfolio Analysis*, MISO, Carmel, IN.

Navigant Research (2017). *Market Data: Demand Response. Global Capacity, Sites, Spending and Revenue Forecasts*, Navigant Consulting www.navigantresearch.com/research/marketdata-demandresponse.

Neuhoff, K. and R. Boyd (2011), *International Experiences of Nodal Pricing Implementation*, Climate Policy Initiative, Berlin.

NREL (2017), *Renewable Energy Zone (Rez) Transmission Planning Process: A Guidebook For Practitioners*, National Renewable Energy Laboratory, Golden, Colorado, www.nrel.gov/docs/fy17osti/69043.pdf.

OECD (Organisation for Economic Co-operation and Development) (2014), *The Governacne of Regulators, OECD Best Practice Principles for Regulatory Policy*, OECD, Paris.

Stephan, A., B. Battke , M. D. Beuse, J. H. Clausdeinken and T. S. Schmidt (2017) "Limiting the public cost of stationary battery deployment by combining applications", *Nature Energy*, www.nature.com/articles/nenergy201679#supplementary-information.

Pöyry (2017), *Overview of RIIO Framework – A Report to AEEGSI*, Pöyry, United Kingdom, www.autorita.energia.it/allegati/docs/17/683-17all.pdf.

SSAB (2018), *HYBRIT – Toward Fossil-free Steel*, SSAB, Stockholm, www.ssab.com/company/sustainability/sustainable-operations/hybrit.

Schmidt, O., Hawkes, A., Gambhir, A. and Staffell, I. (2017) "The future cost of electrical energy storage based on experience rates", *Nature Energy*, vol. 2, p. 17110, DOI: 10.1038/nenergy.2017.110.

The Energyst (2017), *Demand Side Response – Shifting the Balance of Power: 2017 Report, The Energyst*, theenergyst.com/dsr/.

Ueckerdt F., L. Hirth, G. Luderer e O. Edenhofer (2013), "System LCOE: What are the costs of variable renewables?" *Energy*, Elsevier, Amsterdam, Vol. 63, Pagg. 61-75, doi.org/10.1016/j.energy.2013.10.072.

PHOTO CREDITS

page 11 lovelyday12, shutterstock

page 11 mimagephotography, shutterstock

page 11 Bene_A, shutterstock

page 12 solar plant field, Panumas Yanuthai, shutterstock

page 14 Ayrat A, shutterstock

page 15 Uganda/Africa, Drevs, shutterstock

page 15 Sebastian Noethlichs, shutterstock

page 17 Solar Panel Park/France la Colle des Mées, MIKE FOUQUE, shutterstock

page 21 Wind turbine under construction, P. Heitmann, shutterstock

page 23 Back view of solar panel, Romaset, shutterstock

page 25 Heater thermostat, Sascha Preussner, shutterstock

page 25 Fire in the fireplace, Baronb, shutterstock

page 25 Gas boiler room, NavinTar, shutterstock

page 26 Solar water heater, John_T, shutterstock

page 28 SGr, shutterstock

page 29 Wood chips for biofuel, Imfoto, shutterstock

page 30 Wood pellet heating, elena-t, shutterstock

page 30 Closeup of manometer, Vereshchagin Dmitry, shutterstock

page 30 Water tanks in a geothermal heating plant, s74, shutterstock

page 33 Vacuum solar water heating system, Beautiful landscape, shutterstock

page 33 Sonnenkollektor, Manuela Fiebig, shutterstock

page 34 Botswana/Africa, Lucian Coman, shutterstock

page 34 Kettles on campfire, Pavel_Klimenko, shutterstock

page 35 Fire in an outdoor fireplace, Zulashai, shutterstock

page 35 Fresh cooking in a wok pan, 100pk, shutterstock

page 35 Ceramic electric stove, Vladimir Arndt, shutterstock

page 36 Pot on the stove, blue power, shutterstock

page 36 Kolkata/West Bengal/India, AJP, shutterstock

page 36 Kolkata/India, Saurav022, shutterstock

page 36 Chitrakoot/India, Radiokafka, shutterstock

page 39 Bangkok/Thailand, viewfinder, shutterstock

page 41 Charging an electric car, Zapp2Photo, shutterstock

page 42 Traffic in the city, fuyu liu, shutterstock

page 42 Kunming/China, vladgphoto, shutterstock

page 44 German gas station super e10 fuel, Tobias Arhelger, shutterstock

page 44 Parking symbol for electric cars being charged, moreimages, shutterstock

page 45 Aerial view of biogas plant/Czech Republic, Kletr, shutterstock

page 48 Electric vehicle parking, John_T, shutterstock

page 50 Carsharing service of electric car, Paris/France, shutterstock

page 50 Amsterdam/The Netherlands; hans engbers; shutterstock

page 53 Valves on fueling ship, Ted PAGEL, shutterstock

page 55 Milan/Italy, Dizfoto, shutterstock

page 55 Power to gas concept. Hydrogen energy storage, petrmalinak, shutterstock

page 55 petrmalinak, shutterstock

page 57 Federico Rostagno, shutterstock

page 57 High-voltage substation, Sukpaiboonwat, shutterstock

page 59 chombosan, shutterstock

page 61 greenaperture, shutterstock

page 63 xieyuliang, shutterstock

page 64 Kletr, shutterstock

page 64 Wind turbines, Ana Flasker, shutterstock

page 64 Power generation wind farm on Royd Moor, Steve Meese, shutterstock

page 65 Foundation for wind wheel, Bildagentur Zoonar GmbH, shutterstock

page 69 Offshore wind park, petrmalinak, shutterstock

page 70 Pililla Wind Farm, Rizal/Philippines, Kim David, shutterstock

page 70 Zurijeta, shutterstock

page 72 Lisa F. Young, shutterstock

page 73 Denizli/Turkey, Suleyman ALKAN, shutterstock

page 75 greenaperture, shutterstock

page 75 Altamont Pass/Livermore/California, Sundry Photography, shutterstock

page 77 Wind turbine clean energy, apiguide, shutterstock

page 78 Kaunas county/Lithuania, A. Aleksandravicius, shutterstock

page 79 Chile, Pablo Rogat, shutterstock

page 80 Jiangxi/China, humphery, shutterstock

page 84 Oil refinery, Pand P Studio, shutterstock

page 87 Solar plant, Milan Portfolio, shutterstock

page 87 Wind turbines, Ana Flasker, shutterstock

page 88 Ewelina Wachala, shutterstock

page 89 petrmalinak, shutterstock

page 91 chombosan, shutterstock

page 93 Offshore wind farm, lightrain, shutterstock

page 93 guteksk7, shutterstock

page 95 Graphical_Bank, shutterstock

page 99 Wind turbine, David M G, shutterstock

page 99 Biofuel factory, Stockr, shutterstock

page 97 Lampang/Thailand, Aedka Studio, shutterstock

page 100 Freiburg/Germany, Gyuszko-Photo, shutterstock

page 101 DarwelShots, shutterstock

page 102 Normandy/France, Sergey Molchenko, shutterstock

IRENA
International Renewable Energy Agency

International Energy Agency

REN21
Renewable Energy Policy Network for the 21st Century

Renewable Energy

Renewable Energy Policies in a Time of Transition

ISBN 978-92-9260-061-7