TOWARDS 100% RENEWABLE ENERGY:

STATUS, TRENDS AND LESSONS LEARNED

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About

The IRENA Coalition for Action (Coalition) is an international network with a vision for its members to work together to advance renewable energy in order to drive the global energy transition in line with the Sustainable Development Goal on energy.

This white paper has been developed in a joint effort by Members of the Coalition Working Group Towards 100% Renewable Energy. Building on a number of case studies and on-the-ground experience by group members, the paper outlines a broad variety of options for pursuing 100% renewable energy as well as lessons learned from various parts of the world and on various governance levels.

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Abbreviations

CO_2:	Carbon dioxide
EU ETS:	European Union Emissions Trading System
FiP:	Feed-in premium
FiT:	Feed-in tariff
GHG:	Greenhouse gas
GW:	Gigawatt
GWh:	Gigawatt hours
IPCC:	Intergovernmental Panel on Climate Change
KWh:	Kilowatt hours
m^3:	Cubic metre
MW:	Megawatt
MWh:	Megawatt hours
PV:	Photovoltaic
RPS:	Renewables portfolio standards
TW:	Terawatt
TWh:	Terawatt hours
UNFCCC:	United Nations Framework Convention on Climate Change
UNFCCC COP:	United Nations Framework Convention on Climate Change Conference of the Parties
VPP:	Virtual power plant
VRE:	Variable renewable energy

Introduction

The transformation to a renewables-based energy system is already under way. The last decade has seen the cost of renewable energy decline continuously, making it cost-competitive compared to conventional energy in many parts of the world. Since 2009, the module prices for solar photovoltaics (PV) have fallen by around 80%, while wind turbine prices have declined by 30-40%, making the business case for renewable energy stronger than ever before (IRENA, 2017).

In addition to offering an affordable source of energy, renewables provide a wide range of socio-economic and environmental benefits. The transformation to a 100% renewable energy system[1] in all end-uses would generate millions of new jobs, bring significant welfare gains in the form of health benefits from cleaner air and water, as well as increase energy independence and economic growth as shown in various studies (IRENA, 2018a; Energy Watch Group and Lappeenranta University of Technology, forthcoming; University of Technology Sydney, forthcoming) – (see Annex 1 for further information).

One of the most crucial benefits of transitioning to a 100% renewable energy system is the resulting large reduction in greenhouse gas (GHG) emissions. The newly released Intergovernmental Panel on Climate Change (IPCC) special report leaves no doubt about the urgency of limiting the global temperature increase to 1.5°C compared to preindustrial levels – in line with efforts required by the Paris Agreement. To achieve this global warming limit, the IPCC highlights the need for a rapid energy transformation based on a significant increase of renewables (IPCC, 2018).

More than 50 countries and hundreds of cities and regions worldwide are committed to some form of 100% renewable energy target. Several companies are already covering all or most of their electricity demand from renewables, and others are likewise setting renewables targets for transport and/or heating and cooling. Some investors have made environment and sustainability actions a prerequisite for investment and are thus creating an additional incentive for companies to disengage from conventional sources.

To further speed up the transformation of the energy system and facilitate further discussion, the IRENA Coalition for Action has conducted a global mapping of 100% renewable energy targets and put together several case studies from national, regional, city and islands levels to illustrate different paths to a 100% renewable energy transformation. They show that there is no one-size-fits-all approach to achieving 100% renewable energy, and that targets and enabling frameworks need to be adjusted to local circumstances. In general, reaching a 100% renewable energy system will require further analysis and dialogue on what is needed on national as well as sub-national level with regard to target setting, policies and planning. The IRENA Coalition for Action is convinced that tailor-made solutions for achieving 100% renewable energy can be developed for every country, state, region, city or company.

The Coalition for Action stands ready to work with policy makers, industry and civil society on the road to 100% renewable energy.

[1] For the purposes of this paper, this term refers to the sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy.

1. Towards 100% renewable energy

Economic, social and environmental considerations have led governments at all governance levels to accelerate renewable energy deployment via dedicated policies. Enabling frameworks and policies to drive this development are largely dependent on local conditions and the composition of the current energy mix, past and planned energy investments, and other market forces.

This section of the paper provides an overview of 100% renewable energy policies across governance levels and different sectors. Conclusions and key takeaways for a successful renewable energy transformation are presented in Chapter 3.

1.1. 100% renewable energy at different governance levels

In recent years, there has been an increase in 100% renewable energy targets adopted by local and regional governments and countries, especially for the electricity sector.

Country-wide policies often start with the adoption of a fixed long-term target for sustainable energy modernisation followed by an overhaul of regulations and policies. Thus far, countries most directly vulnerable to the impact of climate change, such as small island states, have taken the lead in committing to 100% renewable energy. In November 2016, at COP22 (the 2016 United Nations Climate Change Conference) in Marrakech, Morocco, the 48 members of the Climate Vulnerable Forum committed to meet 100% domestic renewable energy production by 2050 at the latest (Climate Vulnerable Forum, n.d.).

Many of the national 100% renewable energy commitments and policies originate from community-led local or regional initiatives advancing comprehensive sustainability and development goals. Local-level policy development can shape and drive national governments to remove legal and institutional barriers. Conversely, local renewable energy policy-making processes are enhanced when the national government adopts an enabling framework including commitments to a clear, time-bound target.

In addition to government commitments, major players in the corporate sector have come out in support of 100% renewable energy (IRENA, 2018a; RE100, 2018). These companies play a crucial role in the energy transformation as their demand for 100% renewable energy helps investments in renewable energy. IRENA's global mapping shows that companies actively consumed about 465 terawatt hours (TWh) of renewable electricity in 2017, comparable to France's electricity consumption. Corporate sourcing of renewables is already taking place in more than 75 countries, even though most governments have yet to adopt specific policies to encourage such demand (IRENA, 2018c). While taking note of this important development in support of 100% renewable energy, this paper is limited to focusing on governmental pledges and efforts.

1.2. 100% renewable energy across different sectors of energy use

The changes ahead imply a shift from centralised electricity production and decentralised consumption to a more distributed energy system. Companies, independent power producers and millions of citizens are already enabling the operation of renewable energy based systems through their own production and consumption as well as through demand response and distributed storage. To date, commitments and policies for 100% renewable energy have focused almost exclusively on the electricity sector (IRENA, 2018a). Considerable efforts are still needed to speed up the transformation in other end-use sectors such as heating, cooling and transport, among others, widening the scope of the electricity sector to integrate other distributed sectors.

As higher shares of variable renewable electricity will be consumed, flexibility resources for the power sector will be necessary. Increased management of the power demand and significantly more electrification of end-use sectors are anticipated in the future. Sector coupling[2] is gaining more attention as it may improve the economic efficiency of renewable energy utilisation and enable the effective transition of other distributed demand sectors. Policies for smart sector coupling serve to both increase the electrification of end-use sectors and, at the same time, shape the demand profile of the newly electrified sectors to be more system-friendly (IRENA, IEA and REN21, 2018).

While successful cases of electricity-sector transformation towards 100% renewable energy are numerous, few examples of a more comprehensive transformation of the entire energy system have been seen to date.

1.3. 100% renewable energy policy enablers

To enable a successful transformation to 100% renewable energy, ambitious targets supported by stable, long-term and reliable policies are of crucial importance. Government targets for renewable energy provide a high-level important signal of commitment to citizens, investors and other stakeholders. The complexity of the energy system and its increased integration across sectors require any renewable energy target to be well-defined in terms of scope and boundaries in order to provide transparency and legitimacy hence reducing the risk of greenwashing. A credible and clear target is further important as a foundation for policies and planning.

Policy mechanisms to incentivise renewable energy deployment include Renewables Portfolio Standards (RPSs), public tenders or auctions, feed-in policies,[3] net metering/billing policies, fiscal incentives and grants, mandates, emission standards, and technology standards.

In the power sector, RPSs are being used to encourage electricity producers within a given jurisdiction to supply a certain minimum share of their electricity from designated renewable sources. With auctions, a government issues a call for tenders to install a certain capacity of renewable energy in line with their renewable energy deployment plans. Feed-in policies, long-term contracts that guarantee a minimum price per unit of electricity or a premium on top of the market price are typically offered to producers of renewable electricity. In many contexts, feed-in policies are successfully stimulating decentralised private, small-and-medium scale and cooperative and community investments in renewable power capacity, while RPS tendering and auctioning procedures are successfully being applied for utility-scale investment.

With renewable energy being cost-competitive with conventional sources of energy in most parts of the world, governments are moving away from administratively set tariffs/premiums, particularly in the electricity sector, and towards competitively set tariffs/premiums (auctions). As renewable energy technology penetration in the power system increases, power systems are restructured to

[2] The concept of "sector coupling" encompasses co-production, combined use, conversion and substitution of different energy supply and demand forms - electricity, heat and fuels.
[3] Feed-in policies include feed-in tariffs (FiTs), defined as fixed prices paid to electricity producers, and fixed or sliding feed-in premiums (FiP), which are payments to the producer on top of the market price.

accommodate cost-effectively larger shares. This takes place in the form of new grid codes, redesign of market rules, restructuring of the institutional architecture, etc. (IRENA, IEA and REN21, 2018).

In the heating sector, policies include mandates and financial incentives. However, approaches vary greatly according to differences in heat demand, infrastructure and other contextual factors. Policies can be clustered around support for renewables for district heating and cooling, domestic solar hot water systems, industrial heating and hot water, clean cooking, and renewables competing with extensive individual natural gas heating. 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 (IRENA, IEA and REN21, 2018).

Policies for increasing the shares of renewable energy in the transport sector typically focus on the availability of energy carriers and fuels such as the production and consumption of biofuels, the deployment of alternative fuel vehicles (such as electric vehicles or hydrogen-fuelled ones), the development of an alternative energy and fuel distribution infrastructure, and system integration. Considering the high dependence of the transport sector on fossil fuels, the removal of fossil fuel subsidies is essential for the decarbonisation of this sector (IRENA, IEA and REN21, 2018).

1.4. 100% renewable energy financing

According to IRENA's estimates, a cumulative USD 22.3 trillion would need to be invested in renewable energy in the 2015-50 period in its REmap case, compared to USD 9.6 trillion in the current and planned policies scenario (IRENA, 2018a). The REmap case envisages an increase in the share of renewable energy from around 15% of the total primary energy supply (in 2015) to around two-thirds by 2050. To effectively and sustainably transition to 100% renewable energy, the required level of investments in renewable energy would be even higher, but so would the associated benefits. Additional investments will also be needed in power grid and energy flexibility including transmission, storage, demand-side management and sector coupling.

In IRENA's REmap case scenario for example, the additional cost of a comprehensive and long-term energy transformation would amount to USD 1.7 trillion annually by 2050. However, positive externalities from reduced air pollution, improved health and mitigated environmental damage will far outweigh these investments. Savings in these three areas alone would average USD 6 trillion annually by 2050.

The cost of renewable energies has substantially decreased in recent years, making them cost-competitive with fossil fuel technologies and leading to record-high renewable power capacity additions in 2017. However, to transform to a renewables-based energy system, the scaling-up of both public and private funding is essential. The private sector currently accounts for the bulk of annual direct renewable energy investment – contributing more than 90% in 2016 – and it is expected to provide most of future investments should main barriers and risks to renewable energy project financing be addressed (IRENA and CPI, 2018; IRENA, 2017). To reach the scale of investment required for 100% renewable energy, additional capital pools need to be activated – ranging from large institutional investors to community finance groups, which must increasingly be drawn into the renewable energy sector. While market risks have been reduced by the use of long-term contracts and other instruments, perceived or real political risks are still a limiting factor for investors in some regions.

As renewables are increasingly cost-competitive, public finance can be used to facilitate private investment. This can be achieved by extending the use of public finance beyond direct financing, such as grants and loans, to focus on provision of risk mitigation instruments and co-finance with private financiers via structured finance mechanisms, which can help address some of the risks and barriers faced by private investors (IRENA, 2016). Finally, by divesting from fossil fuel-based energy sources and reinvesting in renewable energy projects, public and private lenders such as governments and financial institutions can unlock significant investments.

2. Global status and trends

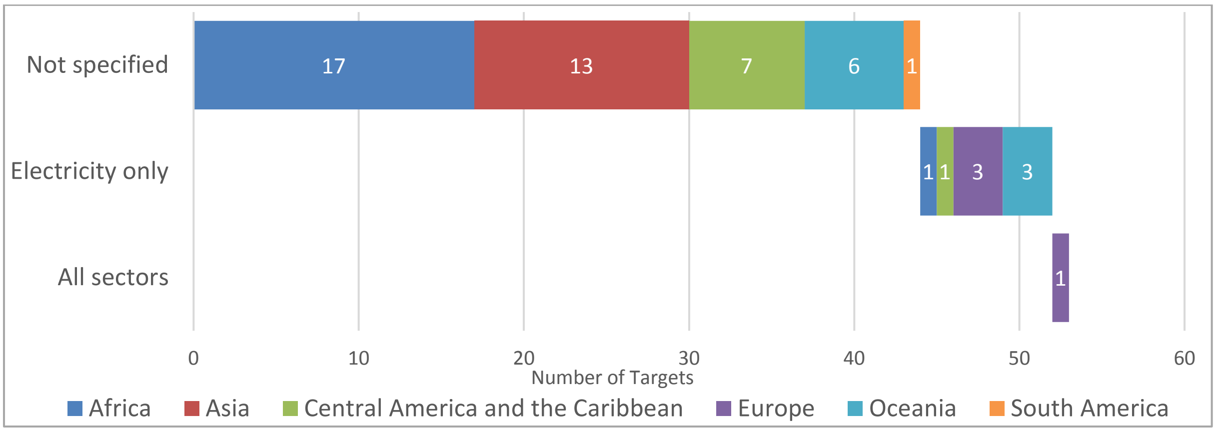
2.1. Mapping of 100% renewable energy targets

In 2018, the IRENA Coalition for Action coordinated with partners[4] to undertake a global mapping exercise to obtain a better understanding of 100% renewable energy targets on both the national and sub-national levels. This section outlines the main findings from this exercise.

National level

As of 2018, Coalition for Action findings reveal that as many as 53 countries had pledged to achieve some sort[5] of 100% renewable energy target. Geographically, these country pledges are distributed as follows: Africa (18), Asia (13), Oceania (9), Central America and the Caribbean (8), Europe (4) and South America (1) (see Figure 1).

Figure 1. Overview of 100% renewable energy targets on a national level



Note: The information in the figure is based solely on data reported to one of the data sources. Accordingly, the countries committed to a 100% renewable energy target may have changed since the data were reported.
"Not specified" refers to countries having not given further indication or defined the scope and boundary of their 100% renewable energy pledges.
Source: Data included in the figure were compiled by IRENA Coalition for Action with material provided by CDP, CAN, C40, Sierra Club, DEnet, DBU, Renewable cities, The Global 100% Renewable Energy Platform and ICLEI.

[4] Partners part of this large global data collection exercise include: ICLEI, CDP, CAN, C40, Sierra Club, DEnet, DBU, Renewable cities, IRENA and The Global 100% Renewable Energy Platform.
[5] Many 100% pledges have not been clearly defined in terms of sectoral and geographical scope and boundaries nor whether they refer to production or consumption, direct or indirect energy use. However, for the purpose of this report all reported pledges to reach 100% renewables have been included in the analysis.

This mapping of targets shows that the level of detail varies with regard to which specific sectors are encompassed by the adopted targets. The large majority – 44 countries – have a 100% renewable energy target without specifying the scope and boundary of their pledge, such as the concerned end-use sectors. Eight countries – Austria, Cape Verde, Costa Rica, Fiji, Iceland, Solomon Islands, Sweden and Tuvalu – have adopted their 100% renewables target specifically for the electricity sector. So far, only Iceland has achieved 100% renewable electricity. Denmark represents the only country with a 100% renewable energy target encompassing all sectors: electricity, heating and cooling, and transport.

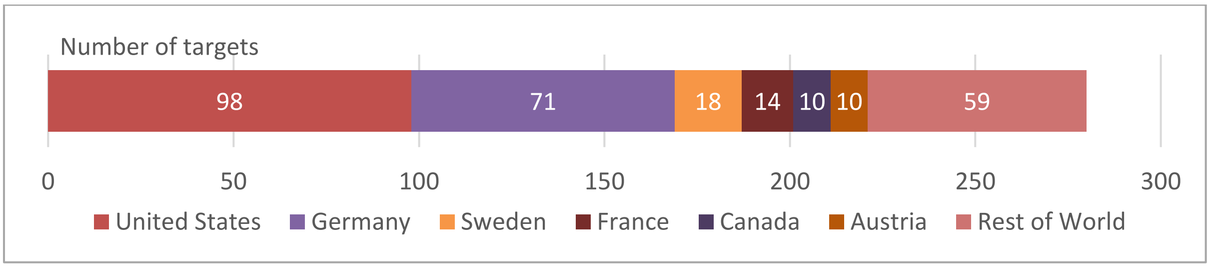
Of the 53, seven countries have committed to reach their 100% target by 2030, two countries by 2040 and the remainder by 2050.

Sub-national level

On the sub-national level, at least 280 stakeholders have committed to some sort of 100%[6] renewable energy target. Of these, 247 are cities and 33 are states or regions. Geographically, these sub-national pledges are distributed as follows: Europe (145), North America (109), Oceania (11), Asia (10), Africa (3) and Central America and the Caribbean (2).

Furthermore, four out of five sub-national 100% renewable energy targets are located in only six countries (see Figure 2), including the United States with 98 commitments, followed by Germany (71), Sweden (18), France (14), Austria (10) and Canada (10).

Figure 2. Overview of 100% renewable energy targets on a sub-national level by country



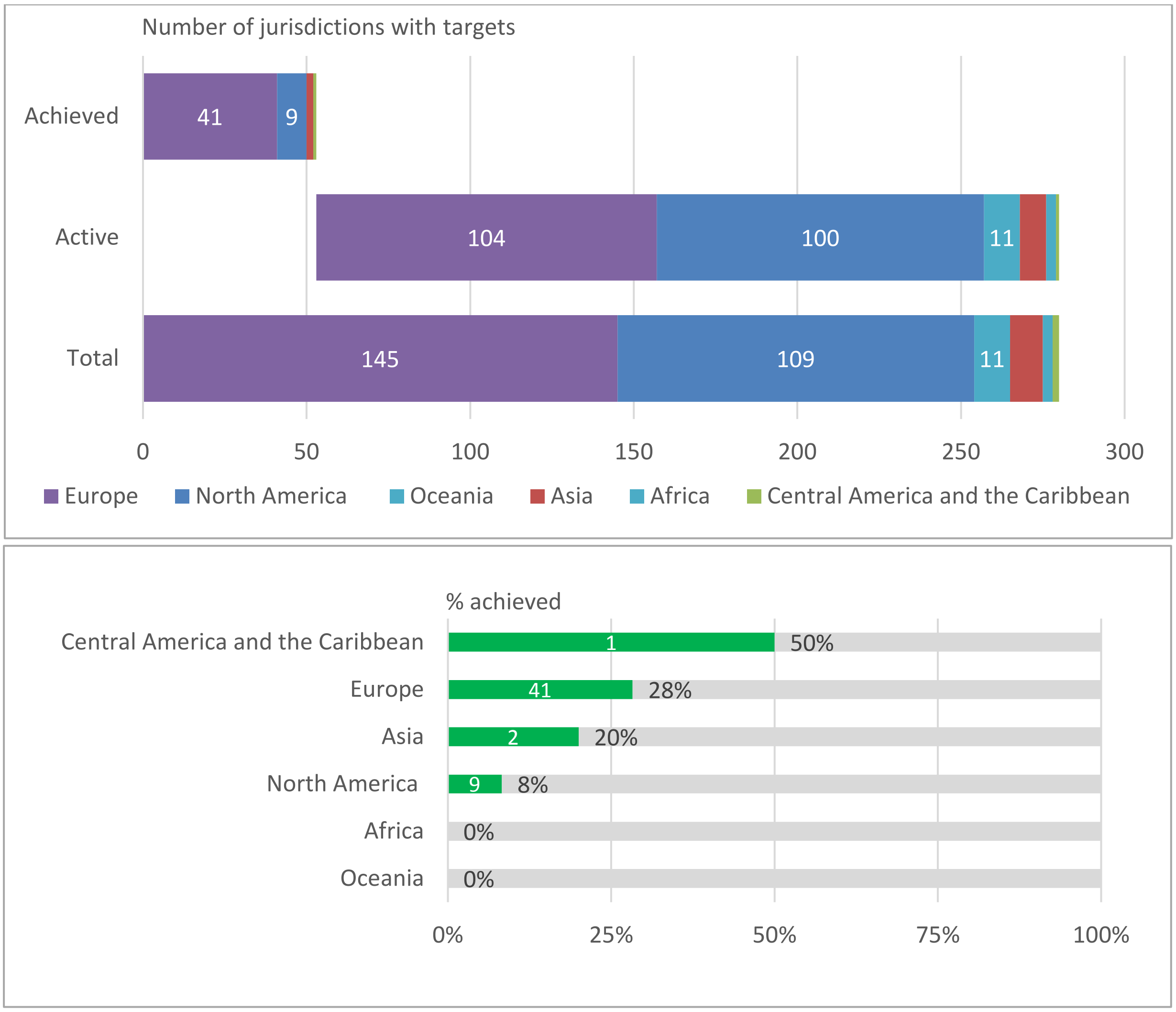
Note: The information in the figure is based solely on data reported to one of the data sources. Accordingly, the cities and regions committed to a 100% renewable energy target may have changed since the data were reported.
Source: Data included in this figure were compiled by ICLEI with material provided by CDP, CAN, C40, Sierra Club, DEnet, DBU, Renewable cities, IRENA and The Global 100% Renewable Energy Platform.

In all, 131 cities, states and regions with active targets have the ambition to reach their target by 2030, while 117 plan to achieve them by 2050. Nine of them have not committed to a time horizon.

Currently, 53 cities, states and regions have achieved their 100% renewable energy target. Out of these, 41 are located in Europe, followed by the United States (9), Asia (2) and Central America and the Caribbean (1) (see Figure 3). Almost two-thirds (62.5%) of these achieved targets (35) were set for the electricity sector only.

[6] Many 100% pledges have not been clearly defined in terms of sectoral and geographical scope and boundaries or whether they refer to production or consumption, direct or indirect energy use. However, for the purpose of this report all reported pledges to reach 100% renewables have been included in the analysis.

Figure 3. Active and achieved 100% renewable energy targets on a sub-national level



Note: The information in the figure is based solely on data reported to one of the data sources. Accordingly, the cities and regions committed to a 100% renewable energy target may have changed since the data were reported.
Source: Data included in this figure were compiled by ICLEI with material provided by CDP, Climate Action Network International (CAN), C40, Sierra Club, DEnet, DBU, Renewable cities, IRENA and The Global 100% Renewable Energy Platform.

A total of 133 cities, states and regions are focusing exclusively on the electricity sector in their pledges, while 68 are including renewable energy in all of the three sectors.

The geographical distribution for 100% renewable energy targets in the end-use sector/s varies. Whereas Asian and European targets are spread among different end-uses, in Africa, North America and Oceania the vast majority of targets are set only for the electricity sector (see Table 1). The 100% targets that incorporate all three sectors are located almost exclusively in Europe (40) and North America (27).

Table 1. 100% renewable energy targets on sub-national level by end-use sector and status

	Targets	E, H&C, T	E, H&C	E, T	H&C, T	E	H&C	T
Total	Active	64	53	4	1	101	1	4
	Achieved	4	12	2	0	32	1	1
Cities	Active	56	50	3	1	90	1	4
	Achieved	4	12	0	0	24	1	1
Regions	Active	8	3	1	0	11	0	0
	Achieved	0	0	2	0	8	0	0

Note 1: E = Electricity, H&C = Heating and Cooling, T = Transport
Note 2: The information in the table is based solely on data reported to one of the data sources. Accordingly, the cities and regions committed to a 100% renewable energy target may have changed since the data were reported.
Source: Data included in this table were compiled by ICLEI with material provided by CDP, CAN, C40, Sierra Club, DEnet, DBU, Renewable cities, IRENA and The Global 100% Renewable Energy Platform.

2.2. Case studies to illustrate 100% pathways

In order to illustrate 100% renewable energy pathways, this paper analyses selected design and implementation of such targets in different countries, states, regions, cities and islands (see Table 2 and detailed case studies in Chapter 4). The case studies cover different end-uses and include an overview of enabling frameworks implemented, and challenges and lessons learned in the transformation process. Case studies were selected by members of the Coalition for Action based on firsthand experience from these jurisdictions. In addition to the case studies, a number of boxes can be found in Chapter 4 providing snapshots of 100% renewables targets in countries and states.

Table 2 provides an overview of selected case studies and snapshots while the following Chapter 3 outlines key takeaways and lessons learned.

Table 2. Overview of case studies and snapshots detailed in Chapter 4

	Jurisdiction	Target
Country level	Costa Rica	100% renewable energy by 2030
	Denmark	100% renewable energy by 2050
	Sweden	100% renewable electricity by 2040
Regional/state level	California, United States	100% clean electricity by 2045
	Fukushima, Japan	100% renewable energy by 2040
	Hawaii, United States	100% renewable electricity by 2045
	Rhineland-Palatinate, Germany	100% renewable electricity by 2030
	South Australia, Australia	100% renewable electricity by 2025
City/municipal level	Stockholm, Sweden	100% renewable energy in transport by 2030
Island level	Cook Islands	100% renewable electricity by 2020
	El Hierro	100% renewable electricity

3. Key takeaways and lessons learned

The mapping of 100% pledges as well as case studies presented in this paper show a broad momentum and a variety of motivations for pursuing 100% renewable energy. While many governments around the world have committed to 100 % renewable energy in some form, more efforts are needed to define and implement these pledges.

The following main takeaways may serve as guidance and inspiration for adopting and further defining targets as well as establishing tailor-made frameworks for implementing 100% renewable energy.

- **The cost-competitiveness of renewable energy and its associated socio-economic and environmental benefits have become key drivers and motivations for transforming the energy system and establishing a 100% renewable energy target.**

  In many parts of the world, including those captured in the case studies in this paper, renewable energy has become the most cost-competitive option for new energy supply. While support schemes have increased their market penetration, barriers still remain to scale up renewables significantly. The analysis shows that investment in renewables has not only been economically beneficial but has also brought important socio-economic and environmental benefits, including job creation, economic growth, and reduced GHG emissions and air pollution.

- **Removing subsidies for unsustainable energy sources effectively levels the playing field for renewables.**

  Addressing market distortions favouring conventional sources of energy could further boost the deployment of renewables. This includes clear strategies and plans for phasing out all direct and indirect subsidies to unsustainable energy sources as well as pricing negative externalities such as all forms of pollution and GHG emissions caused by energy production and consumption. In accordance with national circumstances, meaningful carbon pricing, through floor prices, or emissions performance standards and/or sectoral carbon taxes present some of the mechanisms that have proven effective. The case study of Sweden shows that carbon pricing has had a positive impact on the competitiveness of renewable energy.

- **Driving higher investment in renewable energy, energy efficiency and system integration will be a key factor for accelerating the transformation of the energy systems.**

  In 2017, for the seventh year in a row, capacity additions of renewables outpaced those in fossil fuels. While ambition is higher than ever before, and renewable energy investment is accelerating, the current pace of the energy transformation is still far from what is required to decarbonise the energy sector in line with the objectives of the Paris Agreement. Significantly more investment in renewable energy, energy efficiency as well as transmission, storage, demand-side management and sector coupling is needed by the public and private sectors.

- **Transparent and well-defined targets and their effective implementation, are essential to support a development towards a 100% renewable energy system.**

  Ambitious government targets on renewable energy provide a high-level signal to citizens, investors and other stakeholders as well as a foundation for policies and planning.

The mapping out of 100% renewable energy targets in this report shows that some pledges are yet to be specified in terms of sectoral and geographical scope and boundaries, whether they refer to production or consumption and direct or indirect energy use, among other. To support governments on various levels in this process, the authors of this report recognise that further analysis and the development of a contextual framework for a 100% renewable energy system is useful.

- **Strong political will and active government commitment to achieving agreed targets is a major enabler of the transformation towards 100% renewable energy.**

  The barriers and obstacles delaying or impeding target setting for 100% renewable energy and policy development for implementation are not primarily technical but rather of a political nature based on remaining misconceptions regarding the feasibility of a 100% renewable energy system. Capacity building at the different governance levels about renewable energy technologies, financing, project development, and regulatory and policy frameworks is often cited as a key solution to build public and political support for 100% renewable energy. Such support, going beyond any political term of office, is crucial to create favourable and long-term market conditions and to boost private sector confidence to further increase investment in renewable energy towards a 100% renewable energy system.

- **Longer-term legislative and regulatory reliability and transparent and non-discriminatory administrative procedures for renewables deployment are important elements to support increased investment in renewables.**

  Stable and reliable policies over time as well as fair and transparent administrative procedures are essential to achieve 100% renewable energy targets. Non-transparent and frequent changes in legislation and regulation disturb investors' confidence and impede the development of a stable and reliable market environment, which is essential for renewable energy deployment.

  Longer-term commitments to 100% renewable energy need to be underpinned by ambitious and realistic milestones including regular monitoring of achievements. This includes phase-out plans for unsustainable energies as well as policies for managing structural changes without unnecessary disruption to the affected workforce. By describing which renewable energy sources are eligible for support towards the 2030 milestone, California provides an example of planning clarity for citizens and industry. At the same time, for the years until 2045, the Californian legislation relates only to "clean energy", which leaves the issue of which energy technologies are included open to interpretation.

- **Well-designed and locally adapted policy mechanisms pave the way for market entrance and penetration of renewable energy.**

  Fixed-price payments, known as FiTs (and fixed or sliding premiums on top of the market price), have been successful in advancing renewable energy technologies in the energy mix, as demonstrated in the cases of Denmark and Rhineland-Palatinate. FiTs have been shown to be effective particularly for smaller-scale installations in the electricity sector, including for some megawatt-size installations owned by co-operatives or communities, as well as for innovative new technologies.

Another promising policy to support decentralised and smaller-scale renewables is the combination of feed-in policies with self-consumption and behind-the-meter storage. Furthermore, the inclusion of renewable energy in rural electrification and access programmes can play an important role in achieving 100% renewable energy in remote communities.

With renewable energy now cost-competitive with other energy sources, governments are moving towards encouraging more competition as a main driver of a sustainable energy system. For utility-size installations, an increasing number of countries have introduced public tenders and auctions. RPS and tax exemptions are additional relevant policies for all energy sectors.

For the heating and cooling sectors, among others, carbon pricing, investment support as well as mandatory efficiency standards and building obligations for including renewable technologies in new and/or retrofitted buildings have led to an increase in the use of renewable energy.

For transport, the removal of fossil fuel subsidies is essential for the decarbonisation of the sector along with providing policies to strengthen energy carriers and fuels, electric and hydrogen fuelled vehicles and supported by an enabling infrastructure and system integration.

- **A broad consensus for 100% renewable energy among relevant stakeholders, citizens, businesses and political decision makers is a good enabler for successful policies and their smooth implementation**.

  Successful local and regional policies for 100% renewables are based on early information and participation as well as the direct and active involvement of local citizens, combined with expectations of economic or environmental benefits for citizens and/or community budgets. The Rhineland-Palatinate case study shows that state or country legislation is very useful, but in principle the decision to strive for 100% renewables can be taken and implemented at any governance level, even without supportive legislation at higher levels. The example of the US state of California shows that a local consensus can even overcome limitations set by a national government.

- **Innovative strategies and technologies have already helped overcome many barriers. The potential of innovation remains enormous and will accelerate the transformation to 100% renewable energy.**

  The technologies needed for the energy transformation are cost-competitive and widely available. Innovation, such as in smart grids, system integration, sector coupling, digital marketplaces, increased efficiency and new applications, as well as renewable energy technologies themselves, has enabled tremendous progress already. With future developments and digitalisation accelerating, huge potential remains to be tapped in the future.

  Minigrids and microgrids, usually in a rural context but increasingly also in urban environments, have proven successful in creating an ever-expanding patchwork of 100% renewable energy grid sections. Amidst less-efficient and less-resilient parts of the grid, they are offering a gradual, low-risk/high-return path to universally 100% segmented grids.

- **Increasing system flexibility helps accelerate the shares of renewable energy and the reliability of the energy supply system.**

  An inflexible power system is among the most frequently mentioned barriers for rapid uptake of renewables. Inflexible power plants reduce the grid capacity available for renewables and therefore cause frequent curtailment of renewable energy. Therefore, parallel commitments to renewable energy and to fossil and nuclear energy are delaying the transformation to 100% renewable energy. In addition to increased system flexibility, phasing out of overcapacity of inflexible and/or carbon-intensive assets is an important accelerator of the system transformation.

  For the electricity sector, higher penetration of variable renewables requires a number of changes in the way systems are developed and operated. Intelligent and advanced control systems for variable renewables are already available today and renewable generators are able to provide grid services including frequency stabilization and ramp control. Although there will be continued need for dispatchable energy, updating grid management practices and response methodologies can improve reliability, resilience and cost-effectiveness.

  Market rules need to be adapted[7] to reward flexibility and to allow all renewable energy sources to participate in relevant market segments, including balancing and system services. Trading periods closer to real time and shifting from futures to intraday markets facilitate the development of a market fit for renewable energy.

- **Integration of the different end-use sectors (sector coupling) helps accelerate renewable energy deployment across the whole energy system.**

  Sector coupling provides additional benefits for cross-sectoral energy production and consumption, particularly for integrating high shares of variable renewables. An abundance, or even a surplus, of VRE might become recurrent in power systems with high shares of VRE. 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 may better align demand with VRE production periods if proper strategies for shaping the demand profile are adopted.

- **Policies for increased energy efficiency are paramount for achieving milestones and targets on the way towards 100% renewable energy.**

  With reduced energy consumption and more efficient applications and standards, higher shares of renewable energy can be achieved with less new or upgraded capacity. This also helps reduce acceptance problems in densely populated areas. For buildings, higher efficiency standards drastically reduce energy needs and therefore help accelerate the achievement of much higher shares of renewable energy for heating and cooling.

[7] The energy transformation cannot be considered in isolation to the broader socio-economic structure it is based on. Changes may go beyond the adaptation of current market rules.

- **Capacity building, including vocational training, is needed for the development of a qualified local workforce for a renewables and efficiency-based energy system, and it helps to compensate for jobs lost in the transformation.**

  Capacity building on all levels and for the different sectors affected by the energy transformation is another key element for successfully achieving targets. Strengthening education and vocational training in schools, universities and other learning institutions helps develop the necessary workforce – including qualifying those who lose their jobs in the old energy system. Capacity building is not only needed in technical fields such as science and engineering but also for financial and economic tasks and for developing and operating accompanying framework programmes.

4. Case studies

4.1 Case studies – country level

Costa Rica: 100% renewable energy by 2030

Target

Costa Rica[8] has committed under the objectives set out in the Paris Agreement to become the world's first decarbonised economy. Endowed with significant natural resources and a strong commitment to sustainability, the country aims to achieve a 100% renewable energy mix by 2030.

Enabling framework

There are three main laws that underpin Costa Rica's electricity sector. Law No. 449 establishes that the Costa Rica Electricity Institute Group (ICE Group), an autonomous public institution, is responsible for generating, transmitting and distributing electricity. Law No. 7200 dictates that the ICE Group can buy a limited amount of electricity from private companies (30%) through public procurement or direct contracting. Finally, Law No. 7593 states that generation, transmission, commercialisation and distribution of electricity are defined as public services (ICE Group, 2017).

In 2015, the government established the National Energy Plan 2015-2030. The plan comprehensively examines the electricity, transport and fuels subsectors with a strong orientation towards sustainability, renewables and energy efficiency, as seen in the table below (Ministry of Environment and Energy, 2015).

Table 3. Costa Rica National Energy Plan 2015-2030 work areas

Subsector	Pillars of PNE 2015 – 2030
Electricity	1. **Energy efficiency:** Accomplishing a higher level of energy efficiency throughout the electricity matrix. 2. **Optimal distributed generation:** Improve the conditions for residential and commercial clients to produce electricity on a small-scale. 3. **Sustainability of the electricity matrix:** Increasing and diversifying installed capacity to meet growing demand while improving the competitiveness, regional participation and sectorial planning capacities. 4. **Sustainability of the electricity sector's development:** Improving institutional capacity with regard to environmental aspects of the energy sector.
Transportation and fuels	5. **A more environmentally friendly vehicle fleet:** Considers actions to renew the vehicle fleet, improve emission-control regulations and promote efficient driving and fuel savings. 6. **More sustainable public transportation:** Promotes a higher and more efficient use of public and non-motorised transportation. 7. **Cleaner fuels:** Includes actions to improve the quality of fuels to reduce GHG emissions, develop a biofuel or alternative fuel industry, and provide the accompanying regulations to enable their use.

Source: ESCOIA, E3G, Costa Rica Limpia and CPSU (2016)

[8] This case study builds on the forthcoming IRENA and IKI report *Energy Solutions for Cities of the Future.*

Implementation

Between 2014 and 2018, the country has generated more than 98% of its electricity from renewable sources. As of October 2018, 98.15% of its electricity was generated through five different renewable sources: hydropower (72.24%), wind (16.14%), geothermal energy (8.92%), biomass (0.76%) and solar (0.09%). However, renewable electricity only accounts for about one-quarter of total energy consumption, while oil products still account for the rest, particularly due to the transport sector, which consumes two-thirds of oil and gas products (ICE Group, 2018).

A decarbonisation plan with specific measures for the electrification of public, private and freight transport was announced in September 2018 at the United Nations General Assembly. In addition, the president has called on Congress to support a law to turn the moratorium on petroleum exploration and exploitation into law. The current bill (Expediente 20.641) aims to declare Costa Rica free from oil and gas exploration and exploitation. In addition, it will end the hydrocarbons law that is currently in operation and that leaves a door open to exploration of fossil fuels.

In 2017, the government launched the National Programme Carbon Neutrality 2.0 as a tool to reduce GHG emissions to zero as part of a decarbonised economy (Ministry of Environment and Energy, 2017). In addition to companies, the programme also includes municipalities (*Programa País Carbono Neutral Cantonal*), encouraging them to develop their GHG inventories.

Lessons learned

The latest Generation Expansion Plan (2016-2035) published in May 2017 stated that Costa Rica's installed capacity already meets the electricity demand for the next decade (ICE Group, 2017). Consequently, the ICE Group announced the suspension of the 650-MW hydroelectric project "El Diquis" and the delay of the "Borinquen" geothermal plant to 2026 (La Nacion, 2018).

Given that the electricity sector is almost 100% renewables-based already, stronger focus on system integration and the electrification of the transport and other end-use sectors is being considered. An electric mobility law to provide incentives to public and private electric transportation technologies and to create the infrastructure was approved in late 2017 and signed in January 2018 (La Gaceta, 2018).

Sweden: 100% renewable electricity by 2040

Target

In 2016, the Swedish government, along with most of the political parties in Sweden, concluded an agreement on Sweden's long-term energy policy. The agreement consists of a roadmap for a transformation of the energy system including a target to reach 100% renewable electricity production by 2040 (Government of Sweden, 2016). This target was included in the final Energy Bill adopted by the parliament in June 2018.

In addition to the specific targets on energy, Sweden aims to be carbon-neutral with a target of net zero GHG emissions by 2045 and thereafter to achieve negative emissions (Government of Sweden, 2018c).

Enabling framework

A new Climate Act entered into force on 1 January 2018 (Government of Sweden, 2018a). The Climate Act is part of a climate policy framework and imposes on current and future governments the obligation to pursue a climate policy in line with its climate goals, present a climate report every year and develop a climate policy action plan every four years to monitor progress. The policies are scrutinised by a politically autonomous Climate Policy Council (Swedish Climate Policy Council, 2018).

The main instrument driving the overall renewable energy transformation is the carbon tax. In Sweden, initially introduced in 1991 at USD 30/ton CO_2, the tax on fossil fuels based on carbon content has increased to USD 140/ton CO_2 at current levels. This has affected all the sectors not covered by the EU ETS, including heating fuels for households, small heating plants and the transport sector (Åkerfeldt, 2017).

To further increase the share of renewables in the electricity system, Sweden adopted in 2003 a mandatory renewable energy quota system (Swedish Government, 2018b). The system requires consumers to cancel renewable electricity certificates in proportion to their consumption. The certificates are generated by producers of renewable electricity from new plants, and sold in an open market. Since 2012, certificates have been traded in a joint market between Sweden and Norway. While the system has been extended by Sweden until 2045, it appears to have become less important as the market price during the last years has dropped to only EUR 3/MWh (USD 3.4/MWh), yet record investment decisions in wind power are taken (Swedish Energy Agency, 2017).

Implementation

Since the carbon tax was implemented in 1991, the economy has grown by 75% while the country's emissions declined by 26% (Government of Sweden, 2018d). Renewable energy technologies already contribute more than half (54%) of Swedish energy use, with bioenergy being the largest energy source in the country (37%) (Swedish Energy Agency, 2018).

Hydropower is the largest renewable electricity source in Sweden, followed by wind and biomass. Hydropower generation in recent years has varied between 62 and 78 TWh, and renewable energy has contributed 60-75% of electricity consumption. Nuclear provides most of the remaining power, with fossil fuels only providing around 2%.

No increase in hydropower generation is expected, and owners have decided to close two nuclear reactors by 2020. Since 2000, wind power has increased from 240 MW to 6 520 MW in 2017, passed 10% of generation and is projected to double by 2021 (Swedish Energy Association, 2018).

To promote implementation, the government in 2015 appointed a co-ordinator of Fossil Free Sweden. The initiative is open to all relevant stakeholders in Sweden, and more than 350 actors have signed up for the initiative. So far, a set of roadmaps for the development of different carbon-intensive industries has been produced (Fossilfritt Sverige, 2018).

Lessons learned

The large-scale use of biomass for heating, for co-generation of heat and electricity, as well as for transport has been achieved with economic and environmental efficiency mainly by the carbon tax. With old hydropower as an important foundation, biomass and rapidly increasing wind power are now outcompeting the remaining fossil and nuclear power.

Heating for the industrial and residential sectors is undergoing transformation, with biomass residues offering a viable and sustainable energy supply. Other challenges remain, such as decarbonising the transport sector with a final energy consumption of around 20% of renewable energy in 2015 (Swedish Energy Agency, 2018).

The success of carbon pricing provides an example for other countries of how to develop a competitive market for bioenergy and for other renewable energy technologies.

BOX 1: SNAPSHOT - DENMARK 100% RENEWABLE ENERGY BY 2050

Denmark is the only country with a target of 100% renewables in the overall energy mix.

With the Energy Agreement of 2012, Denmark set a target to transform the country's whole energy system (electricity, heating and cooling, industry, and transport) to 100% renewable energy by 2050 (Ministry of Climate, Energy and Building, 2012). The Energy Agreement of 2018 set new milestones for 2030 with 100% renewables in net electricity consumption and 55% renewables in net energy consumption (Ministry of Foreign Affairs of Denmark, 2018).

As of 2017, Denmark had reached a renewable energy share of 32% in gross energy consumption and a GHG reduction of 33% compared to 1990 levels. Wind power contributed 43% to net electricity consumption (State of Green, 2018).

The 2018 agreement provides budgets and policies for the time after 2020 to achieve the newly set 2030 targets, including using no coal for electricity production after 2030. A total of 2 400 MW of new offshore wind power will be built, tenders worth EUR 564 million (USD 643.8 million) will be held for green electricity at the lowest prices and EUR 537 million (USD 613 million) will be spent on green biogas. Grant pools are established for energy savings in industry and buildings, and reserves for further expansion of renewable energy are established. Modernisation of the heating sector is supported by tax relief totalling EUR 268 million (USD 305.9 million) by 2025. EUR 67 million (USD 76.5 million) is allocated to green mobility until 2020-24, and EUR 134 million (USD 152.9 million) will be allocated annually for energy- and climate-related research (Ministry of Foreign Affairs of Denmark, 2018).

4.2 Case studies – regional/state level

California: 100% clean electricity by 2045

Target

In 2018, California adopted Senate Bill 100 – also known as The 100% Clean Energy Act of 2018 – with a 100% clean energy goal for 2045 and with at least 60% of that energy coming from qualified renewable resources.

Enabling framework

California has a large number of laws and regulations governing energy policy. This includes the Renewables Portfolio Standard (RPS) Programme requiring all retail sellers to procure a minimum quantity of electricity products from eligible renewable energy resources. In 2018, Senate Bill 100 revised the RPS Programme so that the 50% renewable energy target would be achieved by 2026 (instead of 2030) and further increased the target to 60% by 2030 (California Legislative Information, 2018).

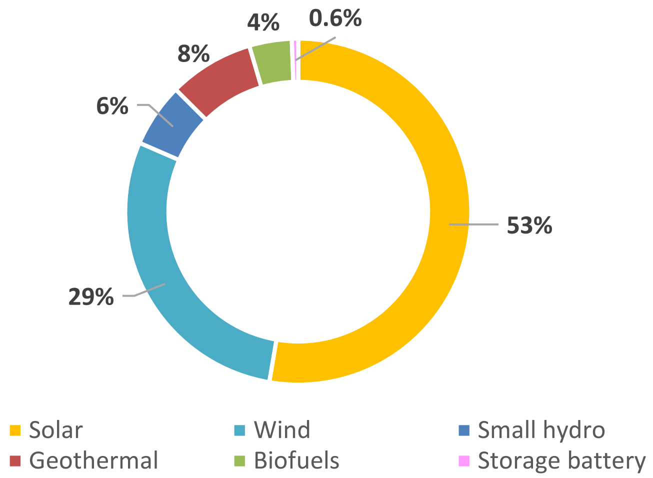
Senate Bill 100 further requires that the Public Utilities Commission, State Energy Resources Conservation and Development Commission, and State Air Resources Board should plan for 100% of total retail sales of electricity in California by 2045. At least 60% of this should come from eligible renewable energy resources and the remainder from zero-carbon resources. Zero carbon – in this case synonymous with clean energy – is not defined in Senate Bill 100, but various stakeholders, including environmental organisations, are emphasising the importance of not considering nuclear energy for this remaining share.

Implementation

The 60% renewables target seems likely to be achieved, given that California is already on track to exceed its earlier 50% RPS requirement.

As of late 2018, California's "qualified" (see Figure 4) renewable energy capacity was about 22.5 gigawatts (GW), with solar providing more than half of that total. Beginning in 2021, the state's environmental and energy agencies, in consultation with California Independent System Operators (CAISO), are required to report periodically to the Legislature on the 100% Clean Energy policy progress with a focus on technologies, forecasts and transmission capacity while maintaining affordability and reliability.

Figure 4. California installed renewable energy capacity



Renewables breakdown (MW)	
Solar	11,864
Wind	6,484
Small hydro	1,238
Geothermal	1,785
Biofuels	978
Storage battery	136
TOTAL	**22,495**

Note: Small hydro (*i.e.*, <30 MW) qualifies as renewable under the RPS; large hydro (>30 MW) does not.
Source: California ISO (2018) as of 11/05/2018

Lessons learned

California is the world's fifth-largest economy, and its high goals for renewable energy have stimulated discussion and actions favouring renewable energy elsewhere, including other countries. The size of California's renewable energy market provides examples of what can be accomplished with political will in a large and complex economy. Nearby states – especially Nevada, Arizona and Colorado – are following California's lead, demonstrating that state-level actions can help lead the way towards a more sustainable energy future.

BOX 2: SNAPSHOT - HAWAII 100% RENEWABLE ELECTRICTY BY 2045

In 2015, Hawaii announced a 100% renewables target for the power sector by 2045 – making it the first state in the United States to do so. With costly oil-based electricity generation accounting for a high share of total generation (65% in 2018), Hawaii has been faced with electricity rates three times higher than the US mainland average (EIA, 2018).

Recognising these challenges and the potential for renewable energy, the Hawaiian State Government established the Hawaii Clean Energy Initiative (HCEI) in 2008, which included RPS legislation. The legislation was revised in 2015 to require all utilities to generate 100% of their electricity from renewable sources by 2045 (CleanTechnica, 2015; Hawaii Clean Energy Initiative, 2015). Eligible renewable technologies include wind, solar, hydro, geothermal, oceans, biofuels and hydrogen produced from renewable energy sources.

In addition to the RPS legislation, a plan for modernising the electricity grid was adopted as well as policies for distributed renewables. As a result of these policies, utilities in the state such as Oahu's Hawaiian Electric Company and its subsidiaries Maui Electric and Hawaii Electric Light have had to undergo far-reaching transformations over the last years. To ensure grid reliability and stability, Hawaiian Electric has established a model that tracks electricity production and demand on an hourly basis, optimising the resource mix in terms of cost and renewables. Other islands such as Molokai and Kauai have also undergone significant renewable energy developments in response to the RPS and the 100% target, working with utilities and supported by the stakeholder engagement of HCEI.

In addition to outlining a strategy for transforming the power sector, HCEI also serves as a roadmap for other end-use sectors to follow. It engages a wide variety of stakeholders through focused working groups, involves the public in the planning and decision-making, and establishes a transparent and fair process to make informed decisions about the path to 100% renewables (Hawaii Clean Energy Initiative, 2015).

Rhineland-Palatinate: 100% renewable electricity by 2030

Target

By 2030, the German state of Rhineland-Palatinate aims to obtain all its electricity needs from renewable energy sources, primarily wind and solar. Following the nuclear accident in Fukushima, Japan, Rhineland-Palatinate was one of the first German states to adopt a resolution on the immediate shutdown of a number of nuclear power plants and the gradual phasing out of nuclear energy by 2022 (Ministry for Economic Affairs, Climate Protection, Energy and Regional Planning Rhineland-Palatinate, 2014; Koalitionsvertrag, 2016).

Enabling framework

An important part of the enabling framework for Rhineland-Palatinate's transformation to 100% renewable electricity includes its Climate Protection Law, which was adopted by the state parliament in 2014. The law includes GHG emissions reduction targets of 40% by 2020 and of at least 90% by 2050 (Rhineland-Palatinate Ministry of Justice, 2014). To achieve these targets, a climate action plan has been established and is updated at least every four years in addition to a monitoring report produced every other year (Ministry for Economic Affairs, Climate Protection, Energy and Regional Planning Rhineland-Palatinate, 2015).

Through a consultative process between 2012 and 2014, the state adapted its rules for regional planning, which strengthened rights for municipalities in the state to designate suitable sites for wind turbines as well as the possibility to build wind power plants in forest areas. The new rules have further allowed for landowners to benefit significantly from the renting out of land for renewable energy deployment (Ministry for Economic Affairs, Climate Protection, Energy and Regional Planning Rhineland-Palatinate, 2014).

An Energy Agency was founded in 2012 to support local capacity building and best practices. One focus area of the agency has been to look at the feasibility of phasing out coal and replacing it with renewable sources.

Implementation

Important progress to increase the share of renewable energy in Rhineland-Palatinate's energy mix has been made to date. In the last decade, the renewables-based share of the state's electricity production has more than doubled to around 50% in 2018 (Ministry for Environment, Energy, Nutrition and Forestry, 2018). Some of the 24 districts have already reached a share of 100% renewable electricity, including Cochem-Zell and Rhein-Hunsrück-Kreis. The latter is a net-exporter of renewable electricity in the sense that the district produces more than it consumes (Federal Ministry for the Environment, Nature Protection and Nuclear Safety, 2016; Rhein-Hunsrück-Kreis, 2018).

As part of the new Climate Protection Programme, many state-owned buildings have been retrofitted and equipped with solar PV panels or solar co-generation units such as solar water and space heating with a gas boiler as back-up. They were used as showcases for private and commercial activities.

In the last 15 years, around EUR 1.3 billion (USD 1.48 billion) has been invested in renewables in Rhineland-Palatinate. In terms of benefits, this strategy provides an annual added value estimated at EUR 44 million (USD 50.5 million) for the state.

Municipalities in Rhineland-Palatinate generate for example significant income from renting out municipal land to wind parks. This income is usually reinvested in other projects supporting the energy transition. Such examples in the state include funding of local renewables-based heating networks, energy-saving measures taken by citizens, and solar power and storage for street lighting.

Lessons learned

Political backing is crucial in achieving 100% renewable energy. Although the state government has played a key role in Rhineland-Palatinate's energy transition through the adoption of an ambitious climate protection law, crucial enabling policies implemented on the federal level have further facilitated the process.

Public acceptance and support have been important contributors to the successful implementation so far. The local districts that successfully overcame opposition did so by demonstrating the benefits of their ambitions to the local population early in the transition.

South Australia: 100% renewable electricity by 2025

Target

In 2003, the State Government of South Australia set a target of 14.5% of electricity generation from renewables by 2010. This was reached a year early and thereafter all targets were achieved ahead of schedule, including a target of 50% by 2020 that was reached in 2017. For the years ahead, the Australian Energy Market Operator (AEMO) expects South Australia to reach a share of 73% renewable electricity by 2021 and the equivalent of 100% by 2025 (AEMO, 2017a; Renew Economy, 2018a) based on committed and potential supply developments predominantly from wind and solar. A related target in the state is to have net zero CO_2 emissions by 2050.

Enabling framework

Since the 1950s, extensive wind resource surveys have been conducted in South Australia. Thus, when federal government incentives were introduced in 2003, investors had solid knowledge on high-resource potential close to the transmission network. The state government offered a package of incentives for investors including wind resource data, electricity network information, initial access to government-owned land, and streamlined and co-ordinated processes of approval and licensing as well as financial support through the federal government's renewable energy certificate scheme.

In 2008, South Australia was the first Australian state to introduce a feed-in tariff (FiT) scheme. The FiT is applicable to households, small businesses and community buildings with solar PV systems producing a maximum of 160 MWh of electricity per year. Initially offered at a fixed rate by the distributor, new systems connected to the grid are able to receive a FiT directly from retailers at a tariff rate that varies between AUD 0.00 and 0.16 (USD 0.00 and USD 0.12) per kilowatt hour (KWh) depending on the retailer (Government of South Australia, 2018).

Implementation

As a result of the enabling framework created by the state with support from the federal government, installed wind energy capacity reached a level of 1 810 MW in 2018 with continuous growth expected in the years to come.

In addition to effective FiT schemes, high electricity prices of approximately AUD 0.40 (USD 0.29) per KWh for households have been a strong motivating factor to install solar PV. In 2018, almost one-third of households in the state had installed rooftop solar PV systems, reaching a total capacity of 800 MW. Although the growth of residential solar PV is expected to decline due to market saturation, solar PV installations among businesses are expected to experience steady growth in the coming years (AEMO, 2017b). In addition to rooftop solar PV, one solar PV farm of 110 MW near Port Augusta has been completed and others are in the pipeline, including CSP (Concentrating Solar Power) plants.

In total, 2 700 MW of wind and solar are connected to the South Australian electricity grid, which has an average load of 1 600 MW and a peak load of just over 3 000 MW. The number of times that renewables provide 100% of load is steadily increasing.

Building on the large penetration of rooftop solar PV and the reduction in costs of battery storage, the state government has unveiled a plan to roll out at least 50 000 residential solar and battery systems to form a Virtual Power Plant (VPP).

The first test phase for the VPP saw the successful installation of home solar and battery systems in 100 houses. The second trial phase is in progress, with another 1 000 homes getting a 5-kW solar panel system and a 13.5-kWh Tesla Powerwall battery at no charge. The current phase of the project is financed through the sale of electricity (Government of South Australia, n.d.; Government of South Australia, 2018).

Another programme to scale up renewables includes a recently launched, private 1 GW initiative focusing on large-scale, energy-intensive industries in the city of Whyalla. The programme is expected to cut power costs and improve energy system reliability for the industries. In this area, where the main source of employment is the steelworks and iron ore mines, plans are being made for a system of dispatchable renewable energy for the steelworks and surrounding industry. The system would include a 280-MW solar farm, a 120-MW/140-MWh battery, a pumped hydro-storage project in a disused iron ore mine, co-generation heat from the steelworks and 480 MW of demand response (PV Magazine, 2018).

Lessons learned

The rapid growth of variable renewable energy (VRE) occurred without a strategic plan for large-scale grid integration, and a whole-state blackout on 28 September 2016 was a wake-up call. Contributing to the blackout were 100-year-event winds, the loss of three out of four transmission lines in the North, fault ride-through settings not properly designed for similar occurrences and available gas generation that did not operate. Since 2016, updated fault ride-through settings for wind generators and scheduling of gas generation at all times has been implemented (AEMO, 2017a) and better forecasting reports introduced. Diesel backup was purchased by the government for use in emergencies, and a 100-MW/129-MWh battery was installed that in six months recouped one-third of its capital cost, mainly through ancillary service benefits. More large batteries and other storage are scheduled for inclusion in the grid. A second interconnector to the eastern states is planned for imports and for future expected large renewable energy exports. AEMO has recently released its first integrated system plan, which looks at transforming the nation’s energy system at the lowest possible cost for customers and with the provision of a flexible network. Demand response is an integral part of the plan.

The blackout accelerated rather than curtailed the energy transformation (Renew Economy, 2018b). However, in a few years’ time on low-load sunny days, rooftop solar could supply all daytime load, which might cause voltage control problems. Additionally, future large increases of VRE capacity could cause challenges. Various initiatives are looking to address these issues, including through increased storage capacity as well as by using excess electricity to produce heat, hydrogen or electric vehicle charging and for export to other Australian states.

BOX 3: SNAPSHOT - FUKUSHIMA 100% RENEWABLE ENERGY BY 2040

Following the nuclear accident in Fukushima in 2011, Fukushima Prefecture revised its energy vision and adopted a 100% renewable energy target in primary energy consumption by 2040. Intermediate milestones include a share of renewable energy in primary energy consumption of 40.2% by 2020 and of 63.7% by 2030 (Fukushima Prefecture, 2012).

Following the adoption of the target, Fukushima Prefecture developed its first Renewable Energy Pioneer Action Plan, focusing on the expansion and integration of solar and wind resources as well as research and development towards a hydrogen-based society (Fukushima Prefecture, 2013).

A regional subsidy programme providing households with a grant equivalent to approximately JPY 40 000/kW (USD 355) in 2018 for their residential solar PV installations has been introduced. Fukushima's plan also includes policies and initiatives for the establishment of a renewable energy promotion centre, a demonstration project of a floating offshore wind farm and the permission to use devastated agricultural land for renewable energy purposes, amongst others. On a national level, a FiT programme was established in 2012 and has resulted in a sharp increase in the number of household and non-household solar power systems, equivalent to 590 MW in 2015 (Renewable Energy Initiative, 2017).

The share of renewable energy supply in the prefecture's energy demand increased from 21.9% in 2011 to 26.6% in 2015, primarily from a growth in solar PV installations followed by biomass, wind and small hydro. A geothermal 400-kW binary cycle generation plant was deployed in 2015 in the Tsuchiyu area (IRENA, 2018d). The project is owned by local stakeholders, including Tsuchiyu-Onsen, which is a hot spring association. In the Aizu region, AiPower, a locally owned renewable energy company, was established to realise energy autonomy (Energy Democracy, 2015). The company has developed dozens of community-owned ground-mounted solar PV projects, reaching a total capacity of over 5 MW in 70 places around Aizu and the Nakadori region.

Fukushima Prefecture further engaged private actors and local municipalities to dedicate resources towards comprehensively implementing the 100% renewable energy target.

4.3 Case studies – city/municipal level

Stockholm: 100% renewable energy in transport by 2030

Objective

Swedish national and local governments over the last decades have shared the ambition to reduce oil dependence. One government said it aimed to break its dependence on oil by 2020, while another called for a fossil-free vehicle fleet by 2030 (McCormick, Peck and Kaberger, 2006). The regional government of Stockholm has pursued this ambition through the publicly owned company Storstockholms Lokaltrafik (SL), which manages all public transport in the region (Stockholms Läns Landsting, 2018a).

Enabling framework

Regional efforts have enjoyed the support of the national government and government agencies in the introduction of renewable biofuels. These efforts were further encouraged by environmental labelling of personal transport provided by Sweden's largest environmental non-governmental organisation, Naturskyddsföreningen (the Swedish Society for Nature Conservation).

The size of the regional public transport system was sufficient for a national bus manufacturing company to develop new fuel systems and engine technologies for it. The region also provided feedback to national regulators when details in regulations made development difficult.

Although public transport is managed by the SL, it is operated by several different operators. Renewable energy requirements have been implemented through the public procurement process, where demand for GHG emissions reductions at a low cost was the important instrument for conversion.

Implementation

In the summer of 2018, Stockholm's last diesel bus was retired. Since then, all trains, subways and more than 2 300 buses in Stockholm's public transport system have been operating on 100% renewable energy (Stockholms Läns Landsting, 2018a, 2018b).

The first test fleet of ethanol buses, using ethanol produced as a by-product of the pulp industry, was deployed in 1996. These buses were supplemented by biogas buses in 2001, using biogas from sewage sludge. By 2011, 58% of buses were operating on renewable fuels, and in recent years the number of buses using biodiesel has increased (Stockholms Läns Landsting, 2018a). Electric hybrid buses were successfully deployed in Stockholm in 2015 with both an electric and biofuel driveline. Failed attempts with early hybrids as well as fuel cell buses did not stop the process. Instead, experiences gained contributed to later successful implementation.

Following early technology tests, the large-scale transition of the transportation sector was achieved via active and functional procurement processes by SL. SL set targets regarding the percentage of transport that should be fossil-free in 2005, 2010 and 2020. Each upcoming tender demanded a certain share of fossil-free vehicles and a certain reduction of CO_2 emissions. The choice of technology was left to the discretion of operators.

This approach was both effective and efficient, as it enabled the utilisation of the most commercial renewable technology type for each specific type of transport mission, such as liquid biofuels for long distances and hybrids for city and suburban operations. Long-term planning enabled operators to replace vehicles as they reached the end of their financial life, thus keeping the cost of the renewable energy transformation low.

To reach 100% renewable energy in the overall public transport system, old boats traveling to islands in the archipelago need to be converted to operate using renewable energy. Despite their historic features, the boats must be converted or replaced by 2030.

In addition to sustainability through renewable energy, public transport environmental policies also address local air and noise pollution as well as energy efficiency and renewable energy in supporting infrastructure.

Lessons learned

Stockholm has long had an ambition to go 100% renewables. Initially, challenges in supply chain coordination were major barriers. Customers interested in renewables needed fuel producers and distributors as well as providers of vehicles that were compatible with the fuel. In Stockholm, this was managed by establishing co-operation and partnerships between the fuel-providing company and Scania, the vehicle provider. This issue is less prevalent today because there are established companies in several renewable propulsion technology supply chains.

Biofuels as a renewable solution have come under scrutiny and criticism for not being entirely sustainable. Although biofuels are renewable, they are not perfectly sustainable because fossil fuels are often used in their production. Unsustainable biomass systems also pose a biodiversity threat. Engines using biofuels also emit polluting substances. These concerns about the development of biofuels have further intensified as non-renewable actors have begun to perceive them as a threat. Knowledge of and expertise with the task of correcting these sustainability issues as well as potential false claims in public are essential, especially as public entities are under political control, in order to avoid policy backlash.

While Stockholm faced various challenges during the initial stages of integrating renewables into its transport sector, it has developed mature supply chains that make using 100% renewables in public transport an easier target to achieve.

4.4 Case studies – island level

Cook Islands: 100% renewable electricity by 2020

Target

The Cook Islands set a 100% renewable electricity target in 2011, aiming to transform its diesel-based power sector to 50% renewable electricity-based by 2015 and 100% renewable electricity-based by 2020 (Office of the Prime Minister Government of the Cook Islands, 2011). These targets are in line with the government's commitment to mitigate the Cook Islands' carbon footprint by following a pathway of low-carbon development and increased climate resilience. As outlined in the Cook Islands Nationally Determined Contribution, the transformation of the electricity sector to renewables could result in an 81% decrease in electricity-related GHG emissions by 2030, thus setting a concrete foundation for the transformation of other sectors in the future (UNFCCC, 2015).

Enabling framework

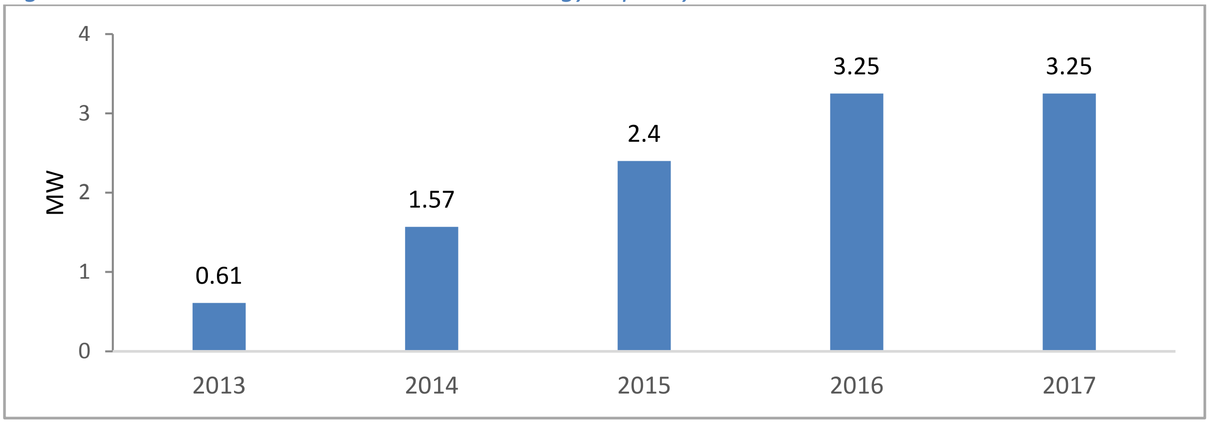
To achieve 100% renewable electricity by 2020, the Cook Islands Renewable Energy Chart was established in 2011 by the Office of the Prime Minister as the entity responsible for the development and implementation of strategies for the electricity sector (Office of the Prime Minister Government of the Cook Islands, 2012). This chart introduces institutional and policy restructuring including the reviewing of existing legislation, regulations and electricity tariff structures. It also explores opportunities for public-private partnerships for finance and investment, and increasing capacity building to conduct comprehensive renewable energy technology assessments.

Te Aponga Uira, the government business enterprise responsible for electricity in Rarotonga, introduced a net metering policy in 2013 to encourage customers to generate their own electricity from renewable sources and accumulate credits for excess energy produced. The government has further subsidised renewable energy production, distribution and consumption for both commercial and household purposes.

Implementation

The Cook Islands Renewable Energy Chart was updated in 2016 to evaluate the progress the Cook Islands have made in achieving the target of 100% renewable electricity. Between 2013 and the end of 2017, installed renewable energy capacity rose from 0.61 MW to 3.25 MW, solely from solar PV projects.

Figure 5. Cook Islands installed renewable energy capacity



Source: IRENA (2018b)

Overall, the Cook Islands currently generate 95% of their electricity through the installation of solar PV-battery-diesel hybrid systems, whilst relying on diesel for the remaining 5% (IRENA, 2018b). In the Northern Group of islands, solar PV and battery storage technologies supply up to 100% of renewable electricity (Office of the Prime Minister Government of the Cook Islands, 2016).

In 2014, the Asian Development Bank, the European Union, the Global Environment Facility and the Green Climate Fund co-financed the Cook Islands Renewable Energy Sector Project in collaboration with the Ministry of Finance and Economic Management and the Renewable Energy Development Division. The aim of the project is to build solar PV plants and battery energy storage systems on five islands and to provide an additional 2 MW to the grid by the end of 2019 (Asian Development Bank, 2017a). As of mid-2017, solar PV developments had taken place on the islands of Atiu, Mangaia, Mauke and Mitiaro, and battery storage system developments had taken place in Rarotonga. In addition, the project is also providing institutional support to the Government of the Cook Islands in implementing the objectives of the Renewable Energy Chart (Office of the Prime Minister, Government of the Cook Islands, 2011). Additional solar PV developments on Aitutaki and battery storage systems on Rarotonga are expected (Asian Development Bank, 2017b).

Lessons learned

The Cook Islands' rapid pace of integrating renewables into their electricity mix is primarily constrained by limitations of the grid. The country's grid is not technically advanced enough to accommodate all renewables being developed. Further innovation and investment are required for grid stabilisation and grid upgrades to manage fluctuations in generation and to allow for more renewable energy generation to be integrated into the grid whilst maintaining the reliability of power generation. This is an essential element for the Cook Islands to meet its 100% target and is a key takeaway of the Asian Development Bank's Cook Islands: Renewable Energy Sector Project (Renewable Energy World, 2016). This is of particular importance on Rarotonga, which accommodates most of the country's business and population, and therefore accounts for approximately 90% of the country's electricity demand.

The Cook Islands' reliance on solar PV systems for renewable electricity restricts night-time generation and raises the necessity for storage and load shifting. While the Cook Islands Renewable Energy Chart outlines potential viabilities for wind projects on islands such as Rarotonga and Aitutaki, the temperamental climate and occurrence of cyclonic winds require proactive management of wind farms in the region for projects to be developed.

Additionally, islands like Rarotonga have limited land availability, which constrains the development of wind projects and results in funders such as the Asian Development Bank and the European Union primarily investing in solar PV and battery storage projects (Office of the Prime Minister Government of the Cook Islands, 2016). Further assessments of viable renewable energy technologies and project site appraisals are required to create a comprehensive technical plan to diversify the energy mix.

Further institutional restructuring is also required for the Renewable Energy Development Division in developing energy audit plans and monitoring schemes to improve energy efficiency and capacity building for renewable energy technology viability assessments.

El Hierro: 100% renewable electricity

Target

The 2006 revision of the El Hierro Sustainability Plan from 1997 underlines the island's objective to achieve a 100% renewable electricity supply in a way which is closely anchored to the island's climate and geology (Cabildo El Hierro, 2006).

El Hierro aims to take advantage of the benefits of its stable and relatively high potential for wind resources and to use the island's favourable topography for the development of a combined pumped hydro-energy storage system (Gorona del Viento El Hierro, n.d.). The renewable electricity supply would be obtained from wind power, and energy storage would help manage the variability of wind generation to guarantee security and the quality of the power supply.

Enabling framework

The 100% renewable electricity objective was developed and supported by strong political will and commitment of the island's government and the regional government of the Canary Islands. It was further supported by the Spanish central government and the European Commission. The Canary Islands' policy framework is further aiming at a coherent and integrated energy vision for the archipelago. It consists of the following objectives 1) strengthening and diversifying the local economy; 2) providing energy security; 3) promoting energy efficiency and renewable energies; and 4) protecting the climate and the environment (World Future Council, 2015).

Another component of El Hierro's long-term strategy for sustainable development is to replace the island's existing 8 000 vehicles, which are currently powered by petrol and diesel, with electric vehicles. (The Local, 2016). Encouraging greater use of anaerobic digestion for the production of biogas by the island's agricultural and waste industry has become another important objective of this strategy. These measures are aimed at reducing El Hierro's dependence on imported polluting oil and other fossil fuels.

Implementation

The Gorona del Viento wind-pumped-hydro power station was commissioned in 2014 and has been in full operation since the beginning of 2015. The station includes an 11.5 MW wind farm, an 11.32 MW hydroelectric power plant with four Pelton turbines of 2.83 MW each, a 6 MW pumping station and two water reservoirs. The upper reservoir is located at 700 metres with water storage capacity of 380 000 cubic metres (m^3) (downsized from the originally planned 500 000 m^3), while the lower one is located at sea level with a capacity of 150 000 m^3 (downsized from 225 000 m^3).

In the station's first year, it supplied 20% of the island's electricity needs. In 2016, this increased to approximately 40%, and in 2017, it supplied 46.5% of the islands' annual demand. In the period January-July 2018, 67.3% of El Hierro's electricity demand was produced from renewables, with July reaching 95.9% coverage (Red Eléctrica de España, 2018). This level of renewable energy penetration is certainly high on a worldwide scale, considering that El Hierro is a totally isolated electrical system. Nevertheless, the work has not yet finished. Improvements are still being made, aimed at achieving the original objectives, including the envisaged 100% renewables.

In February 2018, El Hierro met its electricity needs with 100% renewable energy for 18 consecutive days. The island's power demand had been covered by 100% renewable energy for more than 3 400 hours as of August 2018 (Red Eléctrica de España, 2018).

Lessons learned

One of the main reasons 100% renewable electricity has not yet been achieved lies in the ultimate scale of the constructed water reservoirs, which have an insufficient capacity for storing the water that is pumped uphill by the electricity generated from the wind turbines (The Local, 2016). Further improvements (and probably storage capacity additions) are needed.

Depending on the characteristics of energy demand on an island and the status of the electricity grid in general, a similar pump storage system may or may not be chosen in the case of other islands. For the island of El Hierro, with its high wind potential and complex terrain that allows for the installation of an upper water reservoir at a height of 700 metres, this is a suitable solution. The system also helps supply water from the upper reservoir for agricultural purposes.

In addition to overcoming technical challenges, political commitment has proved to be key in pursuing 100% renewable electricity for an island energy system. The El Hierro case further shows that a 100% renewable energy strategy can increase energy security but must be adapted to local circumstances. There is no one-size-fits-all strategy, but the implementation plan should be based on what is locally available and feasible.

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Annex A. Forthcoming studies on scenarios for 100% renewable energy

In recent years, technical energy scenario modelling has further underlined the case for the feasibility of transitioning to 100% renewable energy as well as informed the discussion of what policies are needed to achieve that goal. Two recent initiatives that look at achieving 100% renewables energy on a global scale are described below:

Global 100% Renewable Energy Simulation is a joint study by the Energy Watch Group and Lappeenranta University of Technology, Finland. The study simulates the global energy system based on 100% renewables across the sectors of electricity, heating, transport and desalination. While the full study is due in early 2019, a first part analysing the electricity sector was released already in December 2017. It shows that a transition to 100% renewables in the global electricity sector is technically feasible at every hour throughout the year and proves more cost-effective than the existing system, with the levelized cost of electricity from renewable sources (LCOE) expected to decline from €70/MWh in 2015 to €52/MWh by 2050 (including curtailment, storage and some grid costs). The study further demonstrates that the global transition to a 100% renewable electricity system would reduce power-related greenhouse gas emissions to zero by 2050 and create in total an estimated 36 million jobs in the electricity sector by 2050 in comparison to 19 million jobs in 2015. The study provides policy recommendations, which can lead to a full transition to 100% renewable electricity even before 2050, if they are successfully implemented.

One Earth Climate Model is a joint study by the University of Technology Sydney, the German Aerospace Centre and the University of Melbourne. The study is expected to be launched in early 2019 and would present detailed pathways to achieve 100% renewable energy by 2050 across all sectors (power, industry, buildings, transport), both globally and across ten geographical regions. It brings together the latest research in climate science, renewable energy technology, employment and resource impacts, and provides the link between renewable energy targets and the measures needed to achieve them. This includes developing sectoral implementation pathways, with special emphasis on differences between developed and developing countries and regional conditions and providing tools to implement the scenarios globally and domestically. In addition, non-energy greenhouse gas mitigation scenarios define a sustainable pathway for land-use change and the agricultural sector. Furthermore, results related to the impact of the scenarios on employment and mineral and resource requirements provide vital insight on economic and resource management implications. This analysis shows, that a 1.5C target is achievable if a rapid 100% renewable energy pathway is combined with a re-forestation strategy.

Coalition membership

The Coalition for Action is facilitated by the International Renewable Energy Agency (IRENA).

ABB

Abengoa Solar

ACCIONA

Access Power

Association Congolaise pour le Développement Agricole (ACDA)

Alliance for Rural Electrification (ARE)

American Council on Renewable Energy (ACORE)

Arizona State University (ASU)

Ashoka – Innovators for the Public

Bester Energy

Boston Consulting Group

Centre for Science and Environment (CSE)

Chinese Photovoltaic Industry Association

Chinese Renewable Energy Industries Association (CREIA)

Cleanergy

Clean Energy Business Council MENA

Climate Action Network (CAN)

Confederation of Indian Industry (CII)

Desertec University Network (DUN)

Dii Desert Energy

Dulas

ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE)

EKOenergy

ENEL Green Power (EGP)

Environment Development Action in the Third World (ENDA)

European Geothermal Energy Council (EGEC)

European Renewable Energies Federation (EREF)

First Solar

Folkecenter

FTI Consulting

German Renewable Energies Agency (GREA)

German Solar Association

Global Solar Council (GSC)

Global Wind Energy Council (GWEC)

Global Women's Network for the Energy Transition (GWNET)

Gold Standard

Greenpeace International

Iberdrola SA

ICLEI - Local Governments for Sustainability

International Geothermal Association (IGA)

International Hydropower Association (IHA)

International Network for Sustainable Energy (INFORSE)

International Network on Gender and Sustainable Energy (ENERGIA)/Hivos

International Renewable Energy Agency (IRENA)

Institut de le Francophonie pour la développement durable (IFDD)

Institute for Sustainable Energy Policies (ISEP)

International Solar Energy Society (ISES)

Ludwig Bölkow Foundation (LBF)

Mainstream Renewable Power

MAKE

Masdar

Middle East Solar Industry Association (MESIA)

National Wildlife Federation

Network Consulting Group

Novozymes

Ontario Sustainable Energy Association (OSEA)

Planet Energy Now

Power for All

Practical Action

Qway Energy

Rahimafrooz Renewable Energy

RE100/The Climate Group

Regional Center for Renewable Energy and Energy Efficiency (RCREEE)

Renewable Energy and Energy Efficiency Partnership (REEEP)

Renewable Energy Institute

Renewable Energy Policy Network for the 21st Century (REN21)

Renewable Energy Solutions for the Mediterranean (RES4MED)

Renewables Grid Initiative (RGI)

RenewableUK Cymru

Revelle Group

Revolve Group

Rocky Mountain Institute (RMI)

Skypower

SolarCoin Foundation

Solar Head of State

Solar Power Europe

Sunlabob Renewable Energy

Syndicat des Énergies Renouvelables (SER)

United Nations Foundation

Vestas Wind Systems

World Bioenergy Association (WBA)

World Future Council (WFC)

World Resources Institute (WRI)

World Wind Energy Association (WWEA)

World Wide Fund for Nature (WWF)

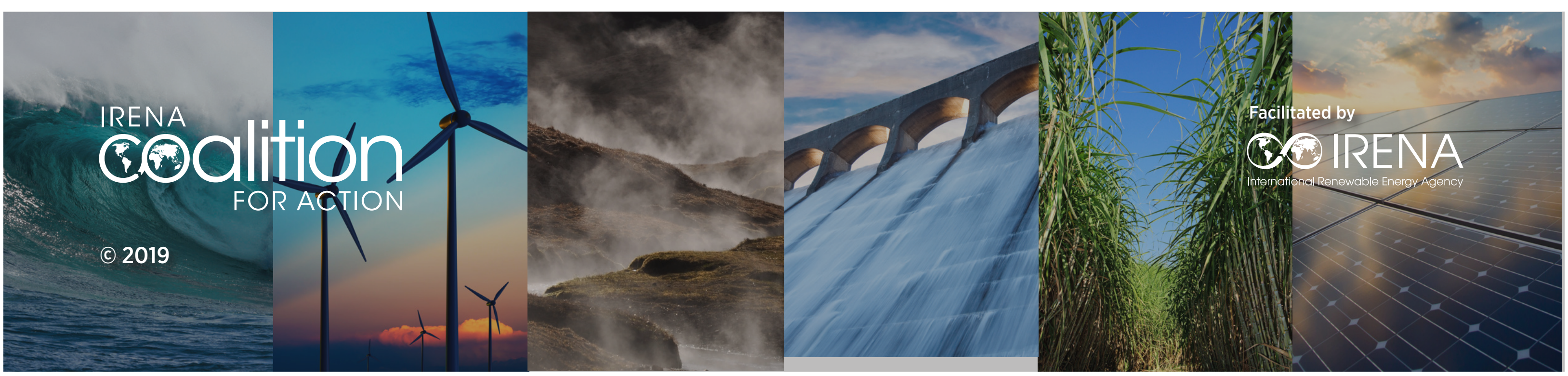
Yansa Group

*January 2019

How to join

The Coalition is open to any entity supporting the widespread adoption and sustainable use of all forms of renewable energy.

To become a member, contact the IRENA Coalition for Action team **(coalition@irena.org)** or download the application form via our web page: **www.irena.org/coalition**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FOR ACTION
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