IRENA

International Renewable Energy Agency

REMAP 2030

RENEWABLE ENERGY PROSPECTS FOR POLAND

OCTOBER 2015

BACKGROUND PAPER

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 cooperation, 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.

REmap material is available for download through **www.irena.org/remap**

For further information or to provide feedback, please contact the REmap team at **remap@irena.org**

Acknowledgements

This publication has benefited from valuable comments and guidance provided by the Ministry of Economy of the Republic of Poland (Sebastian T. Stępnicki, Marcin Ścigan). It was reviewed at the Poland REmap workshop in Warsaw on 6 March 2015 and benefited from input of the expert group (Polish Economic Chamber of Renewable Energy and Distributed Energy, Polish Wind Energy Association, EC BREC Institute for Renewable Energy, Foundation for Sustainable Energy, Polish Geothermal Association, Ministry of Agriculture, Polish Power Grid Company) and presented during the Polish Wind Energy Association Conference and Exhibition in Serock on 14 April 2015.

Authors: Dolf Gielen, Deger Saygin and Nicholas Wagner (IRENA). Wojciech Budzianowski (consultant).

Report citation: IRENA (2015), REmap 2030 Renewable Energy Prospects for Poland. IRENA, Abu Dhabi. **www.irena.org/remap**

CONTENTS

List of Figures

List of Tables

List of Boxes

KEY FINDINGS

- In 2010, renewable energy use in Poland was dominated by biomass in end-use sectors (industry, residential, commercial, services, agriculture, transport) and in power and district heat generation. A range of biomass applications accounted for 90% of total final renewable energy use of 284 petajoules (PJ) in 2010. Biomass demand for space/water heating in buildings and for process heat generation in industry represented three quarters of the total. Renewable electricity from hydropower and wind accounted for the remaining 10% of total final renewable energy use.

- Poland has prepared a detailed projection in 2020 of its renewable energy use and total final energy consumption (TFEC) – the metric used in the rest of this analysis. This forms part of its National Renewable Energy Action Plan (NREAP). A number of other studies prepared for the Ministry of Economy of Poland also provide forecasts for 2030 and 2050. These assessments are the basis for the business-as-usual scenario for 2010-2030 (referred to as the 'Reference Case' in this study).

- The Reference Case takes Poland's renewable energy share in its TFEC to 14.2% by 2020. This is equivalent to 15% if the absolute volumes were expressed in gross final energy consumption (GFEC), the metric applied consistently by all the other European Union (EU) member states. The Reference Case shows that by 2030, the renewable energy share of TFEC reaches 15.5% while its share of GFEC reaches 16.4%. This is based on estimates of TFEC development to 2020 and 2030 by the International Renewable Energy Agency (IRENA). In 2010, the base year of this analysis, the renewable energy share was 10.1% in TFEC.

- Total final renewable energy use more than doubles in the Reference Case from 284 PJ in 2010 to 531 PJ in 2030. Total final renewable energy use includes the consumption of power and district heat from renewable energy sources, renewable transport fuels and renewable fuels for cooking as well as water, space and process heating. The Reference Case renewable energy use continues to be dominated by biomass. In addition, a significant growth for wind is also envisaged, taking total installed capacity from 0.8 gigawatts (GW) in 2010 to 7.5 GW in 2030. Solar photovoltaic (PV) rises to 2.7 GW (including rooftop PV amounting to 0.3 GW).

- REmap 2030 takes the total renewable energy use share to 24.7% of TFEC by 2030. This is equivalent to a 25.9% renewable energy share of GFEC.

- In REmap 2030, the renewable energy share is estimated to be highest in the building (residential and commercial) sector. It triples from its 2010 level to 34.8% in 2030. By contrast, the renewable energy shares of some other end-use sectors double in the same period. For instance, industry increases to 23.6% and transport to 12.4%.

- REmap 2030 assumes a mix of renewable energy technologies is deployed in both power and end-use sectors. The renewable energy share of power generation is estimated to reach 37.7% in 2030 compared to 7% in 2010. Onshore and offshore wind capacities attain 16.4 GW, solar PV rises to 5 GW and bioenergy reaches 5.2 GW. Total renewable power generation grows nearly eightfold in 2010-2030 from 11 terawatt-hours (TWh) to 81.5 TWh per year in 2030.

- Total biomass demand amounts to 820 PJ per year in REmap 2030. This is lower than the total supply potential in Poland according to the estimates of IRENA (1200-1550 PJ per year). This is a favourable outcome from the point of view of resource availability and import dependency. However, deployment will also be determined by the cost-competitiveness of biomass.

- Total average investment needs to fulfil REmap 2030 are estimated at USD 4.5 billion per year in 2010-2030. This is more than twice the annual investment of USD 2 billion estimated for the Reference Case.

- Implementing all REmap Options in REmap 2030 would require an average substitution cost in 2030 of USD 4.9/gigajoule (GJ) of final renewable energy when compared to the annualised costs of the substituted conventional fuels. This is from a business perspective that assumes a 5% discount factor and a coal price ranging from as low as USD 3.6/GJ for the power generation sector to as high as USD 8.4/GJ for the household sector including taxes. Coal is the main fuel assumed to be replaced in power and heat generation sectors. Substitution costs are highest in the district heating sector, estimated at USD 13.8/GJ. This compares with transport sector savings of USD 4.2/GJ (indicated by negative substitution costs). From a government perspective that assumes a discount rate of 10% and a coal price of USD 2/GJ, the average substitution cost of the identified options is estiamted as USD 10.3/GJ. This translates to total net incremental system costs of USD 3.1 billion per year in 2030.

- Poland's 2030 total carbon dioxide (CO_2) emissions under REmap 2030 would be 17.3% lower than in the Reference Case due to total reductions of 52 megatonnes (Mt) CO_2 per year. This is 8% lower than in 2005 and 22% lower than in 1990. When externalities related to human health and climate change are accounted for, the potential of renewables identified can save up to USD 2 billion per year by 2030. This compares with costs of USD 3.1 billion per year in 2030 when externalities are excluded.

- Power transmission and grid development is a key requirement for renewable power expansion in Poland. Interconnections with neighbouring countries are sufficient today, but they are used at below capacity. Their effective use, Baltic Ring and other similar initiatives would help to manage increased capacity associated with variable renewable energy sources.

- Among the non-biomass renewables options, wind power has the largest potential in Poland. The main challenges to its development are the limited number of locations with high wind speeds. Offshore offers better wind speeds than onshore wind, but its capital costs are twice as high.

- Ensuring affordable and sustainable fuel supply chains is the main challenge to bioenergy development. This includes collection, sorting, pre-processing and logistics.

- If renewables would replace natural gas for heating in the building and industry sectors instead of coal, total demand for natural gas would fall by 20% compared to the Reference Case use in 2030. Demand would stabilise in 2010-2030 at around 11 billion cubic metres (m^3) per year, which would help Poland to reduce its reliance to imported natural gas. Net incremental system costs would also be lower at USD 2.6 billion per year compared to USD 3.1 billion per year. This is because natural gas prices are nearly three times higher than coal.

1 INTRODUCTION

Poland's energy policy to 2030 was adopted by the Polish government on 10 November 2009 and indicates support for the sustainable use of renewable energy. It contains a 15% renewable energy target for final energy consumption by 2020, which includes a 10% biofuels share in the transport sector. The details of these binding renewable energy targets are provided in Poland's NREAP, which is part of its contribution to the EU 20/20/20 goals (Ministry of Economy, 2010).

The IRENA REmap programme is a series of renewable energy roadmaps for individual countries. It shows how they can boost their own use of renewables while helping to double renewables' share in the global energy mix by 2030 to about 36% of the overall total. By June 2014, REmap studies of 26 countries suggested that this global share would only reach 21% under current conditions and policy approaches unless extra attention is paid to the matter. This indicates a 15 percentage-point gap (IRENA, 2014a). The scope of the REmap programme has been expanding since 2014 and had already reached 40 countries by 2015. Poland is among these. The country plays a critical role in fulfilling the EU energy and climate goals as it is one of the continent's largest energy users. To raise its renewables use, Poland should employ more of its wind technologies as well as its ample biomass supply for its transport sector and for heat and electricity generation.

In November 2014, the Polish government requested a REmap study from IRENA exploring the potential difference Polish renewables could make to achieve the country's energy policy and objectives to 2050. The government asked IRENA to look at the following areas in particular:

(i) Analysis of possibilities and options for further development of Poland's main renewable energy technologies (biogas, biomass, geothermal, solar, wind).
(ii) Implications of renewables for Poland's energy mix and the cost of development.
(iii) Analysis of the future development of the renewable energy industry in Poland by technology and application (electricity, heating, cooling, transportation).

REmap 2030 is the result of a collaborative process between IRENA, national experts in Poland and other stakeholders. This short report provides detailed background data and the results of REmap's analysis of Poland. It suggests how the renewables uptake could be realistically accelerated. This working paper uses the Polish government NREAP as a baseline of renewables to 2020 and 2030 (Ministry of Economy, 2010). The document also provides projected GFEC for 2020-2030[1]. It then moves on to discuss the realistic potential of renewables in 2030 (known as REmap Options) beyond this baseline. REmap Options are based on the trends seen in the data provided by Poland's government, along with a literature review. Renewables costs and benefits within the Polish energy system are considered in the context of Poland's various policy goals, such as reducing its CO_2 emissions and improving its energy security.

Meeting Poland's energy challenge will require comprehensive action, especially to ensure environmentally sustainable practices. The most likely renewable energy sources for the country are wind, hydropower, different types of biomass, geothermal energy and solar. The right mix of these options can help substitute a large share of Poland's total fossil fuel demand.

This report starts with a brief description of the REmap 2030 methodology (Section 2) and then explains Poland's total energy use growth to 2030 (Section 3). The Reference Case and the selection of REmap Options are explained in Section 4. Section 5 discusses the challenges to realising this potential and suggestions to overcome them.

1 The rest of this paper uses TFEC rather than GFEC as the main indicator. TFEC includes industry consumption (including blast furnaces and coke ovens, but excluding petroleum refineries and non-energy use), buildings (residential and commercial), transport and agriculture.

2 GENERAL REMAP METHODOLOGY

This section explains the REmap 2030 methodology and summarises details about the background data used for the Poland analysis. Annexes A and C provide background data and results in greater detail.

REmap is an analytical approach. It assesses the gap between if all countries worldwide would follow their present national plans, the potential additional renewable technology options in 2030 and the Sustainable Energy for All (SE4All) objective to double the global renewable energy share by 2030 compared to 2010.

By June 2014 REmap 2030 had assessed 26 countries: Australia, Brazil, Canada, China, Denmark, Ecuador, France, Germany, India, Indonesia, Italy, Japan, Malaysia, Mexico, Morocco, Nigeria, Russia, Saudi Arabia, South Africa, South Korea, Tonga, Turkey, Ukraine, the United Arab Emirates, the United Kingdom and the United States. In 2014-2015, 12 new countries had joined REmap 2030: Argentina, Belgium, Colombia, Dominican Republic, Egypt, Ethiopia, Iran, Kazakhstan, Kenya, Poland, Sweden and Uruguay.

The analysis starts with national data covering all energy end-users (buildings, industry, transport and agriculture) and the electricity and district heating sectors. Current national plans using 2010 as the base year of this analysis are the starting point. To the extent data availability allows, information for more recent years (*e.g.,* 2012 and 2013) was provided where relevant. In each report, a Reference Case features policies in place or under consideration, including energy efficiency improvements. The Reference Case includes TFEC for each end-use sector and the total generation of power and district heating sectors, as well as breakdowns by energy carrier for 2010-2030. The energy balances for the analysis base year, 2010, originate from data provided by the International Energy Agency (IEA, 2014a). Where relevant, the data are updated with the national energy statistics provided by Poland's Central Statistical Office (CSO). The Reference Case for Poland was based on its NREAP (Ministry of Economy, 2010). It includes Poland's GFEC and renewable energy use developments to 2020 and 2030.

Once the Reference Case was prepared, additional technology options were identified and labelled in the report as REmap Options. The use of options as opposed to an approach based on scenarios is deliberate. REmap 2030 is an exploratory study and not a target-setting exercise. While the Reference Case is based on Poland's NREAP, the REmap Options for Poland came from a variety of sources. These include a literature review and the longer-term trends beyond 2030.

IRENA developed a REmap tool that allows staff and external experts to introduce data into an energy balance for 2010, 2020 and 2030. They then assess technology options by 2030 if renewable energy deployment were accelerated. As a supplement to the annexes in this report, a detailed list of these technologies and related background data are provided online. The tool includes the capital, operation and maintenance cost and technical performance (reference capacity of installation, capacity factor and conversion efficiency) of renewable and conventional technologies for each sector analysed. These cover industry, buildings, transport, power and district heat. Conventional technologies are defined as fossil fuels, nuclear and traditional uses of biomass.

Each renewable energy technology has its own individual cost, and the cost of each REmap Option is represented by its substitution costs. These are calculated as the difference between the annualised cost of the REmap Option and a conventional technology used to produce the same amount of energy. This is divided by the total renewable energy use in final energy terms (in real USD/GJ[2] of final renewable energy in 2010). This indicator provides a comparable metric for all renewable energy technologies identified in each sector. Substitution costs are the key indicators for assessing the economic viability of REmap Options. They depend on the type of conventional technology substituted, energy prices and the characteristics of the REmap Option. The cost can be positive (incremental) or negative (savings). This is because many renewable energy technologies are

2 1 GJ = 0.0238 tonnes of oil equivalent (toe) = 0.238 gigacalories = 278 kilowatt-hours (kWh).
1 USD was on average equivalent to 3 Polish Zloty in 2010.

already or could be cost-effective compared to conventional technologies by 2030 as a result of technological learning and economies of scale.

Based on the substitution cost and the potential of each REmap Option, country cost-supply curves were developed for the year 2030 from two perspectives: government and business. For the government perspective, cost estimates are as governments would have done them, excluding energy taxes and subsidies. A capital cost of 10% was assumed for the government perspective. The choice of analysis from a government perspective is to ensure a comparison of the costs and benefits across all REmap countries. The business perspective is based on national prices including energy taxes and subsidies. It assumes a capital cost of 5%. By estimating the costs from two perspectives, the analysis shows the effects of accounting for energy taxes and subsidies whereas all other parameters were kept the same. Assessment of all additional costs related to complementary infrastructure, such as transmission lines, reserve power needs, energy storage or fuel stations are excluded from this study. IRENA analysis suggests that these costs would be of secondary importance for countries that just start with a power sector transformation.

Throughout this study the renewable energy share is estimated in relation to TFEC. This can combine all the Polish end-use sectors or be worked out individually for each one (industry, transport, residential, commercial and agricultural sectors), with and without the contribution of renewable electricity and district heating. The share of renewable power and district heat generation is also calculated.

This report also discusses the finance needs and avoided externalities related to increased renewable energy deployment. Three finance indicators are net incremental system costs, total investment needs and subsidy needs. These indicators are briefly defined below.

i) Net incremental system costs are the sum of the differences between total capital and operating expenditures (in USD per year) of all energy technologies. This is based on their deployment in REmap 2030 and the Reference Case in 2010-2030 for each individual year.

ii) Total investment needs are the annual investment needs of all REmap Options and the investment needs required in the Reference Case. Renewable energy investment needs are estimated by multiplying total deployment of each technology in GW to deliver the same energy service as conventional capacity by the investment costs in USD per kilowatt (kW) for 2010-2030. This is annualised by dividing the number of years covered in the analysis.

iii) Subsidy needs are the total subsidy requirements for renewables. They are estimated as the difference in the delivered energy service costs for the REmap Option (in USD/GJ final energy) relative to its conventional counterpart multiplied by its deployment in a given year in PJ per year.

External effects have been worked out relating to greenhouse gas (GHG) emission reductions as well as improvements in outdoor air pollution from the decreased use of fossil fuels.

For each sector and energy carrier, GHG emissions from fossil fuel combustion are estimated as a first step. For this purpose, the energy content of each type of fossil fuel was multiplied by its default emission factors based on lower heating values as provided by the Intergovernmental Panel on Climate Change (IPCC) (Eggleston *et al*., 2006). Emissions were estimated separately for the Reference Case and REmap 2030. The difference between the two numbers yields the total net GHG emission reduction from fossil fuel combustion due to increased renewable energy use. To evaluate the external costs related to carbon emissions, a carbon price range of USD 20-80 per tonne CO_2 is assumed (IPCC, 2007)[3]. This range was applied only to CO_2 emissions and not other greenhouse gases. IPCC reports from 2007 stated that the carbon price should reflect the social cost of mitigating one tonne of CO_2 equivalent GHG emissions.

The external costs related to human health are worked out in a separate step which excludes any effect from GHG emissions. Outdoor air pollution is evaluated from two sources. The first is outdoor emissions of sulphur dioxide (SO_2), mono-nitrogen oxides (NO_x) and particulate matter of less than 2.5 micrometres ($PM_{2.5}$) from fossil fuel power plant operation. The second is outdoor emissions of mono-nitrogen oxides and

3 Krajowa Agencja Poszanowania Energii (2013) suggests a carbon price of USD 17 and USD 33 per tonne CO_2 in 2020 and 2030, respectively. To ensure comparability with other REmap countries, the price was kept to USD 20-80 per tonne CO_2 in this study.

particulate matter of less than 2.5 micrometres from road vehicles. To evaluate the external costs related to outdoor emission of SO_2, NO_x and $PM_{2.5}$ from fossil power plant operation, the following parameters for respective pollutants were used:

i) Emission factor (*i.e.,* tonne per kilowatt-hour (kWh) for 2010 and 2030 taken from the International Institute for Applied Systems Analysis (IIASA) Greenhouse Gas and Air Pollution Interaction and Synergies (GAINS) database (ECLIPSE scenario (IIASA, 2014))

ii) Unit external costs, *i.e.* Euro average/tonne for the European Union (EU), adapted for Mexico from the EU Clean Air for Europe (CAFE) project (AEA Technology Environment, 2005). Potential differences in external effects between the EU and Mexico values are accounted for on the basis of the difference in gross domestic product (GDP) values.

There is an important difference between the two methodologies used to work out the renewable energy share. REmap estimates the share in TFEC while NREAP uses GFEC. The GFEC metric is applied by the European Commission (2009).

TFEC includes total combustible and non-combustible energy use from all energy carriers as fuel (for the transport sector) and to generate heat (for industry and buildings) as well as electricity and district heat. It excludes non-energy use, which is the use of energy carriers as feedstock to produce chemicals and polymers. However, it includes blast furnace and coke oven consumption by the iron and steel sector. This report uses TFEC as an indicator to measure the renewable energy share in accordance with the Global Tracking Framework report (The World Bank, 2013).

GFEC includes the energy commodities delivered for energy purposes to industry, transport, residential, commercial and public, agriculture, forestry and fishery sectors. This includes the consumption of electricity and heat by the energy sector for electricity and heat production, as well as electricity and heat distribution and transmission losses (European Commission, 2009). For this reason, the developments in absolute numbers according to REmap are identical to NREAP, but the estimated shares of renewable energy differ.

3 ENERGY USE GROWTH IN THE REFERENCE CASE

Poland's Reference Case (business as usual) has been prepared on the basis of the country's NREAP (Ministry of Economy, 2010). This is Poland's submission to the European Commission in view of the 2020 renewable energy targets. Reference Case takes into account the developments in Poland's NREAP to 2020 with minor deviations in technology deployment. NREAP also provides projections to 2030 with a breakdown by sector and technology use.

Data for the base year, 2010, are taken from the Polish national statistics office (CSO, 2013) and the IEA energy balances (IEA, 2014a). The growth in each energy carrier and sector for 2010-2030 is the basis for the analysis presented in this study and is supplied in Poland's NREAP (see Table 1). If necessary, data from Krajowa Agencja Poszanowania Energii (2013) are also used. While there are differences between this study and Poland's NREAP in total energy demand, the renewable energy use figures are almost the same.

According to Table 1, Poland's TFEC in 2010 amounted to 65 megatonnes of oil equivalent (Mtoe) per year. This is around 8% higher than TFEC reported in Poland's NREAP (60.2 Mtoe per year), which was prepared before 2010 so the data reported is only a projection. Poland's NREAP forecasts that TFEC increases to 73.7 Mtoe and 78.9 Mtoe per year by 2020 and 2030 respectively. This is equivalent to an annual rise in total energy demand of about 1% in 2010-2030.

Total electricity demand increases faster than TFEC at 1.9% per year in 2010-2030. This represents an increase in end-use electricity demand from 120 TWh to 173 TWh per year. By comparison, gross electricity generation rises to 216 TWh per year. The difference between generation and consumption is explained by energy industry own consumptions and transmission and distribution losses. The share of electricity in TFEC climbs slightly from 16% in 2010 to 19% in 2030. District heating demand grows at an equally high rate of 2% per year. Its share of total energy demand reaches 13% in 2030 compared to 11% in 2010. The share of industrial energy use in TFEC increases from 22% in 2010 to 26% in 2030 whereas the buildings sector share decreases to 40% from 46% over the same period.

Table 1: Total final energy consumption in sectors of Poland's economy

	2010* [Mtoe/year]	2010** [Mtoe/year]	2020* [Mtoe/year]	2030* [Mtoe/year]
Industry[1]	15.4	14.6	17.7	20.3
Transport	15.3	17.0	18.5	23.0
Agriculture	5.1	3.8	5.0	4.2
Buildings	24.4	29.6	27.0	31.4
Total[2]	**60.2**	**65.0**	**68.1**	**78.9**
Fuels & renewable energy	43.8	47.6	47.8	53.3
Electricity	9	10.3	11.2	14.9
District heating	7.4	7.1	9.1	10.7

* Ministry of Economy, 2010
** CSO, 2013; IEA, 2014a
1 Data exclude the energy use by blast furnaces and coke ovens. To account for this, 2.2, 2.6 and 3.1 Mtoe per year was included in total industrial energy use for 2010, 2020 and 2030, respectively.
2 Data exclude non-energy use in chemicals and other sectors. Final energy demand reported by the Ministry of Economy (2010) includes these values. Non-energy use accounts for 7-8% of Poland's total final consumption. This translates into about 16% of total final industrial energy use and about 2% of Poland's total non-industrial energy use. The shares refer to 2006 data – the base year for Poland's NREAP. These values are excluded from this table and the rest of this study.

Box 1: Renewable Energy Act, Auctions and Feed-in-Tariffs

The latest legislative changes in Poland implemented through the Renewable Energy Act introduce two new mechanisms to incentivise renewable energy investment in the power generation sector starting with 2016. The first is an auction system to replace green certificates and the second is the Feed-in-Tariff (FiT) applied to microgeneration (up to 10 kW).

Poland's previous renewable energy promotion system, based on green certificates, led to the development of centralised biomass co-firing. This increased biomass prices and delayed the expansion of other bioenergy technologies. These changes in the Renewable Energy Act will give the government almost entire control over the rate of the deployment of each technology and the volume of related investments. The government can now take into account the most recent economic and technological trends as well as externalities and indirect economic impacts associated with various renewable energy technologies. The auction system is weighted towards the most cost-effective projects and technologies. Thus the winning renewable energy projects should provide relatively cheap electricity.

Economic incentives will allow the development of small-scale private renewables microgeneration in Poland. This might in future make an impact on the facilitated diffusion of distributed renewable energy systems. Microgeneration creates an opportunity for private investment in renewable energy and hence innovative small and medium-sized renewable energy enterprises. FiTs may be considered attractive, but the Act envisages a procedure for theirs potential change. Restrictions imposed in the Renewable Energy Act will also limit the impact of microgeneration. These exclude units greater than 10 kW, limit the eligible time span to 2016-2020 and confine the overall capacity of the programme to 800 MW.

Objectives set out in NREAP and particularly in REmap 2030 would require an auction system that aggressively incentivises investment, as well as attractive threshold prices. These would need to be at around the level of neighbouring countries with similar renewable energy potential. Yet the case for aggressively incentivising investor participation in the auction system may be moderate and should be viewed in the light of Poland's total renewable energy deployment needs. This is between USD 2-4.5 billion per year on average in 2010-2030 according to the Reference Case and REmap 2030. The FiT programme has limited capacity to 800 MW until 2020. Beyond 2020, the programme may be extended and revisions might allow for additional capacities. However, this would depend on the results achieved in the first phase of the programme in 2016-2020.

Incentives could be gradually decreased once renewable energy and national market prices converged and the desired renewable energy capacities are achieved. The auctioning system will cost the government little, but it is unclear whether it will result in an optimal renewable energy system in the long term and how investments will continue in the transition period from green certificate scheme. The direction in which renewable energy evolves in Poland is important; it will need to be underpinned by an enduring, cost-effective system that ensures low energy pricing nationally.

4 REMAP 2030

Three REmap 2030 cases have been devised to provide the Polish government with a range of renewable energy technology options. Each of these cases assumes a growth of renewable energy technologies beyond the Reference Case. However, it shows varying levels of deployment. This paper focuses on the results of the most ambitious of the three (Case 2). Detailed results of all three cases are provided in Annex B.

4.1 Selection of REmap Options

REmap Options are the additional technologies deployable beyond the Reference Case in 2020 and 2030. They have neither a technical nor a cost limit. More renewable energy is possible beyond REmap Options. They are to a great extent estimated from studies envisaging accelerated renewable energy uptake in Poland to 2020 and 2030, experiences from other countries and input from renewable energy experts. The rationale behind individual renewable energy technologies and a brief comparison with available literature is provided below by technology. Table 3 provides a summary of the technology development in 2010-2030 according to the Reference Case and REmap.

Wind

Wind onshore and offshore potential is located in the Baltic Sea region, the site of most of Poland's wind farms at present. Average wind speeds are 2-3 metres per second greater in the Baltic Sea region compared to mainland Poland.

A large body of studies has considered wind deployment potential in Poland. The Polish Maritime Area is 8 682 square kilometres (km^2) while the Polish Exclusive Economic Zone is 22 500 km^2. Within this area, 2 747 km^2 are protected maritime zones belonging to the Natura 2000 network. The Gdansk Maritime Institute indicates the technical potential of the Polish Maritime Area and the Exclusive Economic Zone is 20 GW. However, a correction accounting for the Natura 2000 network zones cuts that potential to 7.5 GW (South Baltic Off.E.R, n.d.). A study prepared by the Polish Prime Minister's office indicated a technical onshore wind potential in 2030 at 31.5 GW. Onshore wind economic potential is assessed by the Institute for Renewable Energy (2010) at 11.5 GW. According to the Polish Wind Energy Association (PWEA) in 2010, onshore wind potential in 2020 is 10.9 GW. In 2014, the European Wind Energy Association (EWEA) suggested a 7-12 GW range for the same year. For offshore wind, the Polish Wind Energy Association (2010) and European Wind Energy Association (2014) estimate 500-1500 MW by 2020. Cetnarski (2014) estimates an offshore wind potential of 3.5-6 GW by 2025. Greenpeace/Global Wind Energy Council/European Renewable Energy Council (2013) estimate much higher growth of 17 GW onshore wind and 10 GW offshore wind.

Total installed capacity in 2013 for onshore wind amounted to 3 390 MW, while no offshore wind has yet been installed. The estimates in this literature would imply annual installation rates of 500-1 230 MW for onshore and 140-330 MW for offshore wind. Poland's NREAP (Ministry of Economy, 2010) envisages an annual installation rate of 490 MW between 2010 and 2020. This falls to an annual rate of 120 MW in 2020-2030. For offshore wind, annual installation rates are 20 MW and 37 MW in 2010-20 and 2020-2030, respectively.

REmap estimates an annual onshore wind growth of about 675 MW in 2010-2030, a rate about 50% higher than NREAP estimates. However, these rates have been achieved in 2012-2013 and are therefore found to be realistic. For offshore wind, the annual installation rate is 110 MW in 2010-2030. These growth rates are at the low end of the range in a number of studies, however, would still require significant effort beyond the NREAP projections.

The first onshore wind farms in Poland were very small. In 2012, the average plant size was only about 3.5 MW per farm (Polish Information and Foreign Investment Agency, 2012). In 2030, they will be larger at 10-100 MW, and even bigger wind parks of up to 500 MW will be evolving. Offshore wind farms will be larger than onshore, possibly attaining capacities of about 500 MW per farm. It is expected that with the auction system, wind onshore plants would be deployed first to 2020. With better cost-competitiveness wind offshore would be deployed mostly after 2020.

The annual capacity factor for onshore wind in the Reference Case is assumed at 26% (based on NREAP, 2 270 hours) and 28% in REmap 2030 (based on Krajowa Agencja Poszanowania Energii, 2013, 2 450 hours). These are higher than the annual capacity factor of 22% (1 930 hours) based on 15 minute increments measured in 2013 by the transmission system operator (TSO) Polskie Sieci Elektroenergetyczne (PSE).

Hydropower

The annual economic potential of hydropower generation is estimated at 8.5 TWh (anonymous, 2009). These exceed the potential in REmap 2030 of hydropower generation at 4.5 TWh. This translates to 1.5 GW installed in 2030 compared to 0.96 GW in 2010.

Hydropower today is mainly associated with two rivers. The Vistula provides 52% and the Oder provides 11% of the total hydropower technical potential (anonymous, 2009). It is therefore expected that the majority of deployment associated with REmap 2030 will relate to these two rivers.

The average size of hydropower plants was 1.2 MW in 2012 (Polish Information and Foreign Investment Agency, 2012). The average installed capacity for small hydropower was about 0.4 MW (United Nations Industrial Development Organization and International Center on Small Hydropower, 2013). For large hydropower it was about 20 MW. By 2020 and 2030, no major changes are assumed for the average installed capacity of hydropower plants.

Solar PV

Deployment of solar PV could follow the trend in Germany but with some delay in deployment given the rather limited solar potential and economic incentives for investors in Poland. Germany has shown it is possible to attain an annual installation rate of 5% of total peak demand. REmap 2030 assumes an annual installation rate of 1% of the total peak demand for solar PV (250 MW in 2010-2030). Poland's peak demand today is around 25 GW.

In REmap 2030, solar PV is deployed in 2020, assuming that recently introduced FiTs for microgeneration drive the deployment of rooftop solar PV. If concentrated solar power (CSP) is deployed, it will be limited to one or two demonstration facilities of small capacity.

Solar PV will be evenly distributed throughout the country since average solar irradiation is more or less uniform across Poland. Northern Poland lacks coal power plants, so this part of the country in particular requires renewable electricity generation. Onshore/offshore wind would already meet some of this demand, and a contribution from utility-scale solar PV can be expected.

In 2012, the average installation size of solar PV systems was 156 kW per plant. These utility-scale solar PV plants would have an average installed capacity of about 0.5 MW by 2030. With the new Renewable Energy Act in Poland there will be a tendency in the next years to have smaller solar PV installations associated with distributed rooftop installations. Auction systems would support larger installations but most projects are to be deployed after 2020.

Geothermal

The geothermal potential in Poland is associated mainly with heating applications because geothermal sources are mostly low temperature. REmap 2030 estimates about 17 PJ for district heating, which will be the major application for geothermal energy in Poland (Dumas and Bartosik, 2014). In addition, some minor potential is associated with recreational spas. It is envisaged that geothermal electricity will not develop by 2030. These assumptions follow trends in Europe where geothermal power has rarely been deployed in countries with geothermal potential similar to Poland. Low-temperature geothermal sources available in Poland cannot be efficiently used to generate power, so without significant financial incentives geothermal power is unlikely to develop until 2030.

Heat pumps

The potential for heat pumps is significant for heating in buildings. REmap 2030 estimates about 20 PJ renewable heat generation from heat pumps in this sector. This is equivalent to around half a million heat pumps

Table 2: Largest biomass power generation plants in Poland, 2012

Location	Total biomass demand (Mt per year)	Total bioenergy (PJ per year)
Połaniec	1.5	26.3
ZE PAK	0.7	12.3
Ostrołęka	0.6	10.5
Białystok (CHP)	0.5	8.9
Dalkia Łódź	0.4	7.0
Dalkia Poznań	0.4	7.0
Warszawa Siekierki (CHP)	0.3	5.3
Bydgoszcz (CHP)	0.3	5.3
Opole	0.3	5.3
Elbląg (CHP)	0.3	5.3
Total	**5.3**	**95.4**

Note: Total biomass demand for CHP plants includes demand for both power and heat generation. Tonnes of biomass were converted to energy by assuming a lower heating value of 17.5 megajoules per kilogramme.
Białystock, Połaniec and ZE PAK plants have units that run with 100% biomass. Other plants listed here burn a mix of biomass and other fuels.
Source: Towarowa Giełda Energii (2012)

supplying heating to 1.9 million people in Poland[4]. In 2013, 15 000 heat pumps of various types were in use in Poland (Lachman, 2014). This number could grow by 22.5% each year until 2030.

Biomass

Polish urban and rural households use biomass for space and water heating as well as cooking. A survey examining consumption in 2009 found 5.7 million households used woodfuel. This is often interchangeable with coal and is typically used in warmer months because of its lower energy content (CSO, 2012). In particular, ageing solid fuel cooking stoves dating back an average of 24 years are used by about 11% of all households (1.5 million). This offers major potential for replacement by modern and efficient cooking appliances, including biomass. Industry also uses industrial and domestic waste as well as biomass for process heat generation. This represents about 10% of the sector's TFEC. Biogas production has started only recently. There are about 200 biogas plants and they are unevenly distributed across the country (Chodowska-Miszczuk and Szymanska, 2013).

Table 2 displays the location of the largest biomass-fired electricity power plants and their total biomass consumption as fuel in 2012. Some of these plants fully operate based on biomass while others use a mix of biomass and other fuels. These plants will account for a significant portion of Poland's biomass demand for power generation to 2020, as well as some of its heat demand. However, new bioenergy projects such as the Tychy combined heat and power (CHP) plant will be also deployed. There are also several other small demonstration units that involve biomass gasification and syngas combustion. Several heat only plants that run fully on biomass also exists, but their sizes are small and dispersed across smaller cities of Poland.

Forest residues, agricultural residues and other organic wastes are typically used as feedstocks. Forest residues are typically used alongside small contributions from agricultural residues. Some biomass plants use imported biomass transported over long distances sometimes exceeding 100 km per trip. Biomass supply is already a considerable logistical and organisational concern affecting Poland today (Rogulska and Krasuska, 2012). Its cost-effectiveness will therefore continue to be a major challenge.

Biomass is expected to serve a variety of applications ranging from the power and district heating sectors to end-use sectors like buildings, industry and transport. Solid biomass will need to be used increasingly locally

4 Assuming 55.2 GJ thermal energy required annually per household including 41.8 GJ renewable thermal energy, 1 kW_e average electrical power per heat pump, 50% capacity factor, 350% thermal-to-electrical efficiency, 15% share of renewable electricity in electricity mix and four people per household.

to avoid long distance transportation. However, more centralised facilities will also be deployed, especially in cities with stable demand. These facilities use biomass power blocks in power plants and biomass CHP plants.

According to ENDS (2014), up to 30 Mt of biomass and waste could be used in Poland for combined heat and power generation. This is six times more than the total biomass demand for power generation today. This total would compromise 12 Mt would waste, 10 Mt forestry residues and 8 Mt dedicated biomass plantations. 30 Mt of biomass and waste can replace about 15 Mt coal.

REmap estimates of current dedicated multi-fuel combustion (co-firing) are based on CSO (2013). This study estimated 5.6 TWh total electricity derived from dedicated multi-fuel combustion in 2010. Hansson *et al.* (2009) and Rogulska and Krasuska (2012) reported similar figures. REmap 2030 assumes that co-firing will be gradually abandoned by 2030 and replaced by other mostly local biomass energy use (*e.g.,* heat only and small-scale CHP). This will make more biomass available for other sectors. More digestible and wet biomass will be also available in greater quantities for anaerobic digestion. In addition, the liquid biofuels sector will benefit from greater biomass availability. This implies the expanded use of conversion technologies like ethanol, biodiesel, pyrolysis or Fischer-Tropsch fuels.

REmap 2030 indicates up to 3.8 GW and 5.2 GW total power generation capacity for 2020 and 2030, respectively. Annual total power generation in 2030 is estimated at 16.5 TWh from solid biomass and 12 TWh from biogas.

REmap assumes an expansion of CHP systems using solid biomass and biogas. This will benefit the power industry and sectors supplying heat (district heating and industry). Different studies suggest a range of numbers for CHP potential based on biomass and its use for power generation. According to a study by the Institute for Sustainable Development in 2009, about 22 TWh of electricity from solid biomass and 24 TWh from biogas can be produced by 2030. REmap 2030 estimates are somewhat lower than these indications. Greenpeace/Global Wind Energy Council/European Renewable Energy Council (2013) envisage electricity generation capacity at 4 GW by 2020 and 6 GW by 2030, which is similar to REmap findings. A recently released cogeneration roadmap has estimated an additional CHP potential of at least 4 GW by 2030 for Poland (Jozef Stefan Institute, 2014). About 3 GW of this total is related to biomass (1.5 GW solid biomass and 1.5 GW biogas). The remaining 1.2 GW is related to gas and coal CHP capacity. REmap 2030 is more ambitious and assumes that biomass can further replace fossil fuels.

Anaerobic digestion for biogas production will be based mostly on various residual organic materials. However, a mix of dedicated short rotation energy crops could be utilised as the next preferred option for biogas generation in Poland if the need emerges (Budzianowski, 2012). The anaerobic CHP power-to-heat ratio will be higher than for solid biomass CHP (0.5-0.6), close to 2 – which is equivalent to today's level.

REmap 2030 assumes that the share of biomass in heating will remain high since the expansion of solar water heaters and heat pump solutions will be limited.

In addition, biomass could be used in individual heat-alone systems in buildings and industry plants. Industry sector could be responsible for 750 MW, which equates to 400-1500 units of 0.5-2 MW heating capacity. The average size of biogas heating plants in 2012 was 0.65 MW. This would require about 1 billion m^3 biogas.

REmap 2030 also indicates a potential 560 MW for buildings, or up to 6 000 units. This is based on a maximum unit capacity of 100 kW. This would require about 0.8 billion m^3 biogas. Only minor additional potential solid biomass use in heat-only boilers is estimated beyond the Reference Case since the main technology option for heat supply is district heating and industrial CHPs.

Biogas plants today are distributed unevenly and located in northwestern and central Poland. Although investors will continue to seek sites that ensure access to cheap biomass, logistics will need to be expanded.

In 2012, the average size of biomass-fired power plants was about 23 MW. The average size of industrial CHP may amount to 5-10 MW, depending on industry. In district heating, larger CHP units are expected with a capacity of about 50 MW depending on local demand. Dedicated multi-fuel combustion (co-firing) and dedicated biomass boilers will co-exist in current and newly constructed CHP power plants.

Table 3: Renewable energy use in the base year, Reference Case and REmap, 2010-2030

	Sector/technologies	Unit	2010	Reference Case 2020	Reference Case 2030	REmap 2020	REmap 2030
1. Power sector							
Power Capacity	**Total renewable power capacity**	GW_e	**3.4**	**10.6**	**15.6**	**13.8**	**28.3**
	Hydropower[1]	GW_e	1.0[1]	1.1	1.2	1.1	1.4
	Wind[2]	GW_e	0.8	5.9	7.5	8.4	16.4
	Onshore wind	GW_e	0.8	5.7	6.9	7.7	14.3
	Offshore wind	GW_e	0.0	0.2	0.6	0.7	2.2
	Bioenergy	GWe	1.7	3.6	4.3	3.8	5.2
	Dedicated multi-fuel combustion (power)[3]	GW_e	1.4	1.7	0.9	1.2	0.0
	Solid biomass (power only)[3]	GW_e	0.0	0.5	1.1	0.5	1.1
	Solid biomass (CHP – district heating)[4]	GW_e	0.2	0.2	1.0	1.1	1.0
	Solid biomass (CHP – industry)[4]	GW_e	0.0	0.4	0.3	0.5	0.7
	Liquid & gaseous biofuels (CHP- district heating)[4]	GW_e	0.1	0.8	1.4	0.9	2.1
	Solar PV[5]	GW_e	0.0	0.001	2.7	0.5	5.0
	Utility-scale	GW_e		0.0	2.4	0.3	3.0
	Rooftop	GW_e		0.0	0.3	0.2	2.0
	Solar CSP	GW_e	0.0	0.0	0.0	0.0	0.3
Electricity Generation	**Total renewable electricity generation**	TWh	**11.0**	**31.2**	**41.6**	**44.9**	**83.5**
	Hydropower	TWh	2.9	3.2	3.2	3.5	4.5
	Wind	TWh	1.7	13.7	32.5	21.5	43.0
	Onshore wind	TWh	1.7	13.0	15.8	19.0	35.0
	Offshore wind	TWh	0.0	0.7	2.0	2.5	8.0
	Bioenergy	TWh	6.4	14.3	18.5	19.4	28.5
	Dedicated multi-fuel combustion (power)	TWh	5.6	7.0	3.5	5.0	0
	Solid biomass (power)	TWh	0.0	2.0	4.8	2.2	5.0
	Solid biomass (CHP – district heating)	TWh	0.4	0.5	2.5	5.0	8.5
	Solid biomass (CHP – industry)	TWh	0.0	0.8	0.8	2.0	3.0
	Liquid & gaseous biofuels (CHP-district heating)	TWh	0.4	4.0	6.9	5.2	12.0
	Solar PV	TWh	0.0	0.0	2.1	0.5	5.0
	Utility-scale	TWh	0.0	0.001	1.9	0.3	3.0
	Rooftop	TWh	0.0	0.000	0.2	0.2	2.0
	Solar CSP	TWh	0.0	0.0	0.0	0.0	0.5
2. District heating		**PJ_{th}**	**12.8**	**23.6**	**55.1**	**75.6**	**124.6**
Solar heating/cooling		PJ_{th}	0.0	0.0	0.0	0.0	0.0
Geothermal heat		PJ_{th}	0.6	9.1	14.2	12.0	17.0
Bioenergy		PJ_{th}	12.8	14.5	40.9	63.6	107.6
Dedicated multi-fuel combustion (heat)		PJ_{th}	1.4	1.5	1.6	2.0	2.7
Solid biomass (heat)		PJ_{th}	0.3	0.5	1.0	15.0	20.0
Solid biomass (CHP)		PJ_{th}	10.3	3.6	18.0	36.0	61.2
Liquid & gaseous biofuels (heat)		PJ_{th}	0.0	0.0	0.5	1.0	1.5
Liquid & gaseous biofuels (CHP)		PJ_{th}	0.7	7.4	12.8	9.6	22.2
3. Industry and other sectors (incl. construction. agriculture/forestry)		**PJ_f**	**82.1**	**92.8**	**102.9**	**123.0**	**157.0**
Solar heating/cooling		PJ_f	0.0	0.0	0.0	4.0	10.0
Geothermal heat		PJ_f	0.0	0.0	0.0	0.0	0.0
Bioenergy		PJ_f	82.1	92.8	102.9	119.0	147.0
Solid biomass (heat)		PJ_f	81.9	82.0	90.0	90.0	100.0
Solid biomass (CHP)		PJ_f	0.0	7.2	7.2	18.0	27.0
Liquid & gaseous biofuels		PJ_f	0.2	3.6	5.7	11.0	20.0
Heat pumps		PJ_{th}	0.0	0.0	0.0	0.0	0.0
Total electricity consumption (mix)		TWh	43.5	47.2	62.0	47.2	62.0

Sector/technologies	Unit	2010	Reference Case 2020	Reference Case 2030	REmap 2020	REmap 2030
4. Buildings (residential and commercial)	**PJ_f**	**123.5**	**151.6**	**188.4**	**189.2**	**235.3**
Solar heating/cooling	PJ_f	0.4	5.3	26.1	24.0	45.0
Geothermal heat	PJ_f	0.6	0.2	0.3	0.2	0.3
Bioenergy	PJ_f	121.7	140.0	155.0	155.0	170.0
Solid biomass (heat)	PJ_f	120.7	130.0	140.0	145.0	155.0
Liquid & gaseous biofuels (heat)	PJ_f	1.0	10.0	15.0	10.0	15.0
Heat pumps	PJ_{th}	0.9	6.2	7.0	10.0	20.0
Total electricity consumption (mix)	TWh	72.3	78.6	103.2	78.6	103.2
5. Transport sector	**PJ_f**	**37.1**	**63.2**	**71.4**	**79.5**	**108.5**
Liquid & gaseous biofuels	PJ_f	37.1	63.2	71.4	79.5	108.5
Ethanol (conventional)[6]	PJ_f	7.9	17.8	20.5	20.0	23.0
Ethanol (advanced)[6]	PJ_f	0.0	8.8	10.5	11.0	15.0
Biodiesel	PJ_f	29.2	33.9	37.4	45.0	62.0
Biomethane	PJ_f	0.0	2.8	3.0	3.5	8.0
Biohydrogen	PJ_f	0.0	0.0	0.0	0.0	0.5
Electricity consumption (renewable)	TWh	0.2	0.6	0.9	0.8	1.2
Rail transport	TWh	0.2	0.4	0.6	0.5	0.8
Road transport (private)	TWh	0.0	0.0	0.0	0.0	0.0
Road transport (public)	TWh	0.0	0.2	0.3	0.3	0.4
Electricity consumption (mix)	TWh	3.3	3.6	4.8	4.2	5.5
6. Total power generation	**TWh**	**157.1**	**166.1**	**216.2**	**166.1**	**216.2**
Renewables share in power generation	%	7	18.8	19.2	27.0	37.7
7. TFEC (IRENA)	**PJ_f**	**2 816**	**2 933**	**3 417**	**2 933**	**3 417**
7. TFEC (NREAP)	**PJ_f**	**2 521**	**2 852**	**3 302**	**2 852**	**3 302**
Renewable fuels for heating and transport	PJ_f	243	308	363	392	501
Renewable power consumption	PJ_f	30	89	120	128	235
Renewable heat consumption	PJ_f	11	21	48	68	109
Total renewables use	**PJ_f**	**284**	**417**	**531**	**587**	**845**
Renewables share in TFEC (IRENA)	**%**	**10.1**	**14.2**	**15.5**	**20.0**	**25.6**
Renewables share in TFEC (NREAP)	**%**	**11.3**	**14.6**	**16.1**	**20.6**	**24.7**
8. GFEC (IRENA)	**PJ_f**	**2 814**	**2 897**	**3 373**	**2 897**	**3 373**
8. GFEC (NREAP)	**PJ_f**	**2 567**	**2 897**	**3 392**	**2 897**	**3 392**
Gross renewable electricity demand	PJ_f	39	112	150	162	292
Gross renewable heating demand	PJ_f	217	262	339	374	487
Gross renewable transport biofuels demand	PJ_f	37	61	69	76	100
Total renewables use	**PJ_f**	**294**	**436**	**558**	**612**	**879**
Renewables share in GFEC (IRENA)	**%**	**10.4**	**15.0**	**16.4**	**21.1**	**25.9**
Renewables share in GFEC (NREAP)	**%**	**11.5**	**15.0**	**16.5**	**21.1**	**26.1**

Note: e: electric; f: final fuel input; th: thermal heat generated.

TFEC (IRENA) refers to the boundaries of the energy system based on the IRENA TFEC definition. GFEC (IRENA) is converted from the TFEC according to the IRENA definition.

1 Total small and large hydropower. Capacity factor in 2006 was 25%, rising to approximately 32% by 2020 and 2030 according to NREAP.
2 The NREAP capacity factor rises from 24% in 2010 to 26% by 2020 and 2030. For REmap, a 28% capacity factor is assumed for onshore wind according to Krajowa Agencja Poszanowania Energii (2013). No capacity factor is provided for offshore wind. This study assumes a 40% and 42% capacity factor for the Reference Case and REmap, respectively.
3 NREAP excludes the development of installed capacity for co-firing. Capacity factors are estimated at 47% in 2006 based on hard coal power plants (both power and CHP). A similar capacity factor of 50% is assumed for biomass-fired power systems, which NREAP also excludes.
4 Biomass CHP capacity factors are estimated based on the generation and capacity installed of certified biogas (57%) and biomass (24%) energy sources in 2007-2009. For REmap 2020/2030, a 50% capacity factor is assumed.
5 NREAP indicates solar PV capacity factor of 9%. In REmap 2020/2030, an 11.5% capacity factor is assumed.
6 Conventional and advanced bioethanol contribute equally to the transport sector's renewable energy use and share.

Biomass is associated with forestry and existing agricultural land or land that can be converted to agricultural or forestry use. It is available in most parts of Poland, but varies locally. Thus both solid power and CHP plants based on biomass and biogas will be found in areas where local biomass potential is highest. Industrial CHP might be needed in industries employing intensive process heating such as some chemicals, pulp and paper producers, as well as other manufacturing industries that employ low and medium temperature process heat.

IRENA (2014b) envisages an annual biomass supply potential of 1196-1541 PJ in Poland by 2030. This is subdivided into energy crops (394-431 PJ), harvesting residue (99-167 PJ), processing residue (70-141 PJ), biogas (around 200 PJ), woodfuel (0-221 PJ), wood residue (218-271 PJ) and wood waste (around 165 PJ). Total demand for biomass in REmap is below these levels (820 PJ).

According to IRENA (2014b), biomass supply costs in 2030 are in the range of USD 3-4/GJ (biogas and agricultural residues) and USD 10-12/GJ (forest residues and energy crops). Wood pellet prices in Poland in September 2013 ranged between USD 6 and USD 8 per GJ for residential users (including value added tax), with small-scale bags costing USD 8-9/GJ. For industrial uses, wood pellet prices were USD 4-6/GJ (excluding value added tax).

Transport

Projections for transportation biofuels are consistent with the Greenpeace/Global Wind Energy Council/European Renewable Energy Council (2013) study, which envisages about 80 PJ biofuels in transport by 2030. REmap 2030 estimates 108.5 PJ. Progress in biomethane as transport fuel is also considered. The potential for renewable electricity use in transport will be mainly limited to rail and urban electric networks while no major development for electric vehicles outside large cities is expected until 2020.

4.2 Renewable energy use prospects to 2030

Reference Case

According to the NREAP, renewable energy share in Poland's GFEC needs to reach 15% by 2020. This implies a total annual renewable energy use of 435 PJ (10 381 ktoe). In 2030, estimated annual renewable energy use would amount to 558 PJ (13 320 ktoe) according to the Reference Case. That would represent 16.5% of annual GFEC at 3 392 PJ. GFEC in Poland would rise by 31% in 2010-2030 whereas total renewable energy use would leap up by 190%.

The renewable energy share of the power sector in TFEC is projected to more than double from 7% in 2010 to 19.2% in 2030, showing increases across all categories. For industry and agriculture, it should climb from 12.3% to 15.0% and in buildings from 12.1% to 22.5%. The equivalent transport figure would increase from 5.3% to 7.7%. These shares include the quantities of electricity and district heating consumed from renewable energy sources.

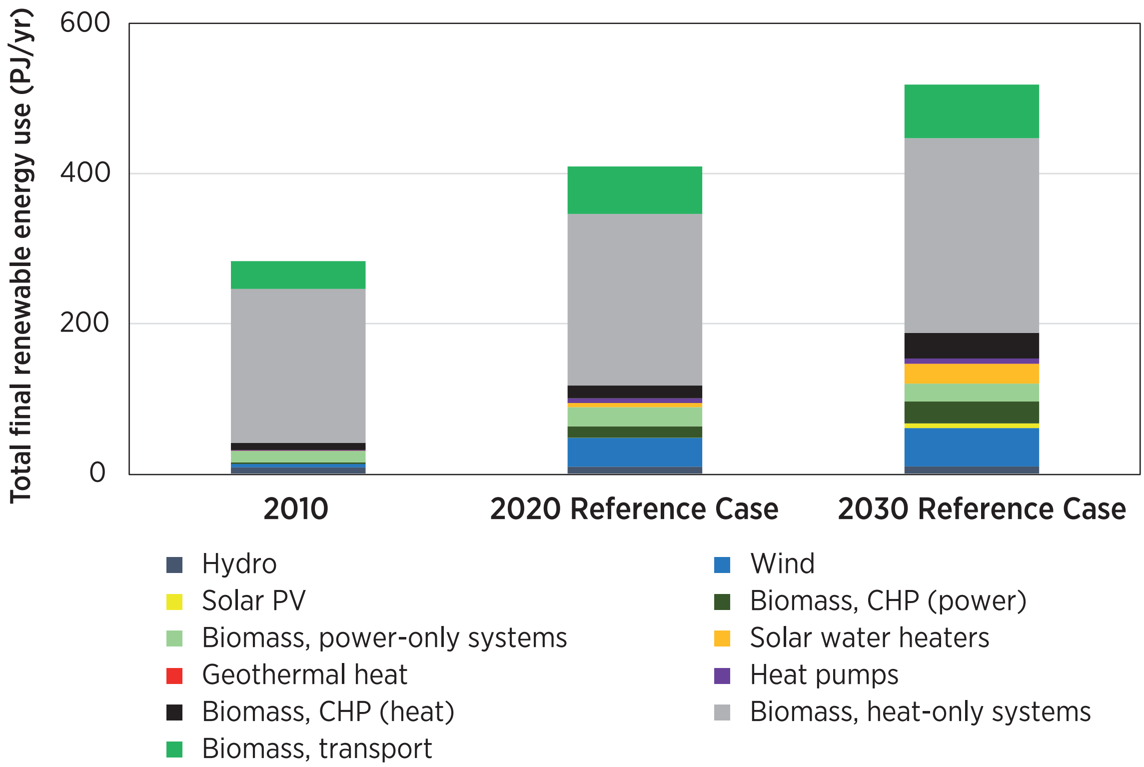
Final renewable energy use is projected to increase from 284 PJ in 2010 to 531 PJ in 2030 (Figure 1). Bioenergy continues to dominate the mix although its share is expected to decrease from 95% in 2010 to 78% in 2030. The hydropower portion falls from 3.5% to 2% because of wind power growth. In the power sector, hydropower and wind account for half of total renewable power production. The other half consists of solid and gaseous biomass. Biomass will be the main source for the heating and transport sectors.

REmap 2030

With all REmap Options implemented, total renewable energy use in Poland's TFEC would reach 845 PJ in REmap 2030. Of this, 28% would be for renewable power consumption (235 PJ) and 72% for renewable gas, heat and fuels (610 PJ). Total renewable energy use in Poland's TFEC would reach 24.7% in REmap 2030, compared to 10.1% in 2010 and 15.5% in the 2030 Reference Case. Installed renewable energy capacity would rise from 15.6 GW in the Reference Case to 28.3 GW, a difference of 12.7 GW. The increase comes mainly from wind (an additional 8.9 GW), solar PV (2.3 GW) and biomass power (0.9 GW). All the additional biomass power capacity in REmap 2030 is assumed to be used for industrial CHP. Minor capacity additions for hydropower and solar CSP are also assumed.

As a result of these additions, total annual renewable energy power generation would double to 81.5 TWh in comparison with the Reference Case at 41.6 TWh. This

Figure 1: Development of renewable energy use in the Reference Case, 2010-2030



is equivalent to a 37.7% share for renewable energy in Poland's power generation sector, and is more than five times the level in 2010.

Significant new capacity would also have been added to the heating and transport sectors. The greatest increase would originate from biomass. Total annual final biomass demand for transport fuels and heating, including district heating, would jump by 45% to 533 PJ under REmap Options compared to 370 PJ in the Reference Case.

Table 4 shows renewable energy developments by sector in 2010-2030 as well as total renewable energy use by sector under REmap Options. Compared to their TFEC, the buildings and industry sectors would have the

Table 4: Renewable energy share and total renewable energy use by sector, 2010-2030

		Renewable energy share (%)		
		2010	Reference Case 2030	REmap 2030
Industry & agriculture	excl. electricity & district heating	10.6	10.0	15.3
	incl. electricity and district heating	12.3	14.7	25.3
Buildings	excl. electricity & district heating	9.9	15.9	17.9
	incl. electricity and district heating	12.1	21.8	34.8
Transport	excl. electricity	5.2	7.4	11.2
	incl. electricity	5.3	7.7	11.9
Power generation		7.0	19.2	37.7
District heat generation		3.7	8.0	24.3
TFEC	**incl. electricity and district heating**	**10.1**	**15.5**	**24.7**

Figure 2: Renewable energy use in TFEC, 2010-2030

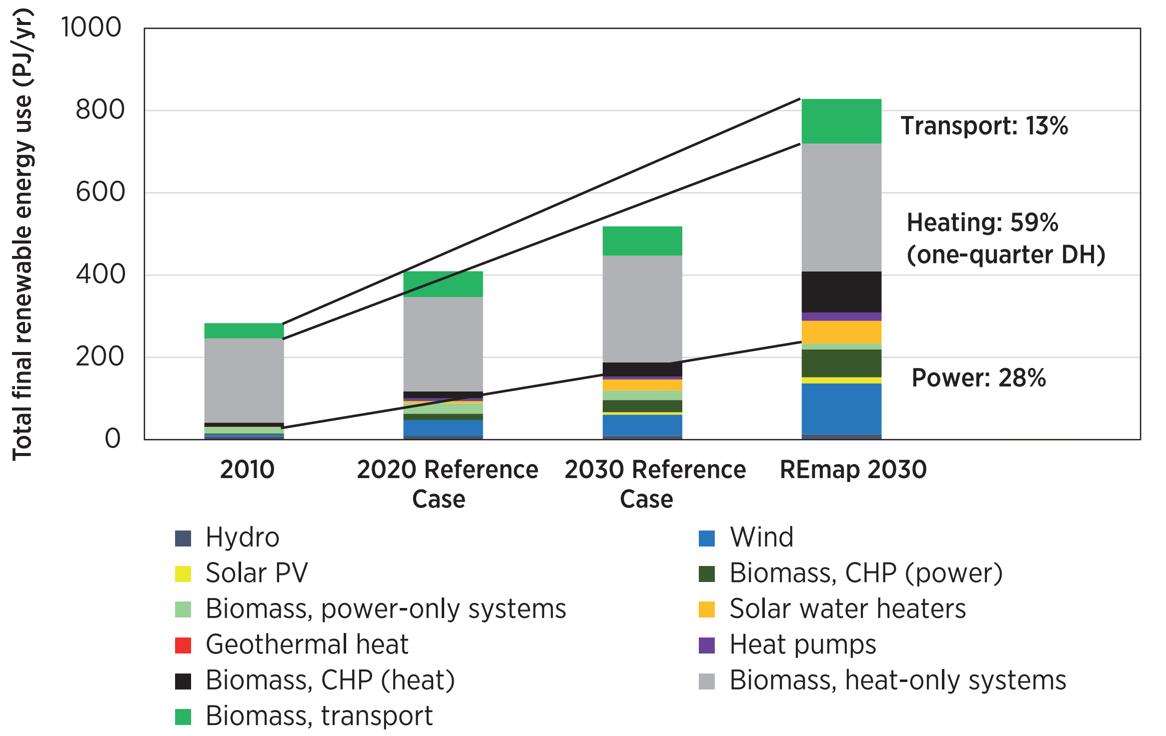
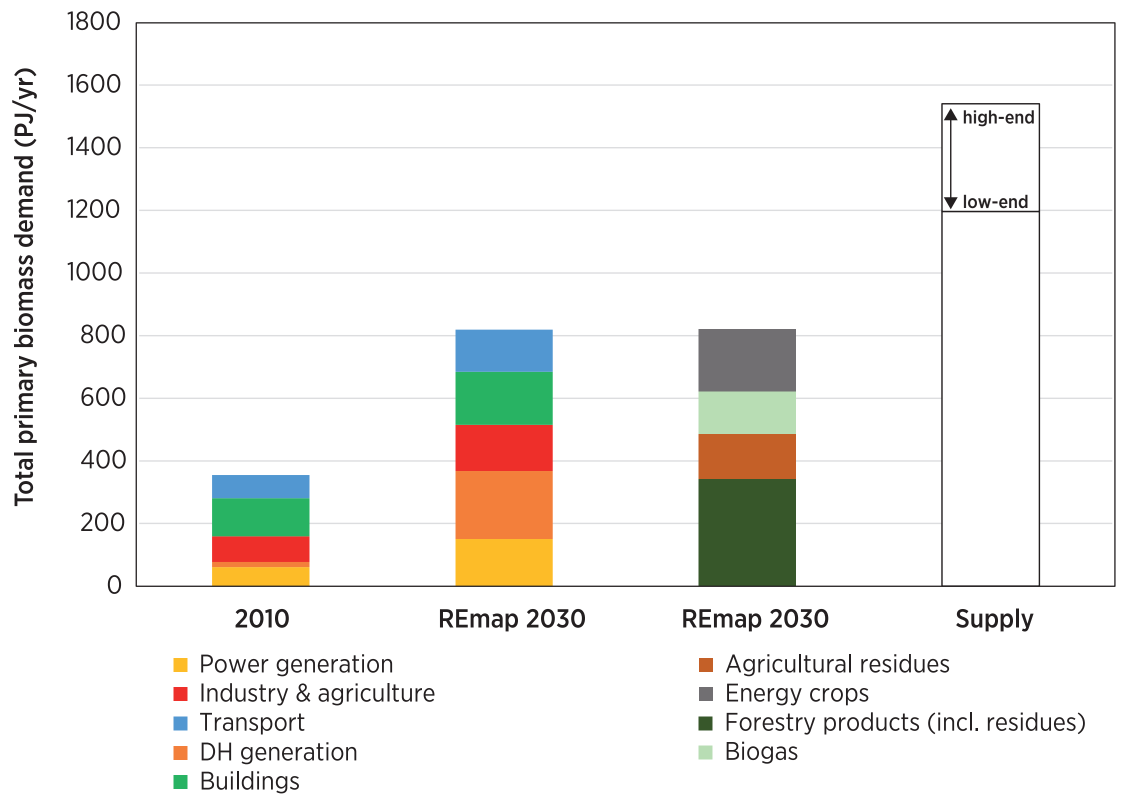


Figure 3: Breakdown of primary biomass use in Poland, 2030



largest renewable energy share at about 15-18% not including renewable electricity and district heating. When these are accounted for, each sector's renewable energy share is estimated at 34.8% and 25.3%, respectively. Transport renewable energy share would rise to 11.9% from around 5% in 2010.

Biomass would be the most important source of renewables in Poland, accounting for 73% of total renewable energy use in REmap 2030 (see Figure 2). Solar and wind would account for 8% and 15%, respectively. The share of hydropower would fall to 1.5% by 2030 because of the substantial growth in all other renewable energy sources in 2010-2030.

Total annual primary biomass demand would be 820 PJ in REmap 2030 (Figure 3). This suggests that 55-70% of domestic potential will be utilised. Domestic potential is 1.2-1.5 exajoules (EJ). More than three quarters of this would originate from two sources: agricultural residues and waste (278 PJ) and forestry products (including residues) (343 PJ).

The heating sector would account for 65% of total biomass demand in 2030, with the balance coming from transport (17%) and power generation (18%). About a quarter of all biomass use for heat would be included in industrial and agricultural processes, with the remainder in buildings and district heating.

Total biogas demand for all applications would come to 135 PJ (5.9 billion m^3). This compares with Poland's annual estimated supply potential of around 200 PJ in 2030.

Table 5: Average substitution costs of REmap Options by sector, 2030

	Business perspective (national prices) (USD/GJ)	Government perspective (international prices) (USD/GJ)
Industry	3.6	8.2
Buildings	-2.3	5.2
Transport	-4.2	-4.6
Power	6.3	13.3
District heating	13.8	12.5
Average of all sectors	**4.9**	**10.3**

4.3 Renewable energy cost and benefits

Costs of renewables in Poland

Table 5 provides an overview of the substitution costs by sector for 2030 based on the business and government perspectives. National prices are based on a discount rate of 5% and take into account energy tax and subsidies in energy prices in Poland. International prices are based on a discount rate of 10% and exclude tax and subsidies in energy prices.

In the business perspective, the most cost-effective options are in the transport sectors given that petrol and diesel are highly taxed in Poland. Satisfying heating demand would be more expensive, because costly forestry products compete with cheap coal. In the building sector, solar water heating compared to expensive natural gas offers savings. Wood pellet-fired biomass boilers for space heating are also close to cost-competitiveness compared to coal. In industry inexpensive agricultural residues are the choice for process heat generation, and this is more cost-competitive.

In the government perspective, average cost of substitution of the selected technology options in each sector is more expensive than in the business case. This is explained by the standard coal price assumed for Poland at USD 2/GJ and the exclusion of taxes and subsidies from energy prices.

The cost of REmap Options are somewhat lower in 2030 than in 2020. This is to great extent explained by technological learning and better capacity factors, which make renewables more cost-competitive than their fossil fuel counterparts. The more cost-effective mix of renewable energy options also plays a role.

Figure 4 and Figure 5 rank the costs of REmap Option substitutions and show their contributions to the potentially increased share of renewable energy. Table 6 shows the substitution costs of REmap Options in 2030 for Poland (the same information plotted in Figure 4 and Figure 5). The cost of options range from USD -30 to as

Figure 4: Renewable energy cost-supply curve by renewable energy resource in 2030 from the business perspective

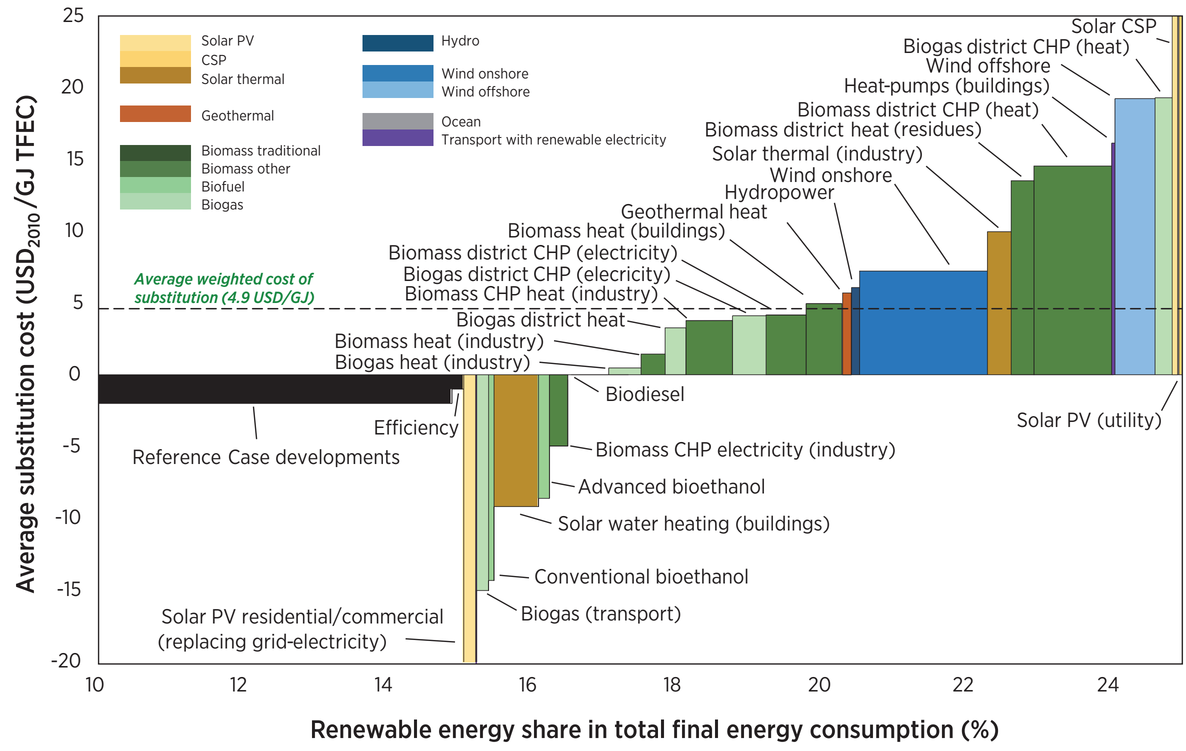


Figure 5: Renewable energy cost-supply curve by renewable energy resource in 2030 from the government perspective

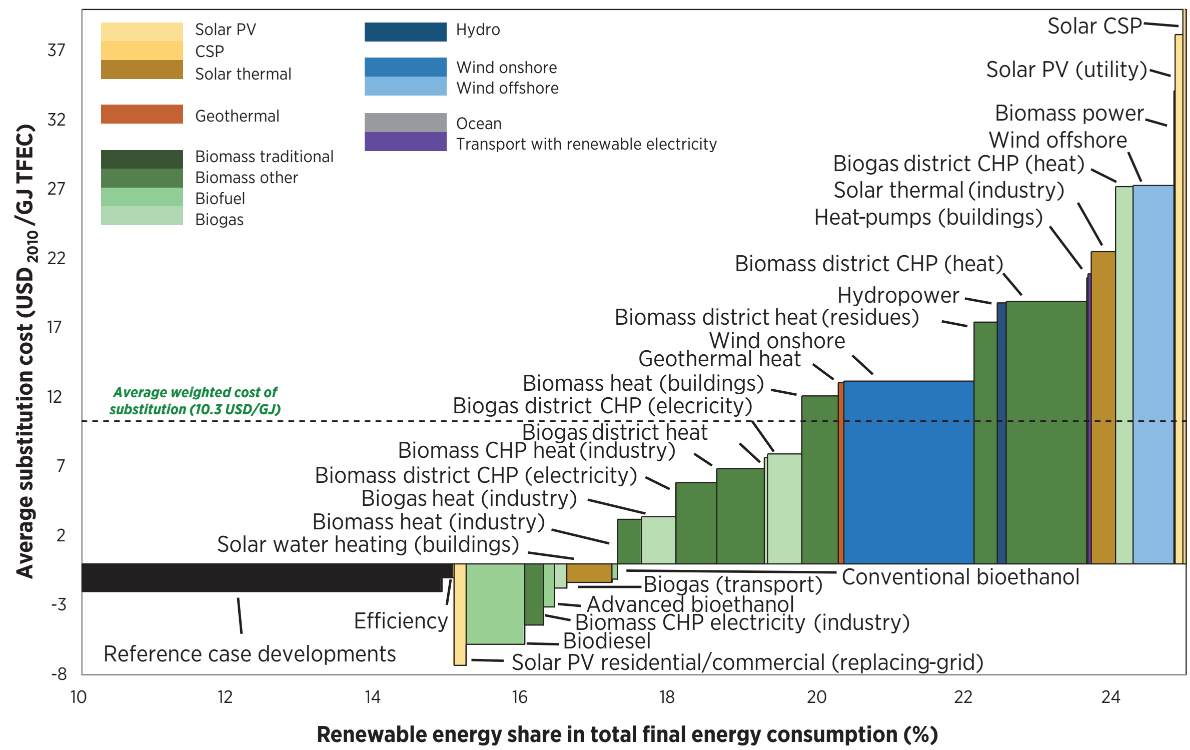


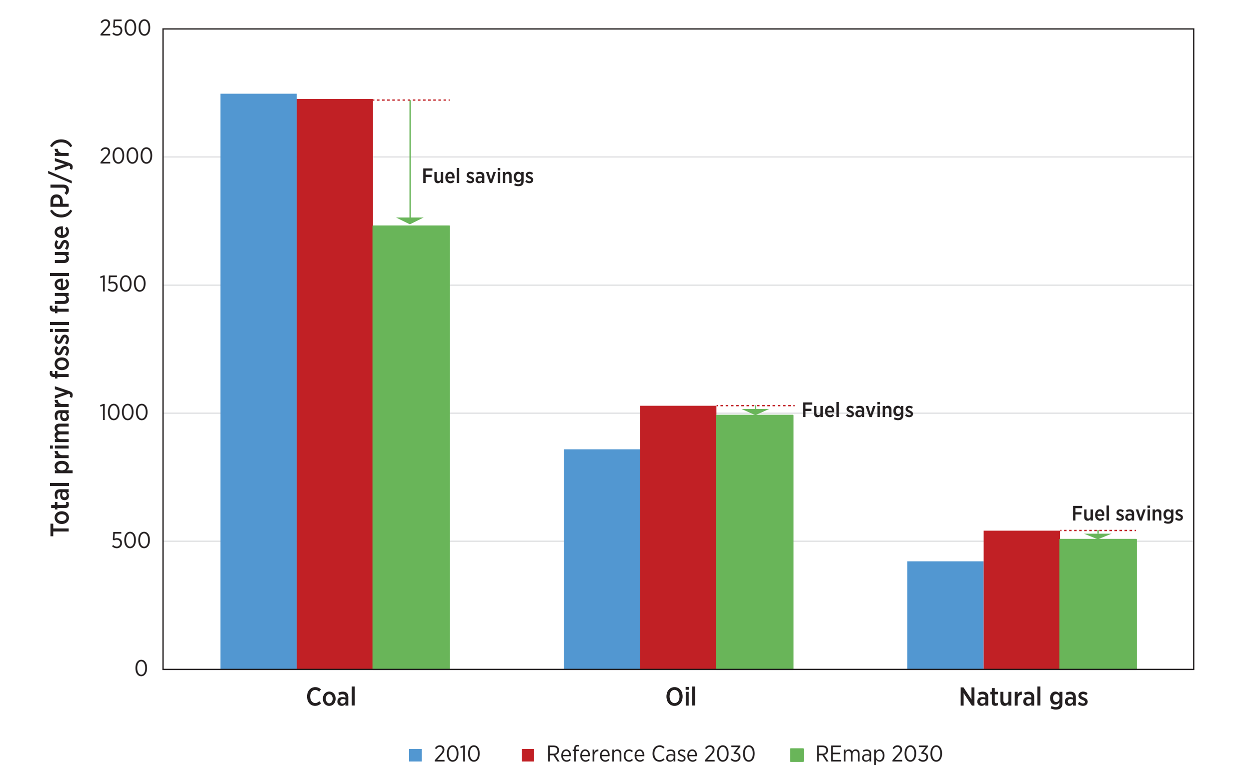
Table 6: Substitution cost of REmap Options by technology in 2030 based on the perspectives of government and business and potential by technology

REmap Option by sector	Business perspective (USD/GJ)	Government perspective (USD/GJ)	REmap Options potential (PJ/year)
Power consumption (energy transformation)			
Hydropower	7.0	18.8	3.6
Onshore wind	7.2	13.2	54.5
Offshore wind	19.2	27.3	17.3
Solid biomass (power only)	28.2	34.1	0.6
Solid biomass (CHP) – district heating	4.2	5.9	17.0
Solid biomass (CHP) – industry	-5.0	-4.4	7.9
Liquid & gaseous biofuels (CHP) district heating	4.1	7.9	14.5
Utility-scale	25.2	38.2	3.1
Rooftop	-44.9	-7.3	5.1
District heating consumption (energy transformation)			
Geothermal	6.0	13.1	2.2
Solid biomass (heat only)	13.5	17.4	9.8
Solid biomass (CHP)	14.5	18.9	33.7
Liquid & gaseous biofuels (heat only)	3.5	7.7	1.2
Liquid & gaseous biofuels (CHP)	19.3	27.2	7.5
Industry and agriculture (energy end-use)			
Solar heating/cooling	9.9	22.5	10.0
Solid biomass (heat only)	1.4	3.2	10.0
Solid biomass (CHP)	3.8	6.9	19.8
Liquid & gaseous biofuels	0.5	3.4	14.3
Buildings (residential and commercial) sector (energy end-use)			
Solar heating/cooling	-9.2	-1.3	18.9
Solid biomass (heat only)	5.0	12.1	15.0
Heat pumps	16.2	20.9	1.2
Transport sector (energy end-use)			
Conventional ethanol	-14.3	-1.1	2.5
Advanced ethanol	-8.6	-3.1	4.5
Biodiesel	0	-5.8	24.6
Other	-15.0	-2.0	5.5

high USD +30 per GJ from a business perspective. The government perspective starts with options that have costs of as low as USD -7 per GJ and ends with options as expensive as USD +40 per GJ. According to both cases, about 20% of all options are cost-competitive and therefore incur a negative substitution cost.

In the business perspective, among all technologies, solid biomass industrial CHP provides the lowest substitution cost for power generation. This is explained by the inexpensive agricultural residue feedstock used in CHP. In comparison, CHP plants using more costly forestry products in the district heating sector deliver power more expensively. Solar PV rooftop is an exception in the sector as the LCOE of this technology substitutes the end-user price of electricity which the consumers pay. Solar heaters and coolers in industry are the most expensive options compared to technologies burning low-cost biomass. Solar water heaters in the buildings sector with higher capacity factors and lower capital costs are the most cost-competitive compared to systems installed in the industry sector. For heat generation, more expensive biomass products are used in buildings and district heating, which make them less cost-competitive than biomass technologies used for process heat generation in industry. Transport sector

Figure 6: Fossil fuel savings, 2010-2030



biofuel technologies are the most cost-competitive of all REmap Options when compared to petrol and diesel. From a government perspective, only few technologies in the transport and power sectors are cost-competitive.

Benefits of REmap Options

Figure 6 shows fossil fuel demand development in 2010-2030 in Poland under the Reference Case and REmap 2030. REmap Options would cut fossil fuel demand by 14.9% compared to the Reference Case. The savings range from 3.6% for oil products to 6.3% for natural gas.

Total coal demand in REmap 2030 would be 22.3% lower than in 2010. In comparison, renewables would reduce the increase in oil and natural gas demand in the 2010-2030 Reference Case from 23% to 17%.

Lower fossil fuel use cuts CO_2 emissions. The bottom-up estimate of the sectors covered in this analysis accounts for 301 Mt CO_2 per year, or 91% of total CO_2 emissions in Poland in 2010 (330 Mt). The remaining 9% originate from fossil fuel extraction and conversion (mining, refineries etc). Table 7 shows that total CO_2 emissions in Poland increase from 330 Mt in 2010 to 313 Mt in 2020 and 349 Mt in 2030 in the Reference Case. If all REmap Options identified in this study are put in place, total emissions reduce to 292 Mt under REmap 2030. This is equivalent to a reduction of 16.3% compared to the Reference Case in 2030 (or an annual absolute volume of 57 Mt CO_2). Renewables can reduce 22% and 8% of Poland's total CO_2 emissions compared to 1990 and 2005 respectively. Higher reductions would require a combined accelerated deployment of renewables and energy efficiency measures.

Table 7: Total estimated CO_2 emissions development in Poland

	Annual CO_2 emissions (Mt CO_2)
1990	375
2005	318
2010	330
2020	313
2030	349
REmap 2030	292

Note: 1990-2010 is based on UNFCCC (2015)

Table 8: Financial indicators for renewable energy use in Poland from the government perspective

Annual energy system costs and benefits in 2030 (USD billion per year)	
Incremental system cost in 2030	3.1
reduced human health externalities	from 0.4 to 1.0
reduced CO_2 externalities	from 1.0 to 4.1
System costs with externalities in 2030	from -2.0 to 1.7
Incremental subsidy needs in 2030	3.1
Benefits from fossil fuel savings (compared to 2030 Reference Case)	
Total annual coal savings (Mt)	20.7
Total annual natural gas savings (bcm)	0.9
Annual reduction in coal and natural gas costs (USD billion)	1.4
Annual additional costs from biomass (billion USD)	2.5

Table 8 shows a number of financial indicators for Poland. REmap Options require an additional cost of USD 3.1 billion per year in 2030. Externalities related to human health can reduce these costs by USD 0.4 billion to USD 1.0 billion per year. With a price range of USD 20-80 per tonne of CO_2, related externalities can save another USD 1.0-4.1 billion each year. Thus REmap Options can result in total savings of up to USD 2 billion per year in 2030 once externalities are accounted for.

The table also shows that Poland can cut its fossil fuel energy bill by USD 1.4 billion a year by introducing REmap Options using less fossil fuel. Of those savings, USD 1 billion (85%) would arise from reduced coal demand. However, REmap Options would increase annual costs of biomass supply by USD 2.5 billion. Including transport sector savings from lower oil product use (based on international petrol and diesel prices in 2030) yields annual net fuel savings of USD 0.4 billion in 2030 under REmap Options.

These results assume that coal alone is substituted to generate power and heating in order to maximise CO_2 emission reductions. Large volumes of imported natural

Table 9: Annual average investments needs in 2010-2030 (USD million per year)

	Reference Case	**REmap 2030**
Sector		
Power generation and district heating (including CHP)	1535	3267
Industry	20	242
Buildings	358	725
Transport	129	219
Total	**2 041**	**4 452**
Resource		
Hydropower	29	78
Wind	650	1578
Solar PV	209	491
Solar water heating	286	779
Geothermal heat	44	123
Heat pumps	18	54
Biomass	806	1347
CHP	442	811
Power-only systems	135	120
Heat-only systems	101	198
Liquid biofuels production	129	219
Total	**2 041**	**4 452**

gas are also used today to generate heat in buildings and industry. This accounts for nearly 40% of the total fossil fuel mix in both sectors. Renewables can be used to substitute imported natural gas to improve energy supply security. If so, they become more cost-competitive than natural gas, and total system costs therefore decline from USD 3.1 billion to USD 2.6 billion in 2030. Furthermore, total annual natural gas savings rise from 0.9 billion cubic meter (bcm) to 2.9 bcm in 2030. This is equivalent to 20% savings in natural gas compared to the Reference Case in 2030 and implies a stabilisation of demand in 2010-2030. Total annual CO_2 emission savings would then amount to 54 Mt. This compares with 57 Mt if coal is the main substitute. This decrease is explained by the lower emission intensity of natural gas compared to coal (0.056 versus 0.095 tonnes of CO_2/GJ). Only heat generation emission reduction declines, and coal is still the main substituted fuel. This means that overall emission savings do not change significantly.

Total annual investment needs in renewables to 2030 will amount to USD 4.5 billion on average (see Table 9). USD 2 billion is required each year to fulfil the Reference Case, and an annual extra USD 2.5 billion per year would be needed to satisfy REmap Options. Most of the additional investment needs are in the power sector (USD 1.7 billion per year), in particular for wind (USD 0.9 billion per year). Biomass technologies (including the capacity to produce liquid biofuels for the transport sector) also require an annual addition of USD 0.5 billion beyond the Reference Case. Biomass CHP technologies alone will require total investments of USD 0.8 billion per year on average. Investment in solar water heaters would require USD 0.8 billion per year on average.

Box 2: Comparison with neighbouring countries

Some European countries have higher renewable energy targets than Poland for 2020. For example, the target for Germany is 18.7% while Sweden aims for 50.2%. Denmark's target is 28%[5] and Estonia's is 25.1%. Some countries are now slightly behind Poland in terms of their 2020 renewables targets. Slovakia is at 15.2% and Hungary at 13%. This puts Poland into perspective in terms of renewables in advanced and emerging countries. The focus is on how Poland's renewable energy differs from other countries and which experiences it can learn from different countries. Cooperation between countries relies on stronger regional economic ties (trade, skills transfer, energy security) and on a regional focus on power and heat biomass utilisation (technologies, logistics, best sustainable practices). The basic reasons for differences between Poland and other countries in terms of renewables deployment and the key findings from the comparisons are briefly explained below:

- Sweden has policies leading to high domestic fossil fuel prices so that renewables deployment can be highly cost-effective. District heating, of which 70% comes from biomass (biofuels, waste and peat) and 8% from heat pumps, plays an important role in the country's total final energy mix today. Biomass and wind increasingly account for a larger share of Sweden's power generation fuel mix. Poland has the potential to realise a similar mix of renewables, so it can benefit from Sweden's experiences.
- Denmark envisages nearly 100% renewable energy by 2035 with electricity generated only from wind and biomass. District heating will rely on biomass in CHP together with heat pumps. This strategy would be challenging for Poland due to a less remarkable cost-effective wind potential. However, Poland could increase its renewable energy share by relying on a mix of biomass and wind together with some contribution from hydropower (non-existent in Denmark) as well as biogas cogeneration for district heating.
- In Germany, attractive FiTs have stimulated a large share of renewable energy projects owned by private investors and project developers. Utility companies only hold 12% of renewable energy capacity. By contrast, the co-firing subsidies in Poland supported domestic large coal-based power companies. The new auctioning system is also likely to support large domestic power companies and the wind

5 IRENA has draft or completed REmap country analyses for Denmark, Germany and Sweden.

industry (at present mainly owned by foreign capital). There is and will continue to be limited potential for domestic private ownership of the renewables industry in Poland. This is a major difference between Polish and German renewable energy policy. Germany has realized 7 GW biogas power generation capacity, and wind offshore is growing with 2 GW additions in 2015. Poland shares similar resource availability as Germany for these technologies, and they are equally important for Poland to reach higher shares of renewables. Poland can benefit from experiences of Germany in achieving higher capacity for biogas and wind offshore.

- Slovakia's experience has shown that it used a great deal of hydropower through relatively few large-scale projects. Although Poland has low economic potential for hydropower, a few large hydropower projects are possible in southern Poland, for instance. However, first of all hydrological concerns would need to be resolved.
- Hungary's experience suggests it has the highest share of biomass (59%). Poland could learn from this. Geothermal sources have the second highest capacity potential in Hungary. However, Poland cannot learn much from this due to less evident potential. Onshore wind in Hungary is developing very slowly, rather as it is in southern Poland.
- Poland expects moderate growth in its total final energy demand. This is not the case in high-income countries like Germany, Sweden and Denmark. In these countries, energy efficiency would be sufficient to meet the demand of growing economies. Poland may need higher renewables in TFEC in addition to energy efficiency. It can thus benefit from the need for new capacity and deploy renewable energy faster than Germany, Sweden and Denmark. The limitations to this arise from high capital expenditure and market price uncertainties.

5 DISCUSSION OF RESULTS

5.1 Opportunities and challenges facing renewables

At present, the deployment of each renewable energy technology faces a number of challenges. This will continue regardless of whether Poland aims to reach the potential in REmap 2030 or restricts itself to its projections according to the NREAP. On the other hand, opportunities are already available for these technologies. This section briefly discusses these opportunities and challenges.

REmap expects increasing competition between various renewable energy sources. This could result in a more balanced portfolio of technologies in the national power mix. Future highly efficient wind technologies (*e.g.,* through taller turbines) could further improve its cost-effectiveness. Offshore wind can benefit from the highest wind speeds in the Baltic Sea area, so this is an interesting way forward for wind technology. Unfavourable natural wind conditions (*e.g.,* low average wind speeds), competition with other renewable energy (*e.g.,* biomass and solar PV in the future) and investment structures comprising mainly external capital are three factors that can limit greater wind expansion.

Major energy companies have shown a growing interest in offshore wind projects. In addition, Poland possesses significant industrial potential to develop the offshore wind energy sector through the shipyard industry lining its Baltic Sea coast. This, along with supporting industries, is based in the cities of Gdansk, Gdynia and Szczecin. Their profile matches the needs of the offshore wind sector in terms of wind turbine component construction, installation works and the manufacture of dedicated vessels serving offshore turbine transportation and installation. Offshore wind energy thus presents an attractive diversification opportunity for the traditional specialised Polish shipyards (SouthBaltic Off.E.R., n.d.).

The Polish wind energy sector, however, already faces many challenges today. Difficulties and additional costs in obtaining the technical conditions for grid connection are one example. Poor rural infrastructure, lengthy administrative procedures and permit approval periods are another (United States Department of Agriculture, 2012). In the past years, much of grid capacity in northern Poland was occupied by project developers who had agreements for grid connection, but had not yet built the projects according to the Institute for Renewable Energy (2010).

Hydropower could be promising in Poland beyond 2030 if the relevant infrastructure is developed. However, Poland needs to resolve water scarcity and ecological issues before then. Hydrological investments thus need to be planned in a holistic way to overcome all these problems together.

The investment costs of solar PV are falling significantly across the world. This trend may finally create a significant opportunity for Poland, if reflected in policies.

Biomass has been a key renewable energy resource in Poland. According to REmap 2030, it will continue to be in the future as well. To date, it was used mainly in co-firing with coal. If the REmap Options are to be implemented, numerous biomass only power generation and heating units will be need to be operated. The prospects of plants using biomass only within a network of sustainable and cost-effective supply chain will be a challenge. Large storage capacity will be required to ensure security of feedstock supply and transportation over long distances will increase biomass prices which is already one of the challenges the biomass sector is facing today.

Liquid biofuel demand in REmap 2030 would increase to about 3.7 billion liters in 2030 if all REmap Options are implemented. Ethanol production in Poland is today about 0.2 billion liters and majority of demand is met by imported ethanol (EurObserv'ER, 2013). There is sufficient availability of local biomass resources to meet this growing demand even when its competing uses with other sectors are accounted for. However, this will require a large investment in production capacity. Alternatively, Poland would need to continue relying on imports as today. Planning of biomass supply to meet this demand potential through domestic production and trade would need to start today.

Rural and sparsely populated areas with significant biomass availability (biogas, forest biomass, agricultural residues) show some potential for local biomass use, renewable heating and off-grid/mini-grid power technologies. There is interest in liquid biofuels use by a number of agricultural transport applications such as tractors. There is also interest in renewable heat. This could be used, for instance, in district heating, local industry, household cooking and agricultural and horticultural applications such as greenhouses. The potential for off-grid/mini-grid technologies is limited due to the high penetration of power grids in Poland. Nevertheless, there may be potential for these in remote locations with poor grid access. They could be suitable for the thinly populated regions of eastern Poland where biomass potential is high and grid coverage is lower than the national average. Solutions of this kind could serve local biomass businesses and thus enhance the development of a bioeconomy.

5.2 Grid concerns

Background

Poland has one TSO – Polskie Sieci Elektroenergetyczne (PSE). This company is fully owned by the Polish state. It is complemented by seven large distribution system operators. Four of these are primarily owned by the

Table 10: Interconnection with neighbouring countries

Name of the connection	Operating voltage (kV)	Capacity (A)	Capacity (MVA)	Season
Chmielnicka -Rzeszów	750	1500	1949	Winter/Summer
Stamo AC/DC -Słupsk Wierzbięcino AC/DC DC-LINK	450	1333	600	Winter/Summer
Albrechtice -Dobrzeń	400	2000	1386	Winter
		1680	1164	Summer
Hagenwerder-Mikułowa tor 1	400	2500	1732	Winter
		1980	1372	Summer
Hagenwerder-Mikułowa tor 2	400	2500	1732	Winter
		1980	1372	Summer
Krosno Iskrzynia - Lemieszany tor 1	400	1500	1039	Winter/Summer
Krosno Iskrzynia - Lemieszany tor 2	400	1500	1039	Winter/Summer
Noszowice -Wielopole	400	2000	1386	Winter
		1680	1164	Summer
Białystok - Roś	220	600	229	Winter/Summer
		415	158	Winter/Summer
Bujaków - Liskowiec	220	1050	400	Winter/Summer
Dobrotwór - Zamość	220	1000	381	Winter
		776	296	Summer
Kopanina -Liskowiec	220	1050	400	Winter/Summer
Krajnik -Vierraden tor 1	220	1370	522	Winter
		1100	419	Summer
Krajnik -Vierraden tor 2	220	1370	522	Winter
		1100	419	Summer

Source: PSE S.A.

Notes: kV : kilovolt ; A : ampere ; MVA : megavoltampere

1. The table lists the scope of capacity of each line depending on the season.
2. Connections, for which only a single value is given, apply to both seasons.
3. Connections marked in yellow are disconnected at present.

Figure 7: Cross-border interconnections in the Polish energy system

Source: Ministry of Economy, 2010

state. The other three are owned by foreign investors. In addition, there are approximately 200 smaller units with a marginal operational area, mostly at industrial plants. PSE owns Poland's high voltage electricity grid and is responsible for grid operation and power dispatch (Global Energy Network Institute, 2007).

Electricity transmission depends on a transmission grid owned and operated by PSE. This company acts as a TSO based on its extra high-voltage transmission grid. At 31 December 2013, this consisted of 246 lines of a total length of 13 519 km. This included a 1 750 kV line of 114 km, 77 400 kV lines of a total length of 5 383 km, 168 220 kV lines of a total length of 8 022 km. There are 103 extra high voltage stations and one undersea direct current line of 450 kV with a total length of 254 km.

Existing interconnections with neighbouring countries

Poland's grid is connected to almost all its neighbours. Table 10 shows the capacity of cross-border interconnections with neighbouring countries. These are either in use at present or have that potential.

These interconnections amount to 11 139 gigavoltampere (GVA) in winter and 9.684 GVA in summer. These figures are calculated as the sum of capacity of all lines and should not be understood as available capacity on cross-border exchanges. In addition, the capacity of disconnected interconnections amounts to 2 178 GVA in winter and 2 107 GVA in summer. Existing cross-border interconnections can meet the requirements set by the EU (10% of national electricity capacity).

To protect the economic interests of the national power industry, phase shifters are being built between Germany and Poland to limit renewable power imports. Despite present developments, Poland's energy policy envisages interconnections with neighbouring countries until 2030. PSE plans to develop its inner transmission grid in western Poland. A third interconnection between Poland and Germany is also under consideration but not before 2030. The final date and scope of the implementation will be determined after an analysis justifying the need for its implementation and arrangements with the German partner.

Operators of distribution systems, especially in northern Poland, plan a range of investments. These involve modernising or constructing the infrastructure. The aim is to connect new users to the grid, improve grid access to renewable sources and increase supply reliability, including interconnections with neighbouring countries. These will allow the exchange of at least 15% of electricity used in Poland by 2015, 20% by 2020 and 25% by 2030. If they materialise, these projections are sufficient for REmap Options, especially if parallel greater investments take place in energy storage facilities and smart grids (Ministry of Economy, 2009).

Barriers to grid integration in Poland

A study by Eclareon and the OEKO Institute that was carried out in 2011 summarizes the barriers to renewables energy integration that are being faced in Poland today. These barriers include the complicated and obscure grid connection process, unclear regulations concerning cost distribution. Renewable power plants are connected to the distribution grid level where most barriers happen. According to the experiences from the industry stakeholders there is an overall lack of investment confidence which results in limited deployment of renewable power capacity. Existing grid also needs to be modernised and expanded. The lack of grid capacity is one of the main barriers. In northern parts of Poland where there is large resource available for wind and solar the grid still needs to be developed.

Variable renewable energy shares and development needs

REmap 2030 estimates that the renewable energy share of power generation can reach 38% by 2030. The variable renewable energy share of total power generation can reach to 23% as a result of high wind penetration. A large share of the remainder is biomass and coal running at high annual capacity factors and thus not particularly suitable for backup power. Therefore, Poland's grid needs to be developed to allow for the further integration of fluctuating renewable power. The ageing thermal power generation sector that needs replacing before 2030 thus creates an important opportunity. New power plants designed to be more flexible will help accommodate an increasing share of variable renewables.

A large share of the remaining 77% is biomass and coal running at capacity factors of 45% and 75%, respectively. According to PSE, wind capacities of about 9 GW installed are still secure in terms of system operation. Up to 12 GW of wind capacity can be accommodated in 2020 given cooperation with CHP, gas plants for balancing and new more flexible coal power plants. This growth is in line with REmap 2030 estimates. New backup capacity is a consideration as far as higher shares of variable renewable are concerned. To produce 43 TWh each year through installed wind power generation capacity amounting to 16 GW, wind penetration (power generation from wind relative to total consumption) reaches about 25% in REmap 2030. At this penetration level, about 10% capacity credit (equivalent to firm wind capacity of 1.6 GW) is assumed, based on studies analyzing variable renewable energy integration in other countries (Holttinen *et al.,* 2011). This represents the share of installed wind capacity that can be considered to reduce conventional power generation capacity without affecting security of supply. Total firm power capacity from renewables and conventional sources amounts to around 34.5 GW. The peak load in 2030 is estimated at 35 GW. Today, the TSO considers a capacity reserve margin of 13% which is assumed to remain unchanged in 2030 (Rączka *et al.,* 2014). Assuming that total peak load and the reserve margin capacity would only be covered with generation capacity, total variable renewable energy capacity in REmap 2030 (mostly wind), would require a total backup capacity of about 5 GW. If this capacity was assumed to be built with gas power plants, this addition would require annual average investment needs of USD 0.3 billion between today and 2030 (this has not been considered in this analysis). Some of this investment needs are already covered in the Reference Case with the introduction of new wind generation capacity.

Yet spare grid capacity is not sufficient in Poland today. The national grids have to be expanded and modernised. Technical improvements through e.g. smart grids, power to gas, and energy storage facilities will be critical to reliably increasing the share of fluctuating renewable power sources. Since wind power plants are to be found mainly in the Baltic Sea region, the development of grids in northern Poland needs to be prioritised. About 6 000 km of new power grid lines may be needed in addition to energy storage facilities and smart grid solutions. To connect wind farms to the power grid, Poland needs 660 km of 440 kV transmission lines until 2015. With the ongoing expansion of wind farms after 2015, further significant expansion of 400 kV transmission lines will be needed (PSE, 2010).

Baltic Ring and supergrid

The Baltic Ring is the planned transmission grid connecting Norway, Sweden, Finland, Denmark, Germany, Poland, Lithuania, Latvia and Estonia (ABB, 2001). This project could mean a large synchronised energy system is established. The diversification of sources would improve security of electricity supply. In particular, it would ensure access to renewable energy sources from wind farms and hydropower plants in Sweden, Norway and Denmark. The target date for completing this project is 2020 (European Commission, 2014). Baltic countries are interested; in the short term, they will benefit from improved energy security (Landsberg, 2007).

The European supergrid is another interesting project that may facilitate the deployment of fluctuating renewable power sources in Poland. To mention just two examples, it will connect national power grids across Europe with wind sources in Western Europe exploiting Atlantic winds and with solar sources in Northern Africa. The major benefit of this grid project is its large scale, which will facilitate power balancing in national grids and improve the future introduction of fluctuating renewable energy.

National power markets are steadily becoming more international due to improved cross-border interconnections and initiatives like the Baltic Ring or the supergrid. This will have economic consequences for renewable energy prospects in Poland. There will certainly be competition between various renewable energy sources, not only within individual countries but also between countries with sometimes very different renewable energy potential. Consequently, accelerating renewables deployment in Poland may bring some economic risk, so renewable energy investment needs to be carefully planned and very cost-effective. Investors need to take into account realistic opportunities to generate low-cost renewable power in Poland and in other places in Europe and beyond. The economic feasibility of the national renewable energy projects needs to be assessed in broader European and international contexts.

5.3 Suggestions for accelerating renewable energy uptake

- Create measures to ensure investor confidence in continuity of renewable energy capacity growth as the policy moves from green certificates to auctions.
- Combine renewables with energy efficiency to reach climate change mitigation and improved energy security policy objectives.
- Ensure a mix of renewable energy technologies is deployed by focusing on non-biomass renewables such as electrification in heating as well as transport coupled with renewable electricity generation.
- Consider externalities of fossil fuels in assessment of renewable energy costs.
- Ensure an orderly transition from conventional coal-fired power supply and ensure power system reliability and resilience.
- Make plans for grid and transmission systems to integrate nearly 20% of total electricity generation from fluctuating renewable power sources, especially wind.
- Plan action driving sustainable and cost-effective biomass supply.
- Strengthen the national renewable energy equipment manufacturing sector, especially by working with wind and bioenergy investors.

REFERENCES

ABB (2001), *The Making of the Baltic Ring*, ABB Review Vol. 2. Zuerich. http://www09.abb.com/global/scot/scot271.nsf/veritydisplay/30641aa1cc265a0dc1256ddd00346da6/$file/44-48%20M673%20.pdf.

AEA Technology Environment (2005), *Damages per Tonne Emissions of PM2.5, NH3, SO2, NOx and VOCs from each EU25 Member State (Excluding Cyprus) and Surrounding Seas,* AEA Technology Environment, Didcot, www.doc88.com/p-476118345143.html.

Anonymous (2009), *Potencjał hydroenergetyczny (hydropower potential)*, http://www.szanuj-energie.pl/files/file/Potencja%C5%82%20hydroenergetyczny.pdf.

Budzianowski, W.M. (2012), "Sustainable Biogas Energy in Poland: Prospects and Challenges," *Renewable and Sustainable Energy Reviews* 16 (1), pp. 342-349.

Chodkowska-Miszczuk, J. and D. Szymańska (2013), "Agricultural biogas plants – a chance for diversification of agriculture in Poland," *Renewable and Sustainable Energy Reviews* 20, pp. 514-518.

Cetnarski, W.P. (2014), *Potential and Implementation Plans for Offshore Wind Energy*. 21 October 2014, Polish Wind Energy Association, Szczecin. http://www.eclareon.eu/sites/default/files/04_psew_potential_and_implementation_plans_for_offshore_windenergy.pdf.

Central Statistical Office of Poland (Główny Urząd Statystyczny) (CSO) (2012), *Energy Consumption in Households in 2009*, CSO, Warsaw. http://stat.gov.pl/cps/rde/xbcr/gus/EE_energy_consumption_in_households_2009.pdf.

CSO (2013), *Energia ze źródeł odnawialnych w 2012 roku (Energy from renewable energy sources in 2012)*, CSO, Warsaw. http://stat.gov.pl/download/gfx/portalinformacyjny/pl/defaultaktualnosci/5485/3/7/2/se_energia_zrodla_odnawialne_2012.pdf.

Dumas, P. and Bartosik A. (2014), *Geothermal DH potential in Europe,* GeoDH project report, European Geothermal Energy Council, Brussels. http://geodh.eu/wp-content/uploads/2014/08/GEODH.potential_NA.pdf.

EurObserv'ER (2013), *The State of Renewable Energies in Europe*. Observ'ER, Paris. http://www.energies-renouvelables.org/observ-er/stat_baro/barobilan/barobilan13-gb.pdf.

European Commission (2009), *Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the Promotion of the Use of Energy from Renewable Sources and Amending and Subsequently Repealing Directives 2001/77/EC and 2003/30/EC,* L 140/16, 5.6.2009, EC, Brussels.

European Commission (2014), *Boosting Poland's energy security and supply – linking Poland and Lithuania's power grid*. 16 December 2014, European Commission, Brussels. http://ec.europa.eu/regional_policy/index.cfm/en/projects/poland/boosting-polands-energy-security-and-supply-linking-poland-and-lithuanias-power-grid.

Eclareon/OEKO Institute (2011), *Integration of Electricity from Renewables to the Electricity Grid and the Electricity Market – RES-INTEGRATION*. 13 March 2012, Eclareon/OEKO Institute, Berlin. http://www.oeko.de/oekodoc/1378/2012-012-en.pdf.

Eggleston H.S. *et al*. (2006), *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, National Greenhouse Gas Inventories Programmes, IPCC (Intergovernmental Panel on Climate Change), IGES, Kanagawa, www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

ENDS (2014), *Poland could eliminate coal from co-generation*. 21 November 2014. Environmental Data Services, Teddington. http://www.endswasteandbioenergy.com/article/1323071/poland-eliminate-coal-co-generation.

European Wind Energy Association (EWEA) (2014), *Wind Energy Scenarios for 2020,* EWEA, Brussels. http://www.ewea.org/fileadmin/files/library/publications/scenarios/EWEA-Wind-energy-scenarios-2020.pdf.

Eurostat (2015), *Energy price statistics*. European Commission, Eurostat, Luxembourg. *http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_price_statistics.*

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) (2012), *International Fuel Prices 2010/2011*. 7th Edition. GIZ, Bonn/Eshcborn. *http://www.giz.de/expertise/downloads/giz2012-en-ifp2010.pdf.*

Global Energy Network Institute (GENI) (2007), *National Energy Grid Poland*. June 2007. GENI, San Diego, CA. *http://www.geni.org/globalenergy/library/national_energy_grid/poland/index.shtml.*

Greenpeace/Global Wind Energy Council/European Renewable Energy Council (2013), *Energy [R]evolution – a Sustainable Poland Energy Outlook*, Greenpeace Poland/GWEC/EREC, Warsaw/Brussels. *http://www.energyblueprint.info/fileadmin/media/documents/2013/0113_gpi_E_R__poland_07_lr.pdf.*

Hansson, J. *et al.* (2009), *The Potential for Biomass Co-firing with Coal for EU-27*, Chalmers University of Technology, Goteborg. *http://www.bioenergytrade.org/downloads/potentialforbiomasscofiringjuliahansson.pdf.*

Holttinen, H. *et al.* (2011), "Impacts of Large Amounts of Wind Power on Design and Operation of Power Systems, Results of IEA Collaboration," *Wind Energy 2011* (14), 179-192.

IEA (International Energy Agency) (2014a), *Energy Balances*, Organisation for Economic Co-operation and Development/IEA, Paris.

IEA (2014b), *Energy Prices and Taxes (quarterly)*. OECD/IEA, Paris.

Institute for Renewable Energy (2010), *Wind power in Poland,* BiznesPolska.pl, Warsaw.

International Institute for Applied System Analysis (IIASA) (2014), "GAINS GLOBAL (Greenhouse Gas – Air Pollution Interactions and Synergies)", IIASA, Laxenburg, *http://gains.iiasa.ac.at/gains/GOD/index.login?logout=1.*

IPCC (2007), *Summary for Policymakers, Climate Change 2007: Mitigation, Fourth Assessment Report*, IPCC, Cambridge University Press, Cambridge and New York, *www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-spm.pdf.*

International Renewable Energy Agency (IRENA) (2014a), *REmap 2030: A Renewable Energy Roadmap, June 2014,* IRENA, Abu Dhabi, United Arab Emirates.

IRENA (2014b), *Global Bioenergy Supply and Demand Projections, a Working Paper for REmap 2030, September 2014*, IRENA, Abu Dhabi, United Arab Emirates.

Institute for Sustainable Development (ISD) (2009), *Poland's Alternative Energy Policy until 2030 (AEP)*. December 2009, ISD, Warsaw. *http://bellona.org/filearchive/fil_Polands_Alternative_Energy.pdf.*

Jozef Stefan Institute (JSI) (2014), *Final Cogeneration Roadmap: Poland.* November 2014, JSI, Ljubljana. *http://www.code2-project.eu/wp-content/uploads/D5.1-Roadmap-Poland_Summary_20141223.pdf.*

Krajowa Agencja Poszanowania Energii (KAPE) (2013), *Prognoza zapotrzebowania na paliwa i energię do 2050 roku (Forecast of fuels and energy demand until 2050),* KAPE, Warsaw.

Lachman, P. (2014), "Analiza rynku pomp ciepła," (Analysis of heat pump market) *Czysta Energia* Vol. 11, pp. 1-8.

Landsberg, M. (2007), *Baltic Ring 2025*, Baltso Development WG, Riga. *http://www.eees.ee/FAILID/PDFid/Erialapaev111207/Baltic%20grid%202025.pdf.*

Ministry of Economy (MoE) (2009), *Energy Policy of Poland until 2030*. MoE, Warsaw. *http://www.mg.gov.pl/files/upload/8134/Polityka%20energetyczna%20ost_en.pdf.*

Ministry of Economy (2010), *National Renewable Energy Action Plan (NREAP)*. MoE, Warsaw. *https://ec.europa.eu/energy/sites/ener/files/documents/dir_2009_0028_action_plan_poland.zip.*

Polish Information and Foreign Investment Agency (PIFIA) (2012), *Energy Sector in Poland*. PIFIA, Warsaw. *www.paiz.gov.pl/files/?id_plik=19610.*

Polskie Sieci Elektroenergetyczne (PSE) (2010), *Plan rozwoju na lata 2010-2025*. March 2010, PSE, Konstancin-Jeziorna. *http://www.pse.pl/uploads/kontener/Plan_Rozwoju_2010_2025.pdf.*

Polish Wind Energy Association (PWEA) (2010), *Wind Power in Poland*. PWEA, Szczecin.

Rączka, J. *et al.* (2014), *Risk of capacity shortage in the Polish electricity system up to 2020,* Forum for Energy Analysis, Agora, RAP (Regulatory Assistance Project) and WISE (Warsaw Institute for Economics Studies). *http://www.agora-energiewende.de/fileadmin/Projekte/2014/Capacity-Shortage-Poland/fae_capacity_shortage_poland_web.pdf.*

Rogulska, M. and Krasuska, E. (2012), *National Targets for Bioenergy in Poland,* presentation at 4 Biomass Final Conference, March 2012, Berlin. *http://www.4biomass.eu/document/file/1_6-rogulska-berlin.pdf.*

South Baltic Off.E.R. (n.d.), *Offshore wind energy in Poland*. South Baltic Off.E.R., Rostock. *http://www.southbaltic-offshore.eu/regions-poland.html.*

Towarowa Giełda Energii (TGE) (2012), *Parkiet biomasy (parquet biomass)*. TGE, Warsaw. *http://www.tge.pl/fm/upload/Parkiet-Biomasy/Parkiet_Biomasy_I.pdf.*

The World Bank (2013), *Global Tracking Framework*. The World Bank, Washington, DC. *http://documents.worldbank.org/curated/en/2013/05/17765643/global-tracking-framework-vol-3-3-main-report.*

United Nations Framework Convention on Climate Change (UNFCCC) (2015), *GHG data from UNFCCC.* UNFCCC, Bonn. *http://unfccc.int/ghg_data/ghg_data_unfccc/items/4146.php*

United Nations Industrial Development Organization (UNIDO) and International Center on Small Hydro Power (ICSHP) (2013), World Small Hydropower Development Report 2013 – Poland. UNIDO and ICSHP, Vienna/Hangzhou. *http://www.smallhydroworld.org/fileadmin/user_upload/pdf/WSHPDR_2013_Final_Report-updated_version.pdf.*

United States Department of Agriculture (USDA) (2012), *Renewable Energy and Bio-fuel Situation in Poland*, USDA, Washington DC.

LIST OF ABBREVIATIONS

a	ampere
bcm	billion cubic meter
CAFÉ	Clean Air for Europe
CHP	combined heat and power
CO_2	carbon dioxide
CSO	Central Statistical Office of Poland
CSP	concentrated solar power
e	electric
EJ	exajoule
EU	European Union
EWEA	European Wind Energy Association
f	final fuel input
FiT	Feed-in-Tariff
GAINS	Greenhouse Gas and Air Pollution Interaction and Synergies
GDP	gross domestic product
GFEC	gross final energy consumption
GHG	greenhouse gas
GW	gigawatt
GJ	gigajoule
GVA	gigavoltampere
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IPCC	International Panel on Climate Change
IRENA	International Renewable Energy Agency
KAPE	Krajowa Agencja Poszanowania Energii
km	kilometre
ktoe	kilotonnes of oil equivalent
kV	kilovolt
kW	kilowatt
kWh	kilowatt-hour
LCOE	levelised cost of electricity
m^3	cubic metre
Mtoe	megatonnes of oil equivalent
Mt	million tonnes
MVA	megavoltampere
MW	megawatt
MWh	megawatt-hour
NOx	mono-nitrogen oxide
NREAP	National Renewable Energy Action Plan
PJ	petajoule
PM	particulate matter
PWEA	Polish Wind Energy Association
PSE	Polskie Sieci Elektroenergetyczne
PV	photovoltaic
SO_2	sulphur dioxide
TFEC	total final energy consumption
th	thermal heat generated
toe	tonne of oil equivalent
TSO	transmission system operator
TWh	terawatt-hour
USD	United States Dollar

ANNEX A:

Comparison of REmap estimates with NREAP

Table 11: Comparison of IRENA estimates with NREAP for 2020, gross final renewable energy consumption

	IRENA estimates from Table 3 (Mtoe per year)	NREAP (Mtoe per year)
Electricity	**2 680**	**2 686.6**
Solid biomass	885.6	892.3
Biogas	344.5	344.5
Wind	1178.4	1178.4
Water	271.4	271.4
Solar PV	0.1	0.1
Heat	**6 254.5 (excl. heat pumps)**	**6 255.9**
Solid biomass	5405.1	5 405.9
Biogas	503.1	503.1
Geothermal	220.9	221.5
Solar	125.4	125.4
Transport	**1 444.1**	**1 444.1**
Sugar and starch bioethanol	425.2	425.2
Biodiesel	808.9	696.8+112.1=808.9
2nd gen. bioethanol	210	210
Biohydrogen	0	0
Biomethane (excl. from NREAP)	2.8	0
Total	**10 381.4**	**10 387**
GFEC according to NREAP	**69 200 Mtoe**	**69 200 Mtoe**
Renewable energy share in GFEC	**15.0%**	**15.0%**

Table 12: Comparison of IRENA estimates with NREAP for 2020, power generation capacities

	IRENA estimates from Table 3 (MW)	NREAP (MW)
Hydropower (large + small)	1135	1135
Wind	5 910	6 089
Solid biomass CHP	620	623
Biogas CHP	805	802
Co-fired biomass	1 700	N/A
Non-CHP biomass	457	N/A
Solar PV	2	2
Total	**10 629**	**8 651**
Total (excl. co-firing and non-CHP biomass)	**8 472**	

N/A = not available

ANNEX B:

Detailed results

Figure 8: Reference Case renewable power generation growth, 2010-2030

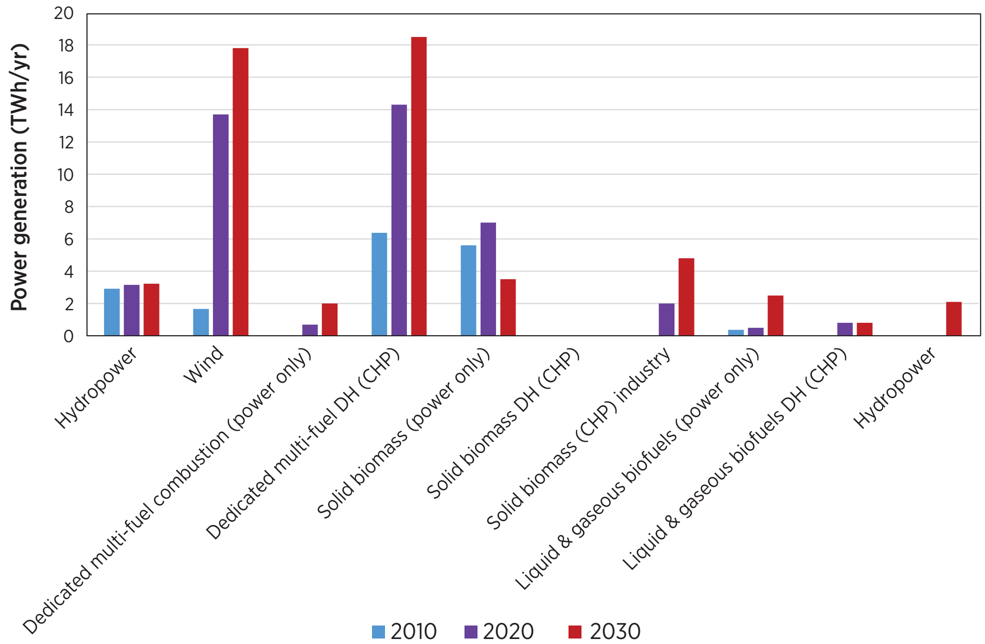


Figure 9: Reference Case renewable fuel and heating increase (industry, buildings and district heating), 2010-2030

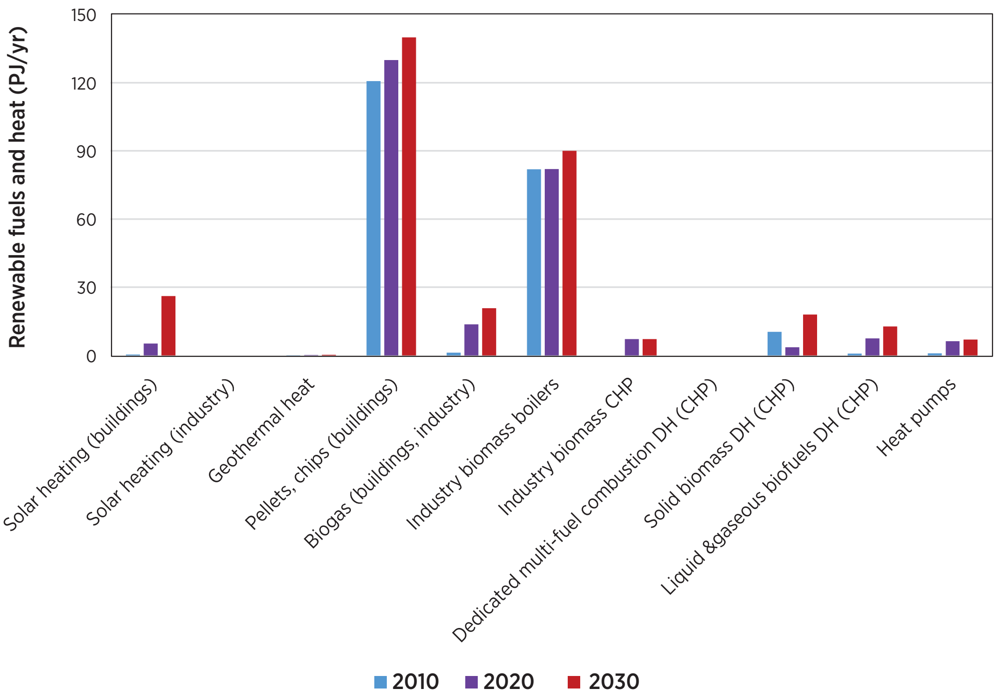


Figure 10: Reference Case increase in renewable fuel for transport, 2010-2030

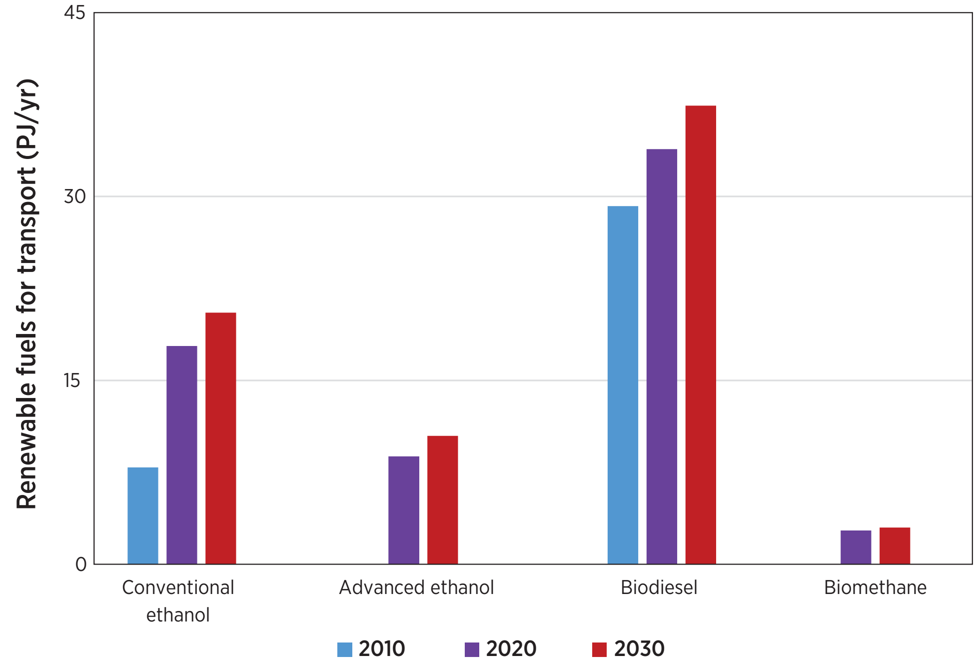


Table 13: Reference Case sector renewable energy share in TFEC

	2010	2020	2030
Power generation	7.0%	18.8%	19.2%
District heat generation	3.9%	5.5%	10.7%
Industry & agriculture	12.3%	13.5%	15.0%
Buildings	12.1%	19.6%	22.5%
Transport	5.2%	8.2%	7.4%
TFEC	**10.1%**	**14.2%**	**15.5%**

Note: end-use sectors (industry, buildings, transport) include the consumption of renewable power and district heating in addition to renewables fuels.

Figure 11: Total renewable energy power generation, 2010 and 2030

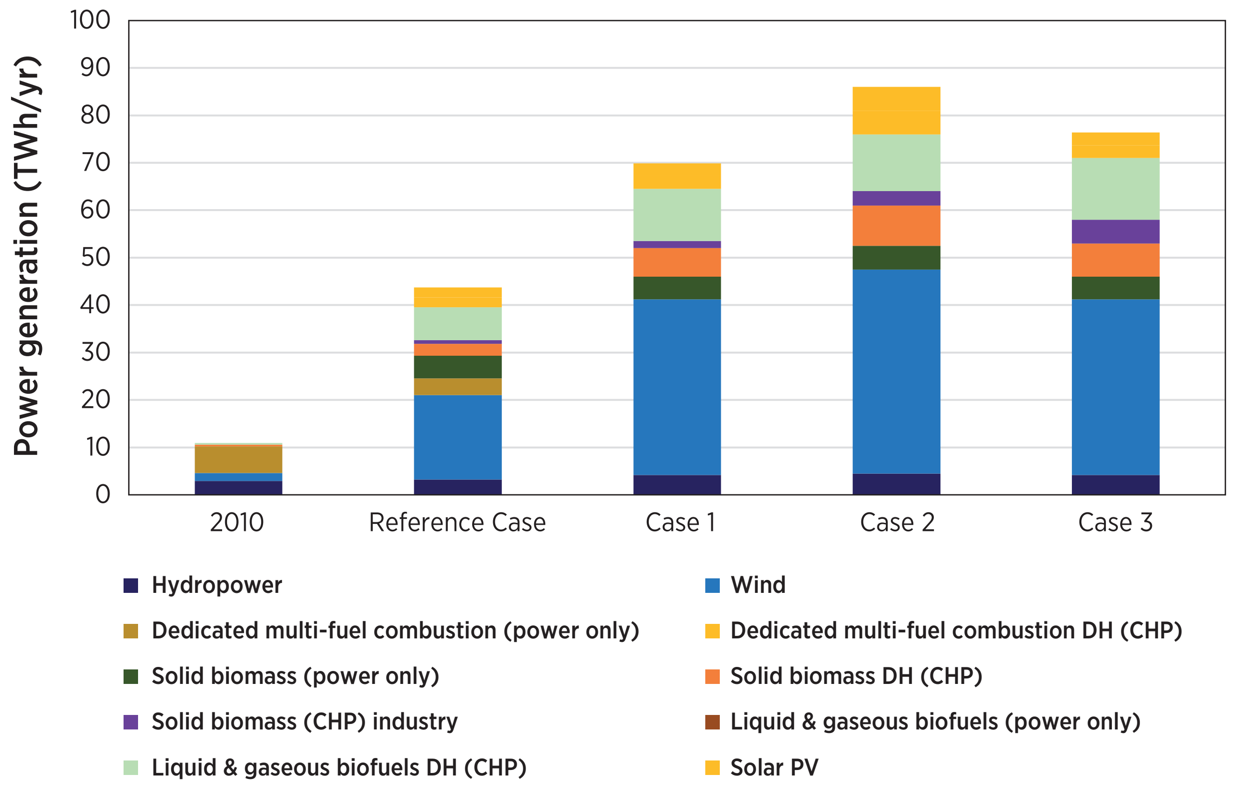


Figure 12: Total renewable energy power generation capacity, 2010 and 2030

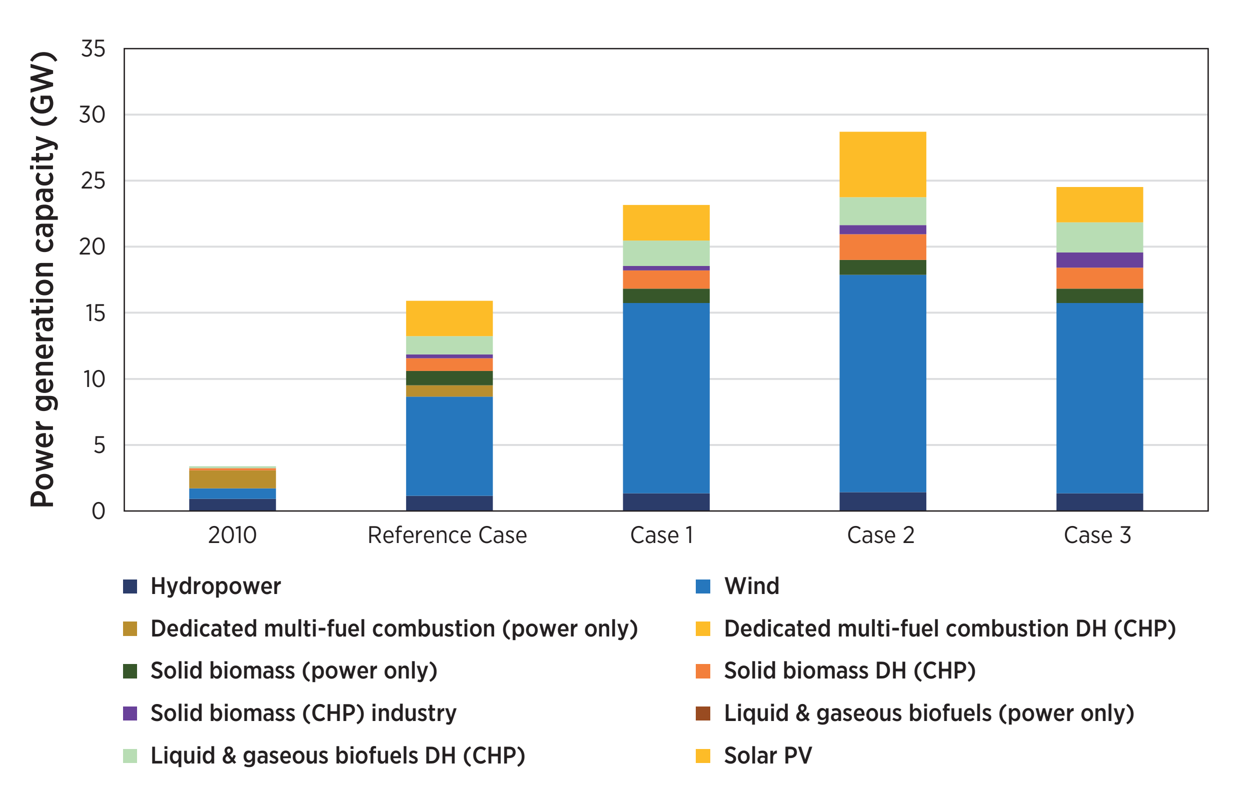


Figure 13: Total renewable energy use in 2010 and 2020 (power, heat and transport)

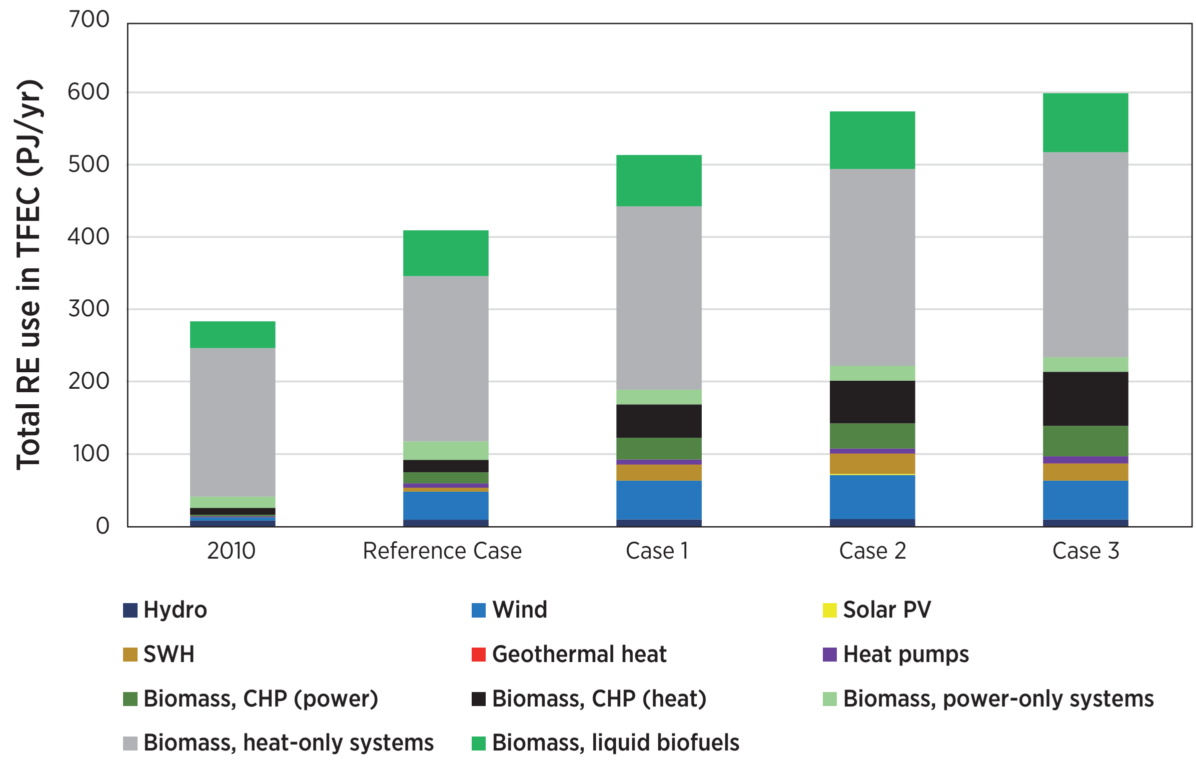


Figure 14: Total renewable energy use in 2010 and 2030 (power, heat and transport)

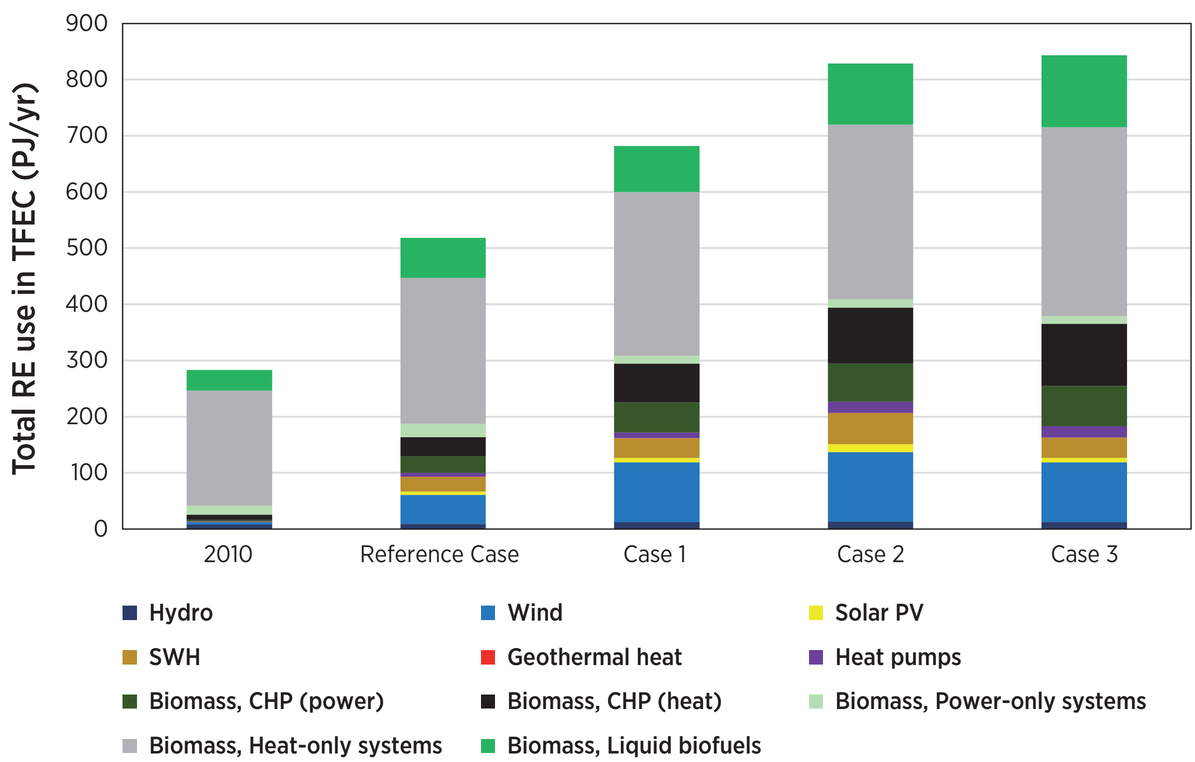


Figure 15: Total primary biomass demand by sector, 2010 and 2030

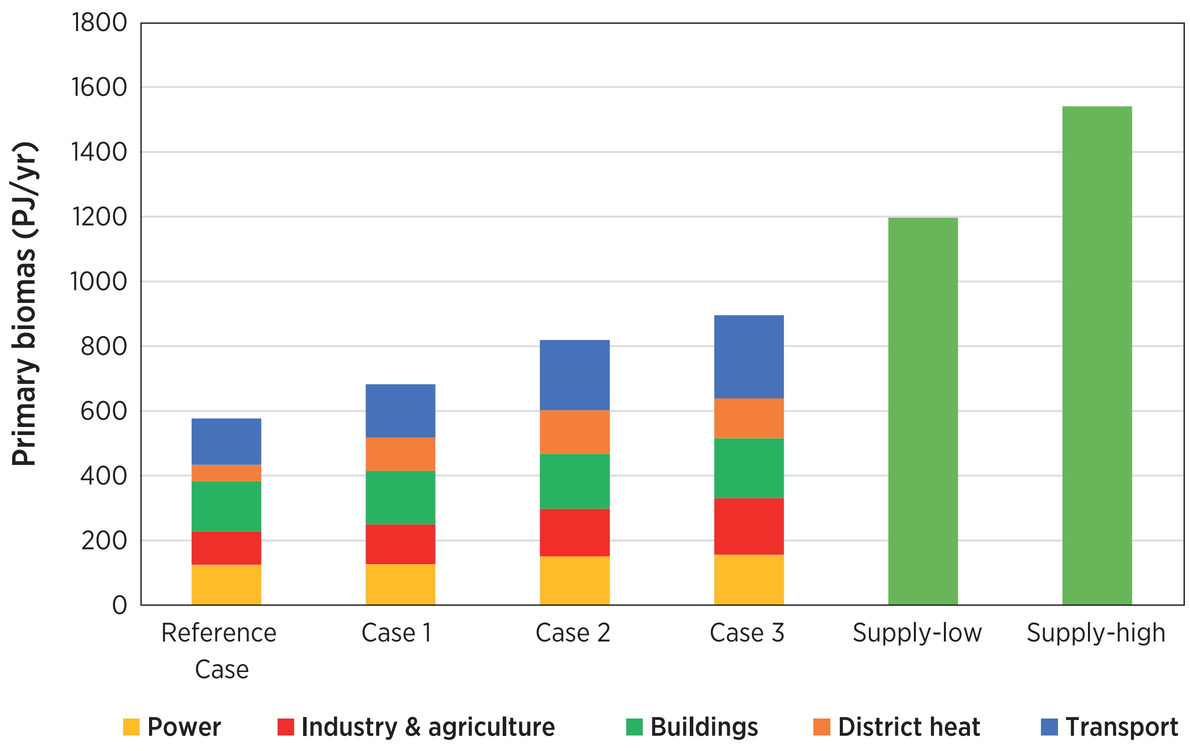


Figure 16: Total primary biomass demand by feedstock type, 2020 and 2030

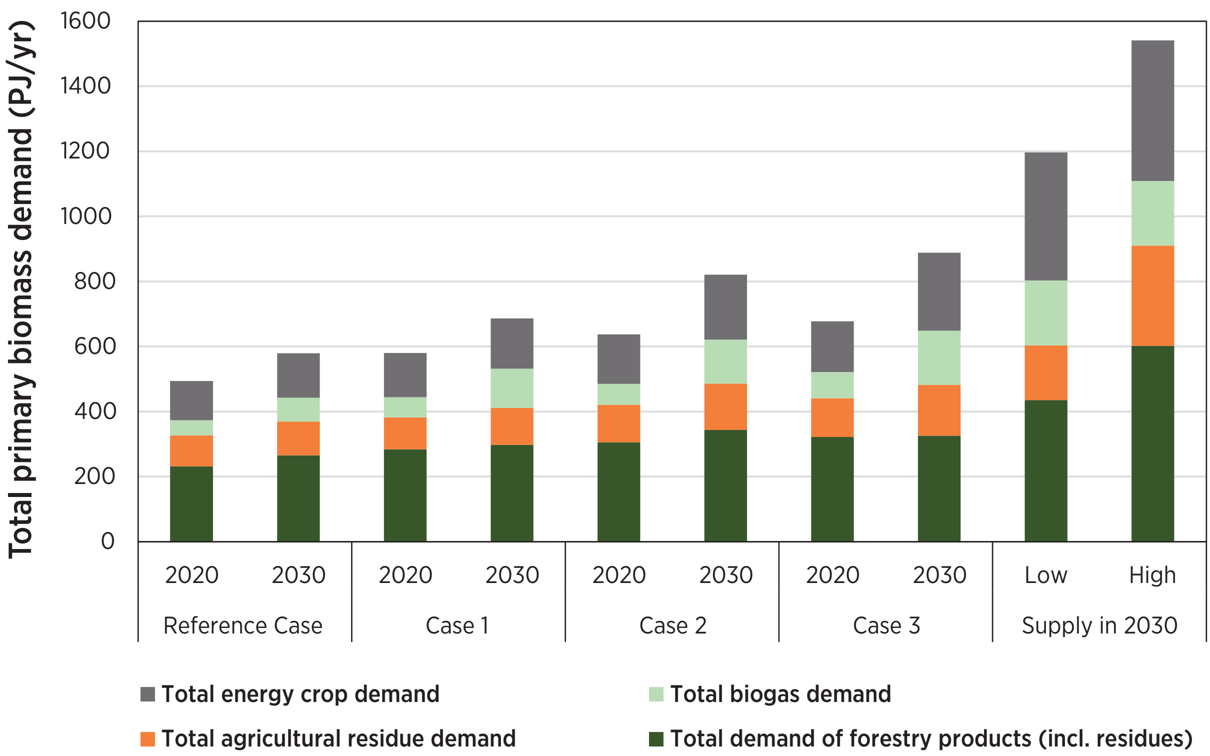


Figure 17: Total installed biomass CHP capacity, 2010 and 2030

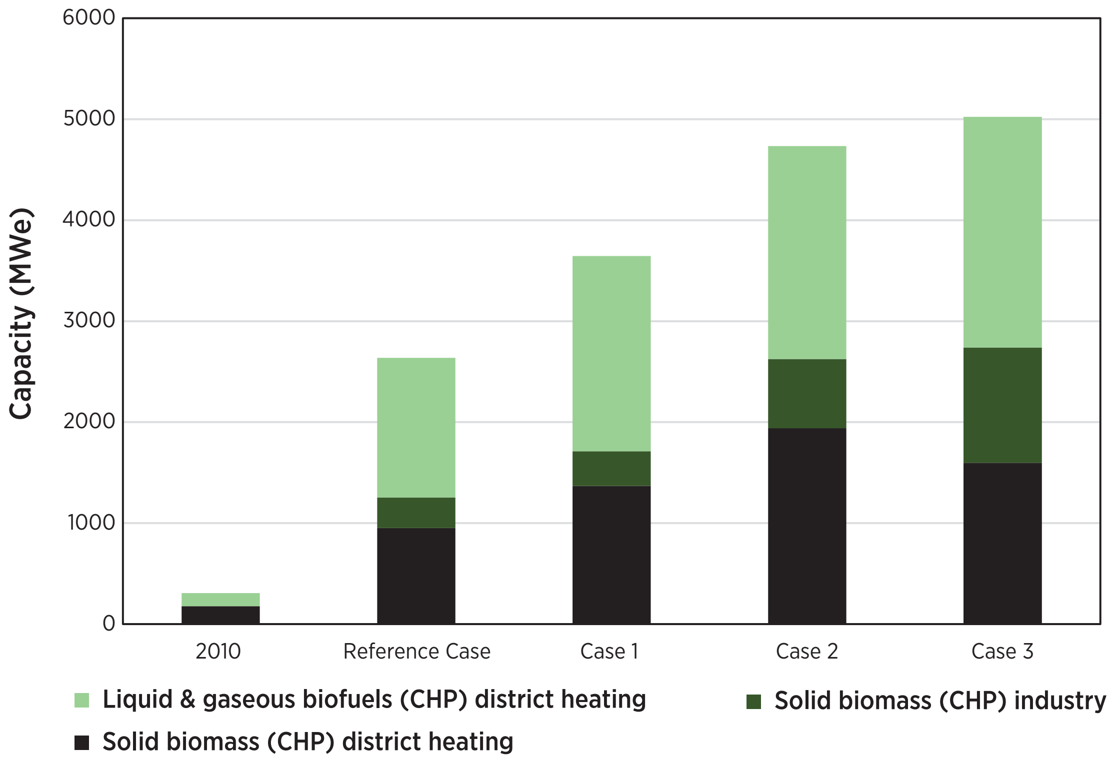


Figure 18: Renewable energy share in total final energy consumption, 2010 and 2030

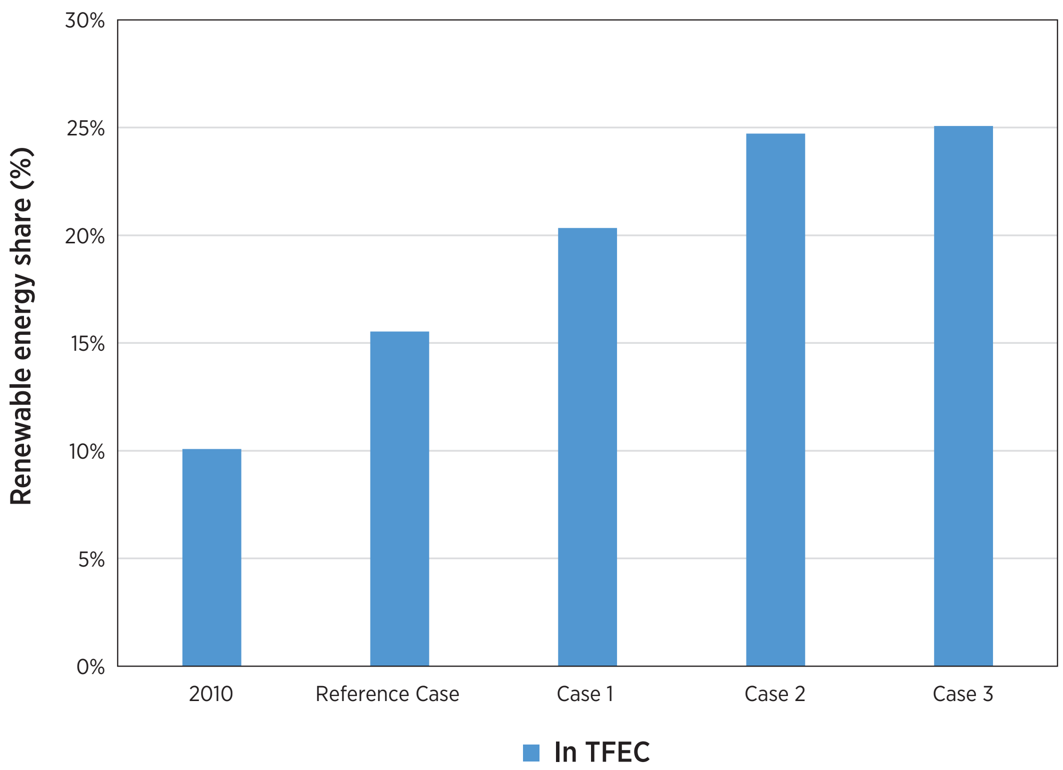


Figure 19: Renewable energy share in power generation, 2010 and 2030

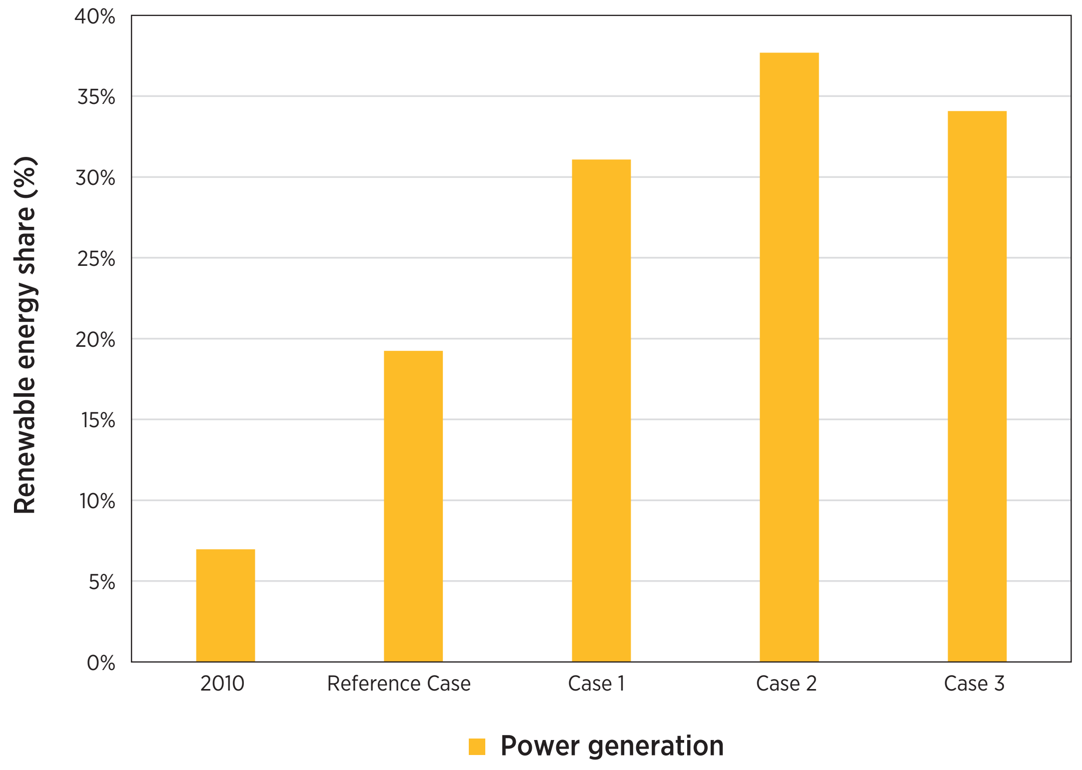


Figure 20: Renewable energy share in industry and agriculture, 2010 and 2030

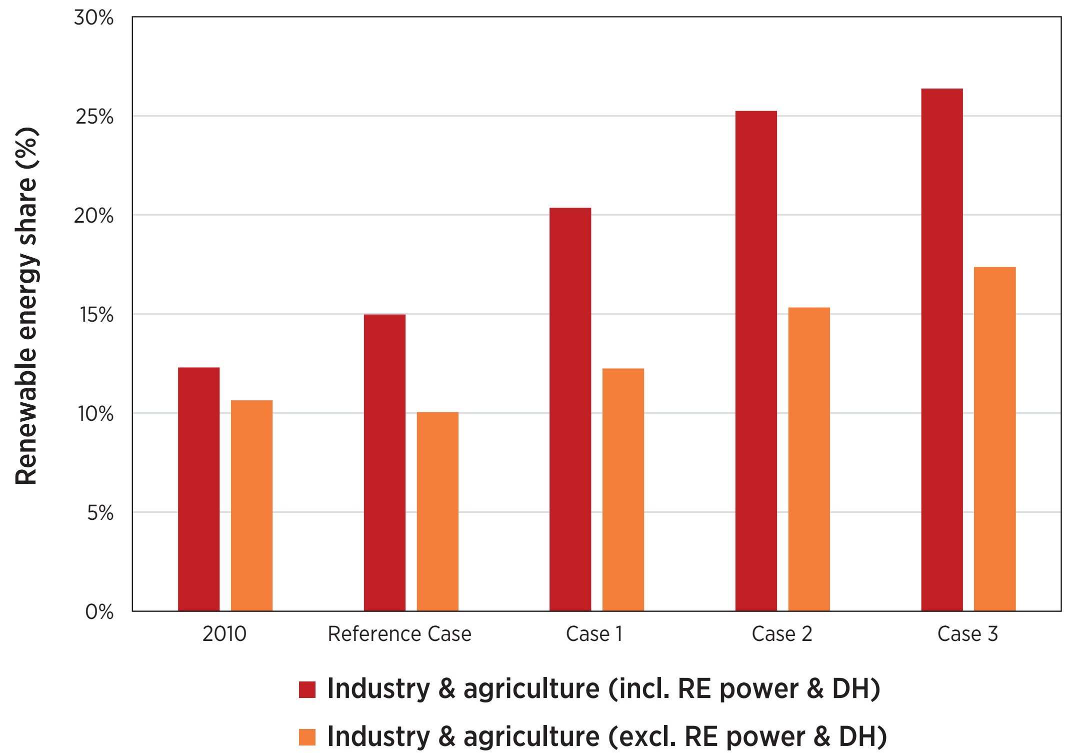


Figure 21: Renewable energy share in buildings, 2010 and 2030

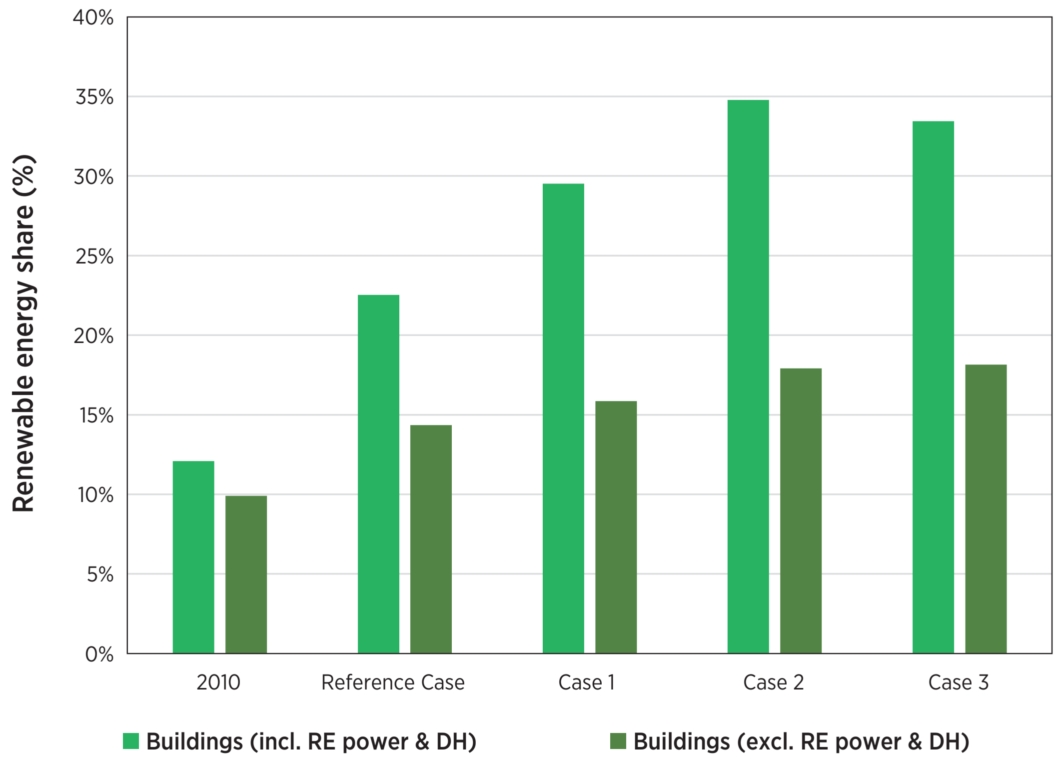


Figure 22: Renewable energy share in transport, 2010 and 2030

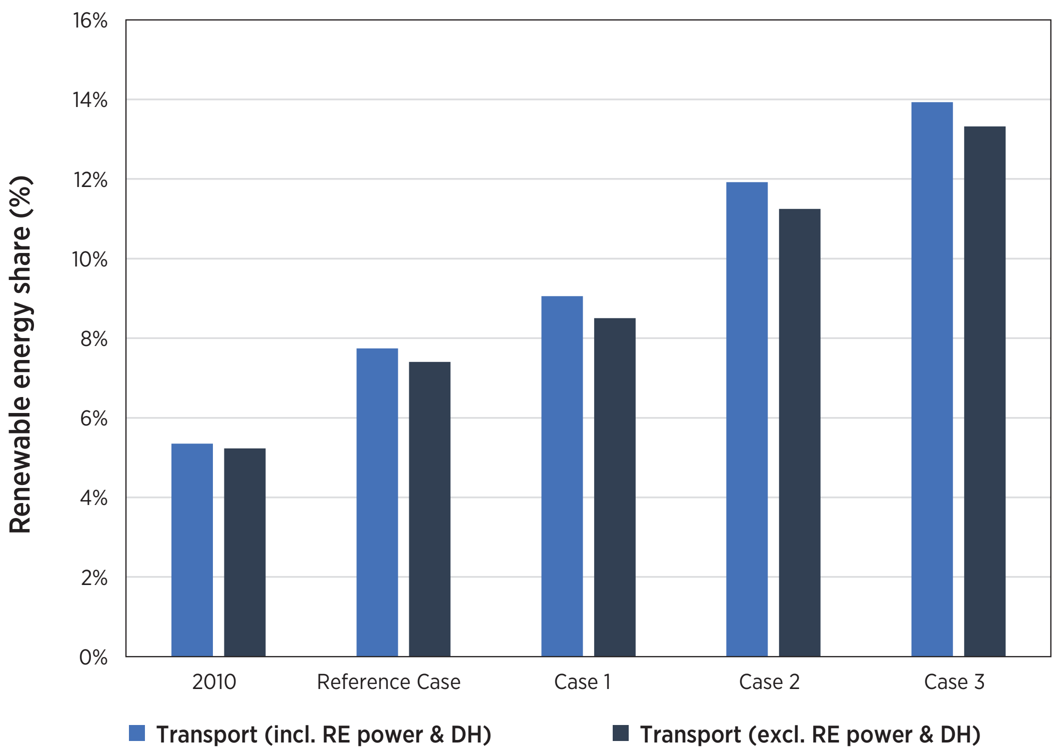


Table 14: REmap 2030 overview

	Sector/ technologies	Unit	2010	Reference Case 2020	Reference Case 2030	Case 1 REmap 2020	Case 1 REmap 2030	Case 2 REmap 2020	Case 2 REmap 2030	Case 3 REmap 2020	Case 3 REmap 2030
1. Power sector											
Power Capacity	**Total renewable power capacity**	**GW_e**	**3.4**	**10.6**	**15.6**	**12.1**	**22.8**	**13.8**	**28.3**	**12.6**	**23.4**
	Hydropower[1]	GW_e	1.0[1]	1.1	1.2	1.0	1.3	1.1	1.4	1.0	1.3
	Wind[2]	GW_e	0.8	5.9	7.5	7.5	14.4	8.4	16.4	7.5	14.4
	Onshore wind	GW_e	0.8	5.7	6.9	6.9	13.0	7.7	14.3	6.9	13.0
	Offshore wind	GW_e	0.0	0.2	0.6	0.5	1.4	0.7	2.2	0.5	1.4
	Bioenergy	GWe	1.7	3.6	4.3	3.6	4.4	3.8	5.2	4.1	5.0
	Dedicated multi-fuel combustion (power)[3]	GW_e	1.4	1.7	0.9	1.2	0.0	1.2	0.0	1.2	0.0
	Solid biomass (power only)[3]	GW_e	0.0	0.5	1.1	0.5	1.1	0.5	1.1	0.5	1.1
	Solid biomass (CHP – district heating)[4]	GW_e	0.2	0.2	1.0	1.0	1.4	1.1	1.9	1.3	1.6
	Solid biomass (CHP – industry)[4]	GW_e	0.0	0.4	0.3	0.2	0.3	0.5	0.7	0.7	1.1
	Liquid & gaseous biofuels (CHP- district heating)[4]	GW_e	0.1	0.8	1.4	0.9	1.9	0.9	2.1	1.1	2.3
	Solar PV[5]	GW_e	0.0	0.001	2.7	0.0	2.7	0.5	5.0	0.0	2.7
	Utility-scale	GW_e		0.0	2.4	0.0	2.2	0.3	3.0	0.0	2.2
	Rooftop	GW_e		0.0	0.3	0.0	0.5	0.2	2.0	0.0	0.5
	Solar CSP	GW_e	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Electricity Generation	**Total renewable electricity generation**	**TWh**	**11.0**	**31.2**	**41.6**	**39.8**	**67.2**	**44.9**	**81.5**	**44.3**	**73.7**
	Hydropower	TWh	2.9	3.2	3.2	3.3	4.2	3.5	4.5	3.3	4.2
	Wind	TWh	1.7	13.7	32.5	19.0	37.0	21.5	43.0	19.0	37.0
	Onshore wind	TWh	1.7	13.0	15.8	17.0	32.0	19.0	35.0	17.0	32.0
	Offshore wind	TWh	0.0	0.7	2.0	2.0	5.0	2.5	8.0	2.0	5.0
	Bioenergy	TWh	6.4	14.3	18.5	17.5	23.3	19.4	28.5	22.0	29.8
	Dedicated multi-fuel combustion (power)	TWh	5.6	7.0	3.5	5.0	0.0	5.0	0.0	5.0	0.0
	Solid biomass (power)	TWh	0.0	2.0	4.8	2.0	4.8	2.2	5.0	2.2	4.8
	Solid biomass (CHP – district heating)	TWh	0.4	0.5	2.5	4.5	6.0	5.0	8.5	5.8	7.0
	Solid biomass (CHP – industry)	TWh	0.0	0.8	0.8	1.0	1.5	2.0	3.0	3.0	5.0
	Liquid & gaseous biofuels (CHP-district heating)	TWh	0.4	4.0	6.9	5.0	11.0	5.2	12.0	6.0	13.0
	Solar PV	TWh	0.0	0.0	2.1	0.0	2.7	0.5	5.0	0.0	2.7
	Utility-scale	TWh	0.0	0.001	1.9	0.0	2.2	0.3	3.0	0.0	2.2
	Rooftop	TWh	0.0	0.000	0.2	0.0	0.5	0.2	2.0	0.0	0.5
	Solar CSP	TWh	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
2. District heating		**PJ_{th}**	**12.8**	**23.6**	**55.1**	**64.7**	**97.8**	**75.6**	**124.6**	**80.9**	**113.7**
Solar heating/ cooling		PJ_{th}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Geothermal heat		PJ_{th}	0.6	9.1	14.2	10.0	15.0	12.0	17.0	10.0	15.0
Bioenergy		PJ_{th}	12.8	14.5	40.9	54.7	82.8	63.6	107.6	70.9	98.7

Sector/ technologies	Unit	2010	Reference Case 2020	Reference Case 2030	Case 1		Case 2		Case 3	
					REmap 2020	REmap 2030	REmap 2020	REmap 2030	REmap 2020	REmap 2030
Dedicated multi-fuel combustion (heat)	PJ_{th}	1.4	1.5	1.6	2.0	2.7	2.0	2.7	2.0	2.7
Solid biomass (heat)	PJ_{th}	0.3	0.5	1.0	10.0	15.0	15.0	20.0	15.0	20.0
Solid biomass (CHP)	PJ_{th}	10.3	3.6	18.0	32.4	43.2	36.0	61.2	41.8	50.4
Liquid & gaseous biofuels (heat)	PJ_{th}	0.0	0.0	0.5	1.0	1.5	1.0	1.5	1.0	1.5
Liquid & gaseous biofuels (CHP)	PJ_{th}	0.7	7.4	12.8	9.3	20.4	9.6	22.2	11.1	24.1
3. Industry and other sectors (incl. construction. agriculture/ forestry)	**PJ_f**	**82.1**	**92.8**	**102.9**	**103.5**	**125.5**	**123.0**	**157.0**	**126.0**	**178.0**
Solar heating/ cooling	PJ_f	0.0	0.0	0.0	0.5	2.0	4.0	10.0	2.0	3.0
Geothermal heat	PJ_f	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bioenergy	PJ_f	82.1	92.8	102.9	103.0	123.5	119.0	147.0	124.0	175.0
Solid biomass (heat)	PJ_f	81.9	82.0	90.0	83.0	90.0	90.0	100.0	85.0	95.0
Solid biomass (CHP)	PJ_f	0.0	7.2	7.2	9.0	13.5	18.0	27.0	27.0	45.0
Liquid & gaseous biofuels	PJ_f	0.2	3.6	5.7	11.0	20.0	11.0	20.0	12.0	35.0
Heat pumps	PJ_{th}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total electricity consumption (mix)	TWh	43.5	47.2	62.0	47.2	62.0	47.2	62.0	47.2	62.0
4. Buildings (residential and commercial)	**PJ_f**	**123.5**	**151.6**	**188.4**	**176.5**	**208.3**	**189.2**	**235.3**	**201.5**	**238.3**
Solar heating/ cooling	PJ_f	0.4	5.3	26.1	21.3	33.0	24.0	45.0	21.3	33.0
Geothermal heat	PJ_f	0.6	0.2	0.3	0.2	0.3	0.2	0.3	0.2	0.3
Bioenergy	PJ_f	121.7	140.0	155.0	148.0	165.0	155.0	170.0	170.0	185.0
Solid biomass (heat)	PJ_f	120.7	130.0	140.0	138.0	150.0	145.0	155.0	150.0	160.0
Liquid & gaseous biofuels (heat)	PJ_f	1.0	10.0	15.0	10.0	15.0	10.0	15.0	20.0	25.0
Heat pumps	PJ_{th}	0.9	6.2	7.0	7.0	10.0	10.0	20.0	10.0	20.0
Total electricity consumption (mix)	TWh	72.3	78.6	103.2	78.6	103.2	78.6	103.2	78.6	103.2
5. Transport sector	**PJ_f**	**37.1**	**63.2**	**71.4**	**71.0**	**82.0**	**79.5**	**108.5**	**81.5**	**128.5**
Liquid & gaseous biofuels	PJ_f	37.1	63.2	71.4	71.0	82.0	79.5	108.5	81.5	128.5
Ethanol (conventional)[6]	PJ_f	7.9	17.8	20.5	19.0	21.0	20.0	23.0	20.0	30.0
Ethanol (advanced)[6]	PJ_f	0.0	8.8	10.5	9.0	11.0	11.0	15.0	11.0	15.0
Biodiesel	PJ_f	29.2	33.9	37.4	40.0	45.0	45.0	62.0	47.0	75.0
Biomethane	PJ_f	0.0	2.8	3.0	3.0	5.0	3.5	8.0	3.5	8.0
Biohydrogen	PJ_f	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.5
Electricity consumption (renewable)	TWh	0.2	0.6	0.9	0.7	1.0	0.8	1.2	0.7	1.0
Rail transport	TWh	0.2	0.4	0.6	0.4	0.7	0.5	0.8	0.4	0.7
Road transport (private)	TWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Road transport (public)	TWh	0.0	0.2	0.3	0.3	0.3	0.3	0.4	0.3	0.3
Electricity consumption (mix)	TWh	3.3	3.6	4.8	3.6	4.8	3.6	4.8	3.6	4.8

Sector/ technologies	Unit	2010	Reference Case 2020	Reference Case 2030	Case 1		Case 2		Case 3	
					REmap 2020	REmap 2030	REmap 2020	REmap 2030	REmap 2020	REmap 2030
6. Total power generation	**TWh**	**157.1**	**166.1**	**216.2**	**166.1**	**216.2**	**166.1**	**216.2**	**166.1**	**216.2**
Renewables share in power generation	%	7	18.8	19.2	24.0	31.1	27.0	37.7	26.7	34.1
7. TFEC (IRENA)	**PJ_f**	**2 816**	**2 933**	**3 417**	**2 933**	**3 417**	**2 933**	**3 417**	**2 933**	**3 417**
7. TFEC (NREAP)	**PJ_f**	**2 521**	**2 852**	**3 302**	**2 852**	**3 302**	**2 852**	**3 302**	**2 852**	**3 302**
Renewable fuels for heating and transport	PJ_f	243	308	363	351	416	392	501	409	545
Renewable power consumption	PJ_f	30	89	120	113	194	128	235	126	213
Renewable heat consumption	PJ_f	11	21	48	58	85	68	109	73	99
Total renewables use	**PJ_f**	**284**	**417**	**531**	**522**	**695**	**587**	**845**	**608**	**857**
Renewables share in TFEC (IRENA)	**%**	**11.3**	**14.6**	**16.1**	**17.8**	**20.3**	**20.0**	**24.7**	**20.7**	**25.1**
Renewables share in TFEC (NREAP)	**%**	**10.1**	**14.2**	**15.5**	**18.3**	**21.0**	**20.6**	**25.6**	**21.3**	**25.9**
8. GFEC (IRENA)	**PJ_f**	**2 567**	**2 897**	**3 392**	**2 897**	**3 392**	**2 897**	**3 392**	**2 897**	**3 392**
8. GFEC (NREAP)	**PJ_f**	**2 814**	**2 897**	**3 373**	**2 897**	**3 373**	**2 897**	**3 373**	**2 897**	**3 373**
Gross renewable electricity demand	PJ_f	39	112	150	143	242	162	292	160	265
Gross renewable heating demand	PJ_f	217	262	339	337	420	374	487	396	507
Gross renewable transport biofuels demand	PJ_f	37	61	69	68	77	76	100	78	120
Total renewables use	**PJ_f**	**294**	**436**	**558**	**549**	**739**	**612**	**879**	**634**	**893**
Renewables share in GFEC (IRENA)	**%**	**10.4**	**15.0**	**16.4**	**18.9**	**21.8**	**21.1**	**25.9**	**21.9**	**26.3**
Renewables share in GFEC (NREAP)	**%**	**11.5**	**15.0**	**16.5**	**18.9**	**21.9**	**21.1**	**26.1**	**21.9**	**26.5**

Note: e: electric; f: final fuel input; th: thermal heat generated.
TFEC (IRENA) refers to the boundaries of the energy system based on the IRENA TFEC definition. GFEC (IRENA) is converted from the TFEC according to the IRENA definition.

1 Total small and large hydropower. Capacity factor in 2006 was 25%, rising to approximately 32% by 2020 and 2030 according to NREAP.
2 The NREAP capacity factor rises from 24% in 2010 to 26% by 2020 and 2030. For REmap, a 28% capacity factor is assumed for onshore wind according to Krajowa Agencja Poszanowania Energii (2013). No capacity factor is provided for offshore wind. This study assumes a 40% and 42% capacity factor for the Reference Case and REmap, respectively.
3 NREAP excludes the development of installed capacity for multi-fuel combustion (co-firing). Capacity factors are estimated at 47% in 2006 based on hard coal power plants (both power and CHP). A similar capacity factor of 50% is assumed for biomass-fired power systems, which NREAP also excludes.
4 Biomass CHP capacity factors are estimated based on the generation and capacity installed of certified biogas (57%) and biomass (24%) energy sources in 2007-2009. For REmap 2020/2030, a 50% capacity factor is assumed.
5 NREAP indicates solar PV capacity factor of 9%. In Remap 2020/2030, an 11.5% capacity factor is assumed.
6 Conventional and advanced bioethanol contribute equally to the transport sector's renewable energy use and share.

ANNEX C:

Cost and energy price assumptions

Table 15: Assumptions for capital costs and capacity factors of different technologies

REmap Options	Unit	Capital cost in 2030	REmap case capacity factor (%)
Power generation technologies			
Hydropower	USD/kW$_e$	3 000	35% (KAPE, 2013)
Onshore wind	USD/kW$_e$	1688 (KAPE, 2013)	28% (KAPE, 2013)
Offshore wind	USD/kW$_e$	3 279 (KAPE, 2013)	42% (KAPE, 2013)
Dedicated multi-fuel combustion (power only)	USD/kW$_e$	500	47% (KAPE, 2013)
Dedicated multi-fuel combustion (CHP) district heating	USD/kW$_e$	3 195 (KAPE, 2013)	50% (KAPE, 2013)
Solid biomass (power only)	USD/kW$_e$	2 642	50% (KAPE, 2013)
Solid biomass (CHP) district heating	USD/kW$_e$	3 195 (KAPE, 2013)	50% (KAPE, 2013)
Solid biomass (CHP) industry	USD/kW$_e$	3 195 (KAPE, 2013)	50% (KAPE, 2013)
Liquid & gaseous biofuels (power only)	USD/kW$_e$	1 952	65% (KAPE, 2013)
Liquid & gaseous biofuels (CHP) district heating	USD/kW$_e$	3 541 (KAPE, 2013)	65% (KAPE, 2013)
Solar PV utility-scale	USD/kW$_e$	1375 (KAPE, 2013)	11.5%
Solar PV rooftop	USD/kW$_e$	1754 (KAPE, 2013)	11.5%
Heat generation technologies			
Dedicated multi-fuel combustion (heat only), district heating	USD/kW$_{th}$	1500	85%
Solid biomass (heat only), district heating	USD/kW$_{th}$	1500	85%
Liquid & gaseous biofuels (heat only), district heating	USD/kW$_{th}$	1500	85%
Solid biomass boiler, industry	USD/kW$_{th}$	750	85%
Solid biomass boiler, buildings	USD/kW$_{th}$	774	85%
Biogas boiler, industry	USD/kW$_{th}$	800	85%
Biogas boiler, buildings	USD/kW$_{th}$	1000	85%
Heat pumps, buildings	USD/kW$_{th}$	800	80%
Solar heating, industry	USD/kW$_{th}$	720	9%
Solar heating, buildings	USD/kW$_{th}$	480	9%
Geothermal, buildings	USD/kW$_{th}$	1500	30%
Transport sector technologies			
Conventional ethanol plant	USD/l	0.6	N/A
Advanced ethanol plant	USD/l	1.5	N/A
Biodiesel plant	USD/l	0.5	N/A
Biomethane plant	USD/Nm^3	1.2	N/A

Note: Unless otherwise indicated, data are based on IRENA

ANNEX D:

Present cost of electricity generation in Poland

Table 16: Energy price assumptions, 2030

	Units	Business perspective	Government perspective	References
Coal				KAPE (2013); Eurostat (2015); IEA (2014b)
Power	USD/GJ	3.6	2	
Industry	USD/GJ	4.1		
Household	USD/GJ	8.4		
Natural gas				
Industry	USD/GJ	12.2	11.1	
Household	USD/GJ	23.3	22.2	
Electricity prices				
Industry	USD/kWh	0.20	0.19	
Household	USD/kWh	0.33	0.25	
Weighted average supply cost of biomass				IRENA (2014b)
Energy crops	USD/GJ	10.1	12.8	
Agricultural residues and waste	USD/GJ	3.1-5.3	3.4	
Forestry products	USD/GJ	7.9-11.5	8.3-11.6	
Conventional ethanol	USD/GJ	57.3	27	
Advanced ethanol	USD/GJ	63	25	
Biodiesel	USD/GJ	68.3	23	
Biomethane	USD/GJ	44	15	
Petrol	USD/GJ	73.5	28.8	GIZ (2012); KAPE (2013)
Diesel	USD/GJ	68.3	28.8	

Table 17: Assumptions for externalities

Carbon prices	**USD/t CO_2**	**–**	**20-80**
Human health unit external costs			
Power sector			
Coal	USD/kWh	0.008-0.022	
Oil	USD/kWh	0.014-0.039	
Natural gas	USD/kWh	0.002-0.004	
Industry			
Coal	USD/GJ	0.9-2.5	
Natural gas	USD/GJ	0.2-0.5	
Transport			
Petrol	USD/GJ	0.5	
Diesel	USD/GJ	0.3	

Source: IRENA (2014a)

Table 18: Present cost of electricity generation in Poland

Generation unit type	Total cost of generation (Zloty/MWh)	
	2013	Q3 2014
Hard coal power plant	233.8	204.5
Hard coal combined heat and power plant	180.9	-
Lignite generation plant	161.6	153.3
Natural gas power plant	305.9	368.1
Biomass power plant	444.5	424.5
Onshore wind	374.4	379.1
Hydropower	178.8	209.1

Source: Energy Market Agency

IRENA

International Renewable Energy Agency

www.irena.org