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International Renewable Energy Agency

REmap 2030
A Renewable Energy Roadmap

RENEWABLE ENERGY PROSPECTS:

MEXICO

May 2015

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.

About SENER

The Mexican Ministry of Energy (SENER) is the institution in charge of driving the country's energy policy, within the national constitutional framework, to ensure an economically viable competitive supply of, sufficient, high quality, and environmentally sustainable energy. With the vision of achieving a country with universal access to modern energy at competitive prices, provided securely by public and private companies of the highest world standards, and with the extensive promotion of the implementation of Energy Efficiency and Renewable Energy.

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FOREWORD

REmap 2030 outlines how countries can work together to double the share of renewable energy in the global energy mix by 2030. It represents an unprecedented international effort that brings together the work of more than 90 national experts in nearly 60 countries. Following the global REmap report released in June 2014, the International Renewable Energy Agency (IRENA) is now releasing a series of country-specific reports built on the same detailed analysis.

As the second largest energy consumer in Latin America, Mexico is committed to contributing to the global transition to a sustainable energy future. Mexico is one of the world's largest crude oil and natural gas producers, but its natural gas imports are rising. Mexico has the opportunity to exploit its rich potential in renewables to diversify its energy supply, reduce its greenhouse-gas emissions, lower health dangers, create jobs and combat energy poverty.

Mexico is seizing the chance and reshaping its energy policy to promote renewables. It has recently enacted a major reform that opens energy markets to competition, creating new opportunities for renewable energy development. The country is fast emerging as a leader of a Latin American energy transformation.

This REmap 2030 report shows how the country can achieve the transition to renewable energy, suggesting specific and practical pathways that would result in a clean and secure energy system. Mexico can achieve this through concerted actions to take advantage of its excellent renewable resource potential, building upon the progress made so far. If Mexico continues on its path towards a sustainable energy future, it will be recognised as a leader not just in Latin America but also in the rest of the world.

Adnan Z. Amin
Director-General
International Renewable Energy Agency

In Paris later this year, the 21st United Nations Climate Change Conference (COP 21) will take place against a background of scientific agreement, that alterations in the planet´s climate system have been induced by human activity. If we are to change our path, we will have to move towards a sustainable energy economy, by scaling up the use of clean technologies. To make the transition to a low-carbon economy, the first step is to match demand for energy services with a sustainable energy supply.

Mexico has set the process in motion by establishing a consultative council on renewable energy, including representatives from academia, industry, the public sector and the legislature. The council has sole responsibility for advising on the development of sector-specific public policies. Its first task was to assess the country's renewable energy resources, resulting in the creation of the National Renewable Energy Inventory.

As part of Mexico's commitment to the sustainability of the energy sector, we are publishing our experiences of developing this inventory. We have also joined forces with IRENA in developing REmap 2030, which promotes international cooperation to enable a doubling of the share of renewables in the energy mix.

If we are to double the renewable energy share in Latin America by 2030, countries in the region must work together. All of us need to promote energy trade, exchanges of expertise and harmonisation of standards. We must create the physical interconnections, as well as market interactions, to move towards a low-carbon energy future.

As this report emphasises, Mexico has the potential to lead such a shift.

Leonardo Beltrán Rodriguez
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HIGHLIGHTS

- Mexico has a large and diverse renewable energy resource base. Given the right mix of policies, Mexico has the potential to attract large-scale investment in renewables that can help diversify its energy supply. Increased renewable energy use would also set Mexico on a pathway toward significantly reducing its greenhouse gas (GHG) emissions. However, development has been limited so far.

- Under current plans, the share of modern renewable energy in total final energy consumption (TFEC) is forecast to increase from 4.4% in 2010 (base year of this analysis) to 10% in 2030. According to REmap 2030, Mexico has the potential to increase this share to 21% by 2030. This implies a threefold growth in total renewable energy use in absolute terms from 0.5 exajoules (EJ) to 1.5 EJ in 2010-30.

- By 2030, Mexico could generate up to 46% of its electricity each year, or 280 terawatt-hours (TWh), from renewable sources. This compares with 18% using business-as-usual developments (116 TWh/year). To achieve a 46% share of renewables in electricity generation, the country is likely to see the greatest deployment in wind (30 gigawatts (GW)) and solar photovoltaic (PV) (30 GW). Together these could account for 26% of total power generation in 2030. Small and large hydropower (26 GW) could contribute 12% of total power generation, with geothermal energy supplying 5% (4.5 GW) and biomass 2.5% (4 GW).

- If renewables uptake were accelerated, all traditional uses of biomass for cooking or heating in the buildings sector would be replaced by modern forms of renewable energy. Total biomass consumption in all end-use sectors for heating or as transport fuels could reach 685 petajoules (PJ) by 2030. This represents more than one third of total renewable energy use. Total installed capacity of solar thermal applications for heating/cooling in buildings and industry would amount to 33 GW, making up almost one tenth of the country's renewable energy consumption.

- Renewables can be an important driver for diversifying Mexico's energy supply. Renewable energy has the potential to reduce Mexico's total coal demand by 62%, natural gas by 21% and oil by 6% compared to business as usual to 2030. As a result, total natural gas demand would grow by 115% in 2010-2030 compared to 175% under business as usual.

- Accelerating Mexico's uptake of renewable energy could result in savings of 7.2 US dollars (USD) per megawatt-hour (MWh) compared to the equivalent new capacity with conventional generation. This saving would equate to 9% of the production cost of natural gas-fired power generation in 2030.

- The result of this higher renewable energy uptake is an annual net savings of USD 1.6 billion in Mexico's total energy system cost by 2030. Meanwhile, if the benefits resulting from lower harm to health and reduced carbon dioxide (CO_2) emissions are taken into account, savings could amount to USD 4.6 billion and 11.6 billion respectively each year.

- To achieve such gains, policy changes in the power market are needed. Planning is essential for transmission, expansion and grid integration to accommodate the full range of renewable power technologies.

- New policies are also needed to promote the uptake of renewable energy for heat and fuel applications in the buildings, industry and transport sectors.

Building a renewable energy market

Mexico accounts for one fifth of all energy use in Latin America, and demand is growing fast. Business-as-usual growth will result in an increase of installed power generation capacity from 64 GW in 2013 to 118 GW in 2030. Mexico is the world's tenth largest oil and natural gas producer. However, natural gas and coal imports are growing, and its dependence on natural gas for power generation has become a major concern. To address these and other challenges, Mexico enacted a series of energy reforms in December 2013. These opened up the energy sector to new players and new ideas, and are set to gradually remove subsidies for oil products and electricity tariffs over the coming years.

In order to fulfil its international GHG reduction pledges, Mexico has also set a clean energy power generation target for 2050. The aim is to reach a share of as much as 40% in power generation from zero or low-emission energy types by 2035, and 50% by 2050. This includes renewables as well as nuclear and fossil fuels with carbon capture and storage. Renewable energy also offers great potential for fostering social and economic development in Mexico's relatively remote and poorer regions. Mexico is taking measures to provide modern energy to nearly three million people in rural areas who lack access to electricity, and to reduce the use of traditional biomass in cooking.

These trends have boosted the case for renewable energy deployment. Mexico has a large and diverse renewable energy resource base. However, development has been limited, so that significant opportunities remain. With the right mix of policies, Mexico can attract large-scale investment in renewables.

REmap 2030: Mexico's renewable energy potential

The International Renewable Energy Agency (IRENA) has developed a global renewable energy roadmap called REmap 2030. This shows how the share of renewables in the global energy mix can be doubled by 2030, both realistically and cost-effectively. This is in line with one of the key objectives of the Sustainable Energy for All (SE4All) initiative led by the United Nations (UN). REmap 2030 is the result of a collaborative process between IRENA, national experts within each of the 26 countries covered by the analysis to date and other stakeholders.

This study is the joint work of IRENA and the Mexican Ministry of Energy (SENER). It identifies the country's possible development path to increase the use of renewables across its entire energy system by 2030. This is one of the first country reports to be released in the REmap 2030 series as part of the IRENA roadmap for doubling the global share of renewables.

Mexico is only just beginning to draw on its large renewable energy potential. As of 2013, total renewable energy capacity in the power sector was 14.2 GW out of 64 GW total system capacity. This share was composed mainly of hydropower (18% of total installed capacity), followed by wind and geothermal (with a combined total of around 4%).

Meanwhile, the renewable energy share in the industry and transport sectors in 2010 (the base year of this analysis) was 5% and 0.8%, respectively. This was largely derived from the combustion of bagasse by-products for industrial process heat generation based on bioenergy, as well as from liquid biofuels. Although the renewables share was higher in the building sector, more than a quarter of that was attributable to the traditional use of biomass (firewood and forestry residues). This is often not sustainably sourced and is not considered a modern form of renewable energy for the purpose of this analysis.

According to SENER and Asia-Pacific Economic Cooperation (APEC) predictions, Mexico's share of modernised renewable energy will only reach 10% of TFEC by 2030 under business as usual. This amounts to more than twice the proportion of 4.4% in 2010. Considered in the light of a 64% growth expected in TFEC, this means a substantial renewable energy scale-up with a significant acceleration compared to historic trends. Even so, the REmap analysis shows far more is possible.

REmap 2030 estimates a portfolio of technology options to accelerate renewable energy deployment across Mexico's entire energy system that could raise the 2030 share to 21%. This implies a threefold increase in total renewable energy use in the same period.

Renewable power generation: wind and solar take the lead

Based on REmap 2030, more than half of Mexico's total renewable energy use would be in the electricity sector.

Mexico has the potential to generate 280 TWh of renewable power by 2030, representing a sixfold increase over today's level of 48 TWh. Achieving this would require a diversified mix of wind, solar, hydro, geothermal and biomass power technologies.

Wind and solar PV combined would account for nearly 60% of Mexico's renewable power generation, and 26% of total generation in 2030. Reaching this level of deployment requires policies that take into account Mexico's major land area, in which demand and supply are often far apart. The country has the potential for significant power generation from biomass and geothermal sources, which are also some of the least expensive power supply options.

Wind power represents a major opportunity across both the north and the south of Mexico, with the potential to produce 92 TWh of electricity per year by 2030. Nearly all of this would be derived from onshore wind. In the context of the country's total installed wind power capacity of 1.7 GW in 2013, a total of 30 GW in 2030 would require an average annual installation rate of 1.7 GW.

Solar PV could contribute 30 GW of power capacity, generating 66 TWh of electricity per year in 2030. This would require an average annual installation rate of 1.5 GW. A quarter of the total installed capacity in 2030 would be in the form of distributed PV and mini-grid applications for street lighting, agricultural water pumping and mobile phone towers (7 GW). An additional 1.5 GW would come from concentrated solar power (CSP).

Bioenergy for power generation would amount to around 4 GW of capacity. Approximately 1 GW of this would come from biomass co-firing in coal plants and 1.8 GW from combined heat and power (CHP) in the manufacturing industry.

Mexico already has the world's fifth largest **geothermal power** installed capacity after the US, the Philippines, Indonesia and New Zealand, and could utilise its high-temperature reservoir potential to reach 4.5 GW in 2030.

Under current plans, Mexico would reach 17 GW of **large hydropower** capacity by 2030. According to REmap, a further 6.5 GW could be installed. **Small hydropower** capacity is already forecast to reach 1.8 GW, equivalent to an annual addition of 90 megawatts (MW) in 2015-30, or about ten small hydropower plants per year. Total installed hydropower capacity would reach 26 GW under REmap 2030.

System integration and expansion of transmission capacity will be essential to ensure the smooth integration of renewables. This is particularly true given the 26% share of variable renewable energy estimated in the accelerated case in REmap 2030. Additional transmission capacity must be planned to exploit wind and solar PV capacity in the northern and western parts of Mexico, which are distant from population centres and industrial activity. The first step will be to fulfil plans to connect Baja California and Baja California Sur to the main grid, both of which have significant resources of solar and wind. It will also be important to plan for rooftop distributed generation. Mexico covers a large area and has many scattered communities. This means mini-grid and rural electrification will play a crucial role, particularly in helping diminish the challenge of grid integration and transmission capacity expansion.

Using renewables to meet transport, buildings and industry energy needs

The other half of total renewable energy use in REmap 2030 would come from non-electricity needs in the transport, buildings and industry end-use sectors.

Modern renewables for heating, cooling and cooking in buildings and industry offer the greatest growth potential, although their use is limited today. Renewable energy use for heating is currently dominated by traditional biomass use, with a small share of bagasse combustion used for industrial process heat and power generation. Solar water heating for buildings is also limited, but there is great potential to replace liquefied petroleum gas (LPG) in this market segment as LPG subsidies are phased out.

REmap 2030 estimates that solar thermal capacity for heating and cooling could reach 33 GW. This includes 13 GW of heating in the manufacturing industry, which represent 6% of heat demand. The buildings sector would account for 20 GW of solar water heaters, contributing 25% of water heating demand. About 5 TWh of power today is used in the residential sector for space cooling, and this is estimated to rise to about 20 TWh/year in REmap

2030. To help meet this need, buildings provide an estimated 4 GW of solar cooling potential. This would reduce total power demand for cooling in the household sector by 5% in REmap 2030. Industry offers the potential for 7 GW of solar thermal use for low-temperature process heat applications (textiles, food production and some chemical processes). There is also potential for more than 2 GW for medium-temperature process heat applications using concentrated solar thermal systems (mainly in chemicals production). Some niche applications already exist in Mexico today in the food sector.

Under current plans, traditional biomass used for cooking will account for 17% of total biomass use in buildings in 2030. REmap estimates traditional uses of biomass will be replaced by modern and efficient cook stoves that use wood for cooking.

Under current policies, only limited growth for renewable energy is forecast for Mexico's transport sector. This is due to rise from 0.8% in 2010 to 2.4% by 2030. In REmap 2030 this could climb to 4.2% in 2030 with the introduction of about six billion litres of liquid biofuels. This would constitute an important step in raising the renewables share in the transport sector, which accounts for nearly half of Mexico's total energy demand today. Dedicated policies based on renewables are needed, both to increase biofuels uptake and to promote mass transportation and electric transport.

In REmap 2030, total use of primary biomass would reach 810 PJ/year, mostly for heating in industry and buildings. This volume is as much as 10% of Mexico's total primary energy supply in 2010.

Cost and benefits of REmap 2030

Increasing the renewable energy share to 21% of Mexico's total final energy mix would result in financial savings. The cost and benefits of renewables are presented in the REmap analysis from both business and government perspectives. The former is based on the national cost of capital and commodity prices that include local taxes or subsidies. The international or government perspective is based on standard international commodity prices and a fixed 10% discount rate.

The results from REmap 2030 show that more than half of all renewable energy technology options could be deployed with cost savings when compared to conventional technology options. From the business perspective, this translates into savings of USD 0.4/MWh (USD 0.1 per gigajoule (GJ)). From a government perspective, this results in savings of USD 7.2/MWh (USD 2/GJ). These estimates are based on 2030 capital cost projections for energy technologies and assume an increase of 50% in fossil fuel prices between 2010 and 2030. These cost savings, however, do not account for infrastructure (*e.g.,* additional generation or transmission capacity) and enabling technology costs (*e.g.,* grid integration).

Savings related to socio-economic benefits arise from increasing the share of renewables as estimated in this study. When accounting for externalities resulting from reduced health effects and CO_2 emissions, total savings could be USD 4.6 billion-11.6 billion in 2030. The health savings are estimated based on the unit external costs of sulphur dioxide (SO_2), mono-nitrogen oxides (NO_x) and particulate matter ($PM_{2.5}$) emissions. These cause outdoor air pollution from fossil fuel combustion in power generation, heating and transport, as well as through traditional biomass use resulting in indoor pollution in Mexico. In addition, a price range was assumed of USD 20-80 per tonne of CO_2, with the same range applied to all other countries in the REmap study.

The replacement of conventional technologies by renewable energy in REmap 2030 cuts fossil fuel demand by almost 1.5 EJ by 2030 compared to business as usual. Lower fossil fuel demand leads to an estimated reduction of 102 megatonnes (Mt) per year of CO_2 emitted by 2030. This amounts to a 17% reduction compared to the business-as-usual case in 2030. Three quarters of that total mitigation potential comes from the power sector.

Implementing all the options indicated by REmap would more than halve Mexico's total coal demand by 2030 compared to 2010 levels. REmap Options also represent an opportunity to reduce total demand for natural gas by 21% compared to current policies for 2030. Savings in oil products are lower – about a 6% reduction. Two thirds of these savings are located in the manufacturing sector.

Policies to accelerate renewable energy

Recent progress in renewable energy uptake indicates that the country has begun to deploy its high renewable energy potential. But further policies are still needed to ensure progress. These recommendations can be categorised into five core areas in which action can be taken to achieve higher renewable energy shares.

Planning transition pathways: planning for renewable power generation capacity needs to go hand in hand with planning for related infrastructure. There is a need for clear and adequate market operation rules and codes for grid connection and access. These need to guarantee renewable power capacity development. The major low-cost renewable energy potential in the end-use sectors needs to be more fully extracted through targeted renewable energy policies. There is a need to accelerate the uptake of solar water heating and biomass-fired CHP capacity, and new policies will be essential to make use of biofuels in Mexico's transport sector.

Creating an enabling business environment: improving cost-effectiveness starts with reducing risks for investors in renewable energy, as well as deploying new capacity. Suitable policy frameworks are needed to implement effective economic, financial and fiscal incentives to accelerate investments. Furthermore, the market needs mechanisms to account for externalities. Continuing the discussion around fossil fuel and renewable subsidies for transport and electricity will also be important.

Ensuring smooth integration of renewables into the system: the integration of a major proportion of different renewable energy technologies is accompanied by three main challenges:

- building and paying for enabling grid infrastructure to address variability
- planning for the most effective use of solar rooftops in buildings
- securing bioenergy supplies, and replacing the use of traditional biomass

Creating and managing knowledge: improving information on renewable energy among policy makers, manufacturers, project developers/installers and users is essential. Applying appropriate system models to create knowledge of Mexico's power system will provide insight into how higher shares of variable renewable power generation can be accommodated in terms of transmission, demand-side resources and grid operation.

Unleashing innovation: technology innovation will play a key role in realizing Mexico's renewable energy potential. Mexican Energy Innovation Centres have started to make important contributions. Expanding these further could help the sector to break down barriers related to the costs and availability of technologies that have so far seen only limited growth. A number of issues are under examination in these and other similar centres. They include, for instance, construction, testing and certification of medium-scale and grid-friendly wind turbine concepts, industrial solar thermal innovations, and solar-powered cooling systems.

1 INTRODUCTION

In 2011, the UN Secretary-General launched the SE4All initiative with three interlinked objectives to be achieved by 2030: (i) ensure universal energy access to modern energy services (ii) double the rate of improvement in energy efficiency (iii) double the share of renewable energy in the global energy mix. In this context, IRENA developed a global renewable energy roadmap (REmap 2030). This is a bottom-up analysis applied to individual countries. It shows how accelerated penetration of renewable energy in each case could help double the share of renewables in the global energy mix by 2030. Key factors to achieve this goal are biomass for heating, power generation and biofuels, wind, solar PV and greater electrification of the energy sector. Based on an analysis of 26 countries[1], REmap 2030 suggests that renewable energy expansion, as currently planned, will result in a 21% share of renewables worldwide in 2030 (IRENA, 2014a). This leaves a 15 percentage-point gap to achieving a 36% renewable energy share in 2030 as indicated in the SE4All Global Tracking Report (Banerjee *et al*., 2013). REmap 2030 notes specific measures to facilitate meeting this target.

REmap 2030 is the result of a collaborative process between IRENA and national REmap experts within the individual countries, as well as other stakeholders. The current report focuses on the actual and potential role of renewable energy in Mexico, the second largest energy consumer in Latin America after Brazil. In 2010 (the base year of this analysis), Mexico's TFEC was 4.5 EJ, equivalent to 1.4% of global TFEC (SENER, 2012a) (IEA, 2013). Half of Mexico's TFEC in 2010 was consumed in the transport sector. Energy consumption in industry followed with 30%, 20% in the buildings sector. Finally, 3% of TFEC was consumed in the agriculture sector.

TFEC in Mexico is projected to increase significantly, growing from 4.5 EJ in 2010 to 7.4 EJ in 2030, an increase of nearly 70%. In the same time period, the Reference Case for this study shows that Mexico's modern renewable energy share in TFEC will grow only from 4.4% (0.2 EJ) in 2010 to 10% (0.74 EJ) in 2030[2]. This is based on current policies.

Mexico has significant potential to go beyond its Reference Case developments. According to the REmap analysis Mexico could reach a total 1.5 EJ of final renewable energy use, or a 21% renewable energy share in TFEC by 2030. This depends on whether the realisable potential of all renewable energy technologies identified in REmap is deployed. These additional technology potentials are called the REmap Options. Available renewable energy resources include mainly solar, geothermal, biomass, wind and hydropower. The first three can be used either for power or heat generation, depending on resource availability and on the technologies implemented.

This national potential would also contribute to the global renewable energy share. Figure 1 provides a breakdown of total renewable energy use among the 26 countries that have developed REmap Options. Six of these countries account for over half the total additional renewable energy potential and the worldwide REmap Options. Mexico accounts for 1% of the renewable energy potential identified in the Remap 26 country grouping.

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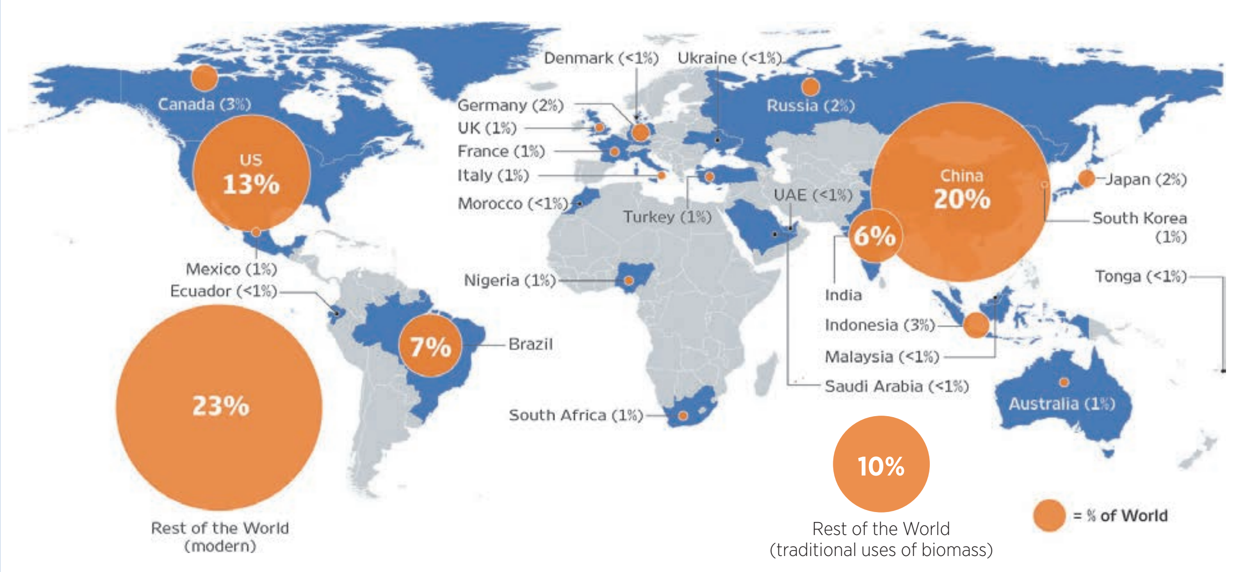
1 The analysis published in June 2014 included 26 countries that account for three quarters of global TFEC. Another 14 countries are being added in 2014/2015 that raise the global coverage to 80%. TFEC includes the total combustible and non-combustible energy use from all energy carriers as fuel (for the transport sector) and to generate heat (for industry and the building sectors) as well as electricity and district heat. It excludes non-energy use. This report uses this indicator to measure the renewable energy share, consistent with the Global Tracking Framework report (Banerjee *et al*., 2013).
TFEC includes the consumption of industry (including blast furnaces and coke ovens, but excluding petroleum refineries), buildings (residential and commercial), transport, agricultural, forestry, fishing and other small sectors. The potential of renewables is estimated for the industry, buildings and transport sectors accounting for about 97% of TFEC in 2010. In that same year, the non-energy use in Mexico was about 7% of total final consumption, which includes both the energy and non-energy use of energy carriers. Final non-energetic consumption registers the primary and secondary energy consumption as a commodity. This occurs in the processes that use inputs for the elaboration of non-energetic goods. For example, Mexican Petroleums (PEMEX), a petrochemicals company, uses dry gas and oil derivatives for the production of plastics, solvents, polymers, rubber etc. Consumption of sugar cane bagasse used for paper production, bonded boards and cattle feed in other sectors are included.

2 These shares exclude the use of traditional biomass that, if included, would raise the renewable energy share in TFEC to 10%.

Figure 1: Contribution of the 26 individual countries in REmap 2030 to total global renewable energy use



Note: the contribution of the 26 REmap countries represents 75% of global final energy consumption.

While six countries account for half the global potential, the other half is located in other countries where Mexico plays a key role.

The objective of this report is to provide detailed background data, present the results of Mexico's REmap country analysis, and suggest how these results could be translated into action.

The report starts with a brief description of the REmap 2030 methodology (Section 2). It continues by explaining the present energy situation in Mexico and recent trends in renewable energy use (Section 3). Section 4 provides the details of the Mexico Reference Case. Section 5 discusses the current policy framework and the details of Mexico's energy reform launched in December 2013. This is important given that the transformation of the sector brought about through these reforms is opening up participation in energy sector activities to new players. Section 6 shows Mexico's renewables potential. Section 7, the core of the report, quantifies the potential of the REmap Options. This is followed by a discussion of the opportunities for and barriers to renewable energy in Mexico (Section 8). Section 9 provides policy recommendations for an accelerated renewable energy uptake for Mexico. This study assumes that all renewable energy options are taken together by 2030. However, the last section also includes a discussion of energy sector and policy recommendations related to the transition period from now to 2030.

2 METHODOLOGY AND DATA SOURCES

This section explains the REmap 2030 methodology, and summarises details about the background data used for this Mexican analysis. These background data are listed in greater detail in the annexes.

REmap is an analytical approach for assessing the gap between current national renewable energy plans, additional potential renewable technology options in 2030 and the SE4All objective to double the global renewable energy share by 2030.

REmap 2030 assessments for 26 countries were completed in June 2014, These were Australia, Brazil, Canada, China, Denmark, Ecuador, France, Germany, India, Indonesia, Italy, Japan, Malaysia, **Mexico (the present analysis)**, Morocco, Nigeria, Russia, Saudi Arabia, South Africa, South Korea, Tonga, Turkey, Ukraine, the United Arab Emirates, the United Kingdom and the United States.

The analysis is based on data covering both national energy consumption in end-use sectors (buildings, industry and transport) and power generation[3]. 2010 is the base year for this analysis[4]. This base year data for Mexico originates from the national energy balance (SENER, 2012a)[5].

The Reference Case is the business-as-usual energy scenario for 2030. It reflects policies in place or under consideration, including energy efficiency improvements. The Reference Case includes the TFEC of each end-use sector and the total generation of the power sector, with a breakdown by energy carrier for 2010–2030. The Reference Case for Mexico was based on the following sources:

- Business-as-usual scenario of the Energy Demand Supply Outlook 2013 by APEC (2013a) for final energy consumption in the Mexican end-use sectors[6].
- National projections from SENER for power generation and consumption from the report 'Power Sector Perspectives' (Prospectiva del Sector Eléctrico), issues 2012-2026 (SENER, 2012b) and 2013-2027 (SENER, 2013a), and from data provided directly by SENER.
- 'Renewable Energy Perspectives' (Prospectiva de Energías Renovables), issues 2012-2026 (SENER, 2012c) and 2013-2027 (SENER, 2013b). These determine the expected deployment of solar water heaters (for buildings and industry), based on business-as-usual scenario.
- A prospective study of bioenergy use in Mexico (Islas, Manzini, & Masera, 2006), to establish the proportion of traditional and modern uses of biomass in the household sector. This is also used to establish the proportion of traditional and modern forms of biomass in the base year 2010.
- SENER and IEA (2011) data on energy efficiency indicators to show the breakdown for energy end-use by application in buildings.

Once the Reference Case was prepared, further potential renewable energy technology options were identified. These renewable energy additions are defined as REmap Options. A scenario approach was rejected in favour of an options approach. This is because REmap 2030 is an exploratory study, not a target-setting exercise.

REmap Options for Mexico originated from a variety of sources outlined below:

- Renewable Energy Perspectives 2012-26 (SENER, 2012c) and the National Commission for Efficient Energy Use (Comisión Nacional para el Uso Eficiente de la Energía) (CONUEE) study for the promotion of solar water heaters in Mexico (CONUEE, 2007) to set a potential high solar

3 Mexico has no district heat generation sector.

4 Subject to data availability, information for more recent years (*i.e.*, 2012, 2013) is provided where relevant.

5 Some numbers were adjusted according the International Energy Agency (IEA) balances or the APEC Energy Demand and Supply Outlook for 2010. These related to energy consumption in the domestic aviation and maritime sector, and biofuels use. The power sector numbers have been adjusted according to SENER projections (see Section 3).

6 APEC forecasts for electricity demand in 2030 were adjusted according to projections provided by SENER.

water heating penetration scenario for the buildings sector.

- National Energy Strategy 2013-27 (SENER, 2013c) to assess the economic potential of wind, geothermal, mini-hydro power and solar PV by 2020.
- Power Sector Perspectives 2013-27 (SENER, 2013a) for additional wind developments by 2027, according to the 'alternative' (high renewable development) scenario, to produce 35% of power generation from "clean technologies" by 2024.
- National Renewable Energy Inventory (Inventario Nacional de Energías Renovables) (INERE) (SENER, 2014a) to assess the technical potential of solar, wind, geothermal power and small hydropower.
- Hydropower & Dams, World Atlas 2014 (Hydropower & Dams, 2014) to establish the economic potential of hydropower.
- Biomass supply potential and cost estimations by IRENA (2014b) for power and heat generation and for biofuels production (IRENA, 2013a).
- Bioenergy in Mexico, current status and perspectives by the Mexican Network for Bioenergy (Red Mexicana de Bioenergía) (REMBIO) (2011) as reference for biomass supply potential.
- IRENA Roadmap (IRENA, 2014c) on renewables for industry for solar and geothermal heat generation in Industry.

IRENA developed a REmap tool that allows staff and external experts to input data in an energy balance for 2010, 2020 and 2030. They can then assess technology options that could be deployed by 2030 in line with an accelerated renewable energy deployment. In addition to the information in the annexes of this report, a detailed list of these technologies and the related background data is provided online[7]. The tool includes the costs (capital, operation and maintenance) and technical performance of renewable and conventional technologies (fossil fuel, nuclear and traditional use of biomass) for each sector analysed. The technical performance is worked out as the reference capacity of installation, capacity factor and conversion efficiency. Sectors covered include industry, buildings, transport and power.

7 www.irena.org/remap.

Each renewable energy technology is characterised by its costs, and the cost of each REmap Option is represented by its substitution cost. Substitution costs are the difference between the annualised cost of the REmap Option and of 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 2010 USD/GJ[8] of final renewable energy). 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 replaced, energy prices and the characteristics of the REmap Option. The cost can be positive (incremental) or negative (savings). This is because certain renewable energy technologies are or could be cost-effective compared to conventional technologies by 2030 as a result of technological learning and economies of scale.

Country cost-supply curves were developed from the perspective of government and business for the year 2030. They were based on the substitution cost and the potential of each REmap Option.

In the **government perspective**, energy prices exclude taxes and subsidies, and a standard 10% discount rate is used. This allows for comparison of the costs and benefits across all REmap countries. This calculation shows the cost of doubling the global renewable energy share as governments would calculate it.

In the **business perspective**, the process was repeated using national energy prices including taxes and subsidies.[9] A national cost of capital of 10% was used for Mexico. The use of these combined parameters serves to generate a national cost curve. This approach shows the cost of the transition as businesses and investors would calculate it.

Assessment of all additional costs related to complementary infrastructure, such as transmission lines, reserve power needs and energy storage or fuel stations, are excluded from this study. However, where relevant,

8 1 GJ = 0.0238 tonnes of oil equivalent (toe) = 278 kilowatt-hour (kWh) = 0.175 barrels of oil equivalent = 0.947 million British thermal units. In 2010, 1 USD was equivalent to 12.645 Mexican Pesos.

9 In the case of Mexico, all subsidies which exist today are assumed to be phased out by 2030.

the implications of infrastructure needs on total system costs are discussed on the basis of a literature review.

Throughout this study, the renewable energy share is estimated relative to TFEC. Based on TFEC, the renewable energy share can be estimated for the total of all end-use sectors of Mexico or for each end-use sector (with or without the contribution of renewable electricity). The share of renewable power generation is also calculated. Further details of the REmap 2030 methodology can be found online in IRENA's REmap webpage at: www.irena.org/remap.

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

1) *Net incremental system costs*: this is the sum of the differences between the total capital (in USD/year) and operating expenditures (in USD/year) of all energy technologies. This is based on their deployment in REmap 2030 and the Reference Case for each year in 2010-2030.
2) *Net incremental investment needs*: this is the difference between the annual investment needs of all REmap Options and the investment needs of the conventional technologies being replaced. Investment needs for renewable energy capacity are estimated by calculating the total deployment of each technology in kilowatts (kW) or MW[10] to deliver the same energy service as conventional capacity. This is multiplied by the investment costs (in USD/kW) for 2010-2030. This total is then annualised for the number of years covered in the analysis.
3) *Subsidy needs:* total subsidy requirements for renewables are the difference between the delivered energy service costs for the REmap Option (in USD/GJ final energy) and the delivered costs of its conventional counterpart. This is multiplied by its deployment in a given year (in PJ/year).

Externalities have been estimated related to GHG emission reductions as well as improvements in outdoor and indoor 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 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 estimates yields the total net GHG emissions reduction 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). This range was applied only to CO_2 emissions and not to other GHG. According to IPCC (2007), 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 estimated in a separate step, which excludes any effect related to GHG emissions. Outdoor air pollution is evaluated from the following sources:

1) outdoor emissions of SO_2, NO_x and $PM_{2.5}$[11] from fossil fuel-based power plant operation,
2) outdoor emissions of NO_x and $PM_{2.5}$ 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:

a) 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))
b) unit external costs *i.e.* Euro average/tonne for the European Union (EU), adapted for Mexico from the EU Clean Air for Europe

10 1 GW = 1000 MW = 1000 000 kW = 1000 000 000 watts.

11 PM emissions come in different sizes. Particles smaller than 10 micrometres can enter lungs, resulting in health problems. Particles smaller than 2.5 micrometres originate from various types of fossil fuel combustion, including power plants, stationary (*e.g.* steam boilers) and mobile (*e.g.* vehicles) emission sources. Emissions with particle size of 2.5-10 millimetres (PM_{10}) originate also from crushing, grinding or dust that comes off the road as vehicles pass by. With the introduction of modern filtering systems, emissions of this size have been reduced. This study therefore focuses on emissions of particulate matter size of less than 2.5 millimetres.

(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[12].

An extended version of the methodology of the REmap analysis can be found online[13].

12 These factors are specific to the location. They include, for instance, climate and geographical conditions that contribute to the impacts of air pollution and are excluded from GDP. Furthermore, air pollution impacts may differ within a country, particularly in cases like Mexico, which cover a large territory. None of these differences and potential impacts was considered in this study. As a result, the externality estimates in this study can be considered conservative.

13 www.irena.org/remap.

3 RECENT TRENDS

KEY POINTS

- The share of total renewable energy in Mexico was 8.9% (or around 440 PJ) of TFEC in 2013. Nearly 60% of this was traditional use of biomass (255 PJ). Mexico still has major potential to deploy renewable energy in its transport and other end-use sectors.
- Renewable energy accounted for 22% of installed capacity in the power system in 2013 (14 GW).
- The transport sector is the largest energy end-user in Mexico, accounting for half of Mexico's TFEC in 2010.
- Water heating and space cooling are the applications with the greatest energy consumption in Mexico's buildings sector.
- Within the next decade, the Mexican government aims to provide electricity to the 40-50% of rural communities that lack power access today.
- Mexico is the world's tenth largest crude oil and natural gas producer, but natural gas imports for power generation are increasing.
- The US accounted for nearly 60% of Mexico's total electricity exports in 2013 via 11 interconnections. Mexico's electricity exports represent 3% of its total consumption.
- Energy subsidies have been an integral part of Mexico's energy system to support various sectors of the economy. As in other oil-producing countries, this provides the general population with a share in the wealth from national oil and gas production. The energy reforms aim inter alia to reduce market distortions and improve energy efficiency in part by reducing subsidies.

The following section discusses the energy situation in Mexico at aggregate level. It also provides a brief overview of the latest renewable energy developments and capacity additions.

3.1 Recent trends in renewables and in Mexico's total energy system

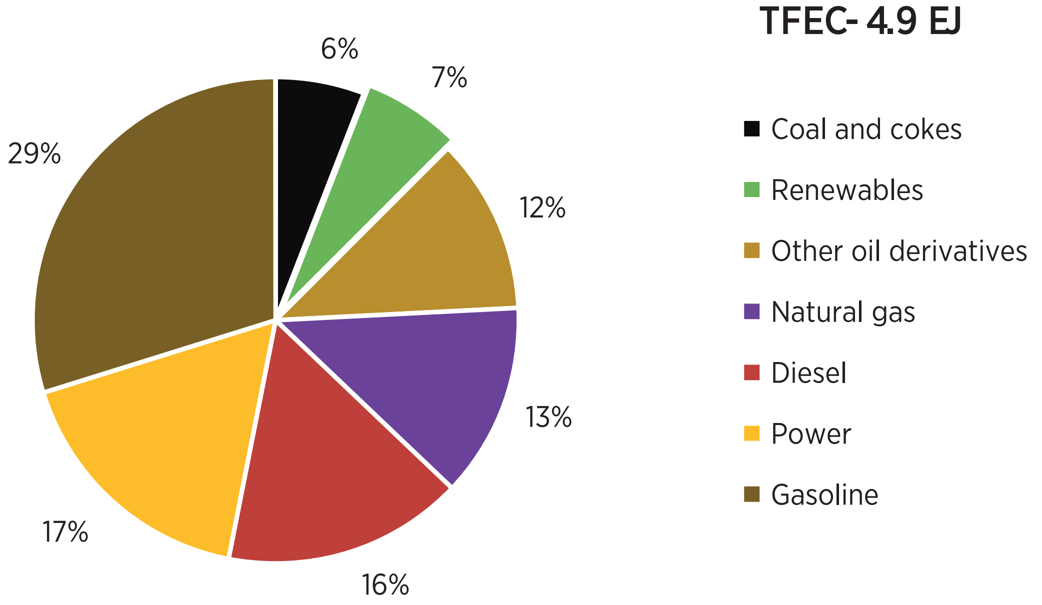
Mexico produces fossil fuels. It is the world's tenth largest oil and natural gas producer. Given that oil and gas production has a major impact on Mexico's economic wellbeing, the commitment to developing renewable energy sources is especially noteworthy. According to the National Energy Balance 2013, TFEC for 2013 was about 4.9 EJ, 90% of which consisted of fossil fuels. The total share of renewable energy, including electricity, was 8.9% of TFEC. Biomass comprises over 70% of this total, or around 318 PJ, of which 255 PJ is traditional use of biomass from firewood and other forestry residues (SENER, 2014b). If traditional use of biomass is excluded, the share of modern renewable energy falls to 3.8%.

Power sector

At the end of 2013, the national power system largely relied on natural gas-fired combined cycle gas turbine (CCGT) plants. Fossil fuel power generation capacity dominates the system with some 72% (46,234 MW) of total installed capacity. Yet renewable power already has a respectable capacity share of 22% (14 177 MW). In 2013, this included hydropower (82.1% or around 11.6 GW), wind (11.6% or 1.6 GW), geothermal (5.8% or 823 MW), biogas (0.3% or 44 MW) and solar PV (0.3% or 40 MW) (see Table 1).

Total installed small hydropower (SHP) capacity (<30 MW) is 453 MW, of which 354 MW corresponds to plants with installed capacity of up to 10 MW. The Federal Electricity Commission (Comisión Federal de Elec-

Figure 2: Total final energy consumption in Mexico, breakdown by energy carrier, 2013



Source: National Energy Balance 2013 (SENER, 2014b)

The share of total renewable energy (including renewable power) in Mexico was 8.9% (or around 440 PJ) of TFEC in 2013. Nearly 60% of this was traditional use of biomass. Mexico still has major potential to deploy renewable energy in its transport and other end-use sectors.

Table 1: Total installed capacity breakdown, by source and generation scheme, 2013

	Installed capacity (MW)	Installed capacity (%)
Total	**64 412**	**100%**
Fossil	**48 834**	**75.8%**
Gas (CCGT)	22 477	34.9%
Others	23 757	36.9%
Coal	2 600	4.0%
Nuclear	**1 400**	**2.2%**
Renewables	**14 177**	**22.0%**
Hydropower	**11 632**	18.1%
CFE	11 508	17.9%
Self-supply	124	0.2%
Biogas	**44**	0.1%
Self-supply	22	0.0%
Cogeneration	20	0.0%
Geothermal	**823**	1.3%
CFE	823	1.3%
Photovoltaic	**39**	0.1%
CFE	6	0.0%
Self-supply	3	0.0%

	Installed capacity (MW)	Installed capacity (%)
Small Producers	30	0.0%
Wind	**1638**	2.5%
CFE	87	0.1%
Self-supply	1035	1.6%
IPP	511	0.8%
Small producers	5	0.0%

Source: SENER (2014b)

Note: Total installed generation capacity for renewables excludes distributed generation of 29.2 MW in 2013. Solar PV installations accounted for 90% of total distributed generation.

In addition to CFE, the table provides four other categories in Mexico which depend on power generating electricity for national consumption prior to the energy reform. They are listed below:

1) *Independent Power Producers (IPPs), are limited to contracting bilaterally with CFE to match its energy supply needs.*
2) *Self-suppliers, which generate electricity for their own consumption – typically industries and large commercial consumers.*
3) *Small Producers (<30 MW) allowed to sell renewable electricity to CFE at a fixed rate of 98% of the total short-term cost at the point of connection (equivalent to a nodal price);*
4) *CHP plants.*

Under this regulatory framework, CFE was the single buyer for the electricity generated by IPPs according to its energy supply needs. When a renewable energy producer was seeking a large customer other than CFE for its electricity, the only possibility was through the legal constitution of a civil self-supply trade association.

Under the new legislation, these four specific types of generation will no longer be available. Other production and consumption schemes will be in place as the new energy market opens up to competition. This also means that the conditions and benefits that were applicable for private renewable energy generators under these modalities will be modified. In some cases they will be ended. See section 5 for further details on the reform.

Renewable energy accounted for 22% of installed capacity in the power system in 2013 (14 GW).

tricidad, CFE) owns 42 small hydropower plants with a total capacity of 301 MW (Liu, Masera, & Esser, 2013).

Renewable power generation in 2013 provided 42 213 GWh out of a 296 343 GWh total, a share of 14.2%[14]. Renewable electricity was produced primarily from hydropower (77.6% of the renewable share), followed by geothermal (11.2%), wind power (10.6%), biogas (0.5%) and solar PV (0.2%) (see Table 2).

The recent development of renewables in electricity generation began in late 2008 when Mexico's government enacted the Law for the Use of Renewable Energies and the Financing for the Energy Transition (Ley para el Aprovechamiento de las Energías Renovables y el Financiamiento de la Transición Energética, LAERFTE). Its objective was to regulate the use of renewable energy sources and clean technologies[15] generating electricity not meant for public service (*i.e.*, self-supply outside the CFE grid). Since then, private sector interest in developing renewable energy has increased, as indicated by the rise in applications for renewable energy generation permits. This is shown in Figure 3[16].

Renewable power deployment for self-supply is economically appealing in many cases. This accounted for around 11.5% of total electricity generated from

14 Renewable energy share in power generation in 2013 is lower than 18.5%, the 2010 level, because total power generation grew faster than power generation from renewables.

15 According to the Electricity Industry Law (August 2014), clean energy includes energy sources and power generation processes for which emissions or residues are below a predefined threshold set by national regulation. Besides renewable energy sources, the term clean energy mainly includes power generated using hydrogen, nuclear power, efficient CHP and thermal power stations with carbon capture and storage (SEGOB, 2014a).

16 There is no guarantee that this capacity will be deployed. This is due to the uncertainties related to the transition as the sector goes through the energy reform coupled with the lack of economic profitability for many projects under the previous legislative framework. For instance, as of September 2014, there were approximately 1.2 GW of permits issued for solar PV projects under small producer generation scheme (CRE, 2014) representing almost 98% of total planned capacity for PV technology. In many cases, the economic compensation they would receive (linked to Costos totales de corto plazo (CTCP)) is simply not attractive enough.

Table 2: Power generation breakdown, by source and generation scheme, 2013

	Generation (GWh/yr)	Generation (%)
Total	**296 343**	**100%**
Fossil	**243 638**	**82.2%**
Combined cycle	141 261	**47.7%**
Others	86 333	**29.1%**
Coal	16 044	**5.4%**
Nuclear	**11 800**	**4.0%**
Renewables	**40 905**	**13.8%**
Hydropower	**28 710**	**9.7%**
CFE	28 029	**9.5%**
Self-supply	681	**0.2%**
Biogas	**261**	**0.1%**
Self-supply	132	**0.0%**
Cogeneration	129	**0.0%**
Geothermal	**6 069**	**2.0%**
CFE	6 069	**2.0%**
PV	**110**	**0.0%**
CFE	13	**0.0%**
Self-supply	10	**0.0%**
Small producers	86	**0.0%**
Wind	**5 755**	**1.9%**
CFE	190	**0.1%**
Self-supply	3 867	**1.3%**
IPP	1 677	**0.6%**
Small producers	22	**0.0%**

Source: SENER

Note: Generation excludes distributed generation of 8.5 GWh in 2013, of which three quarters was derived from small-scale solar PV.

The renewable energy power generation share in 2013 was 13.8%.

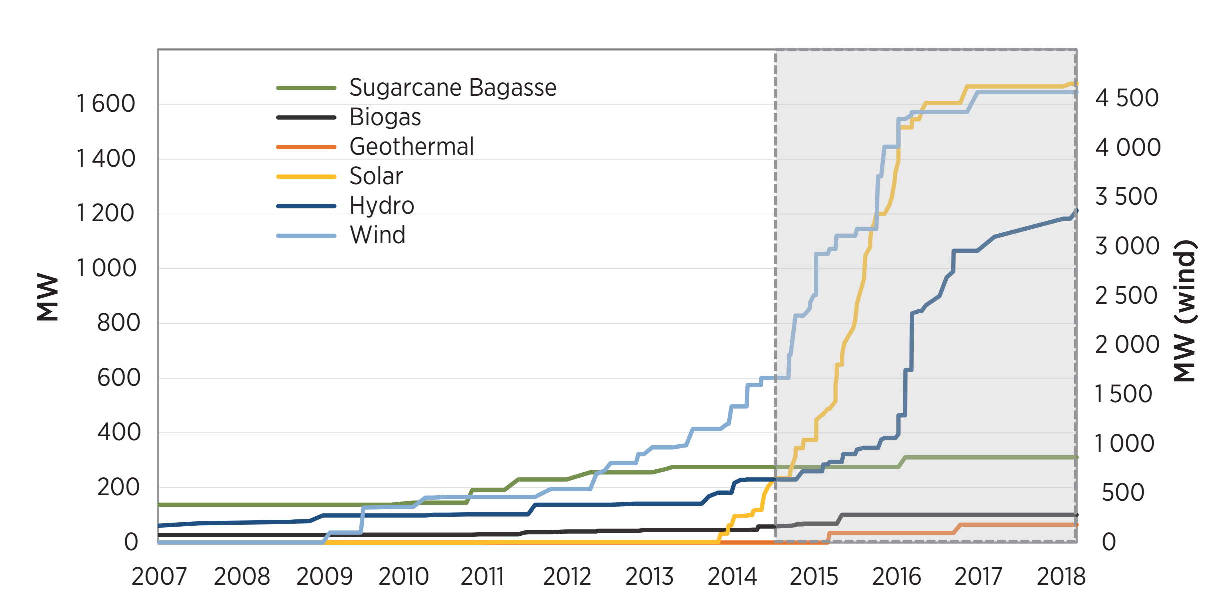
renewable sources in 2013, mostly from wind (see table 2). The levelised cost of electricity (LCOE)[17] of certain distributed generation technologies was already lower than the average electricity tariffs for residential and large industrial consumers in 2010 at around USD 0.09/kWh. For commercial consumers LCOE was around USD 0.20/kWh according to a study published by the Inter-American Development Bank (2011) (Gischler & Janson, 2011). However, deployment so far has been limited for various reasons. These include limited experience with renewables in the sector and the limited availability of suitable financing or incentives to improve profitability, especially for plants not yet cost-competitive.

High solar irradiation levels mean small-scale distributed solar PV can provide energy bill savings for commercial sector consumers and for residential users subject to the DAC tariff[18]. These two types of customers now pay USD 0.2-0.28/kWh (CFE, 2014). Deployment of this application has been further supported by the introduction of a net-metering scheme in 2007, which has until now been administered by CFE. Around 1600 consumers

17 The LCOE of a given technology is the ratio of lifetime costs to lifetime electricity generation. These are both discounted back to a common year using a discount rate that reflects the average cost of capital.

18 The doméstico de alto consumo (DAC) tariff is the highest electricity tariff paid in the residential sector, applicable for consumers with high electricity demand.

Figure 3: Evolution and short-term perspective of installed renewables capacity by private generator, 2007-2018



Source: SENER

Note: This figure shows total capacity of all permits issued by the Energy Regulatory Commission before the energy reform was passed. (See Section 5 of the energy reform for further details.) They include completed as well as those planned plants (taking into consideration a potential average delay of one to two years from plant authorisation). Large hydropower is excluded from the figure.

The shaded area represents projections. The right axis corresponds to wind capacity.

were participating by end 2012 (IEA-PVPS, 2013). The early deployment of solar PV for self-supply started in off-grid installations for rural electrification (Wehner *et al.*, 2010). This then spread to urban rooftops and now appears to be particularly promising in the commercial sector (Bloomberg Finance, 2013). As of 2013, small and medium scale distributed PV accounted for around 40% of the total PV installed capacity (or some 20 MW and 7 MW respectively).

Many existing projects have been developed using project financing, a scheme used by most IPPs to minimize costs and reallocate investor risks. Project developers owning such projects have undertaken power purchase agreement (PPA) contracts under the self-supply scheme with large well-established companies that benefit from high credit ratings. This facilitates access and thus far has lowered the cost of financing for wind power generation. Such contracts also tend to be designed to limit project investor liability.

End-use sectors

Transport

The transport sector is the largest energy user in Mexico, with the highest expected growth rate in energy use. Utilizing the opportunities to reduce the transport sector's growing energy demand will play a key role in determining Mexico's future total energy consumption.

Most energy demand in the sector is for road transport, and most of this is based on petroleum products. The promulgation of standardised regulations for fuel efficiency for road transportation has helped make a good start in reducing demand. The two major options for renewable energy are biofuels substitution for petroleum products and electric vehicles (EVs) instead of internal combustion engines. To date the major focus in Mexico is on biofuels. The Bioenergy Law (Ley de Promoción y Desarrollo de los Bioenergéticos, LPDB) was published in February 2008 as part of Mexico's low carbon strate-

Table 3: Ethanol and biodiesel production and storage capacity

Type	Maximum production capacity	Maximum storage capacity
1 Ethanol production permit[1]	25 000 litres per day	30 000 litres per day
15 biodiesel exception notices[2]	7 500 litres per day	15 000 litres per day
1 ethanol exception notice	500 litres per day	1 000 litres per day
Total	33 000 litres per day	46 000 litres per day

Source: SENER

1 Production plant construction authorised under the permit is under way and is expected to start producing anhydrous ethanol in early 2015.

2 According to the Bioenergy Law, exception notices are given when the maximum production capacity of any given plant reaches 500 litres, and maximum storage reaches 1 000 litres.

gy. Since then, the Ministry of Energy has issued permits for the production, storage, transportation and marketing of biofuels such as anhydrous ethanol or biodiesel. However, actual biofuels deployment has been limited by market size and structure: for example, a high standard grade of diesel/biodiesel needs to be developed and introduced.[19]

Today ethanol production in Mexico is derived from four main crops: sugar cane, grain sorghum, sweet sorghum and sugar beet. Of these crops, sugar cane is the only one with a production surplus. Grain sorghum is the cereal with the most productive potential for ethanol production, and sweet sorghum could have the highest yield of litres per hectare. Nevertheless it is not a commercial crop. Biofuel production from corn is banned due to a policy assuring the protection and primacy of food production.

The production of biodiesel was supported in 2007-2011 through economic incentives granted for cultivating oil palm and jatropha curcas. Four biodiesel pilot plants were built. As a result, 49 200 litres of biodiesel were produced from oil plant plantations in 2010 and almost 60 000 litres in 2011. The support for jatropha curcas was intended to result in 2.4 million litres of annual production, but this has not yet materialised (SEGOB, 2014b).

The current production capacity of bioenergy (ethanol and biodiesel) in Mexico is shown in Table 3.

19 To date, there are no standardised quality regulations for diesel fuel. The market is too small to justify the cost of the upgrades needed to meet tougher standards. In addition, there are no fuel efficiency standards or emission controls for heavy trucks.

There is a growing interest in developing a more sustainable automotive market including market incentives and adequate infrastructure for introducing hybrid and electric vehicles. Since Mexico has a rapidly growing motor vehicles manufacturing and export industry, it is well placed to design, produce and introduce EVs in the domestic market.

Heating/cooling sector

In 2012, total installed solar water heater capacity in Mexico was 1.5 GW (over 2 million square metres (m^2)). More than 40% of the total installed capacity was flat plate collectors. Unglazed collectors (582 MW) and evacuated tube collectors (228 MW) accounted for the rest (Mauthner & Weiss, 2014). About 40% of solar water heaters were used for swimming pool heating (0.8 million m^2 installed capacity in Mexico City) with the remaining 60% for domestic hot water production. The market for solar water heaters is growing fast at a rate of about 11% per year. This trend is also in progress in other Latin American countries such as Brazil or Chile.

An IEA preliminary assessment in its Solar Heat for Industrial Processes database on concentrated solar heating shows 32 countries have introduced concentrated solar thermal technology in some 139 projects (AEE INTEC, 2014). Mexico contains six such heat generating facilities built with parabolic trough-collectors with a total of 600 kW of installed capacity. This is roughly equivalent to a collector area of 600 m^2 (AEE INTEC, 2014). These projects are at present supplying process heat for the manufacture of dairy products.

Direct use of geothermal for heating has been largely overlooked in the buildings and industry sectors, as opposed to its use for power generation. Direct geo-

Figure 4: Geothermal fields for direct uses

Source: Arrubarrena & Pelayo (2012)

thermal uses in Mexico have a total installed capacity of 550 PJ (or 156 MW) scattered across 19 states in about 165 sites. These sites produced some 2.6 PJ of heat in 2010 mainly for recreational purposes such as baths or spas (Figure 4) (IEA-GIA, 2013) (GEA, 2013). However, many locations in Mexico have major potential for use beyond the current focus.

Table 4: Total final energy consumption by energy carrier, 2010

	2010 (PJ/yr)	Share in 2010
TFEC	**4 609.9**	**100.00%**
Coal	5.5	0.1%
Biomass	297.0	6.4%
Solar	4.9	0.1%
Coal coke	62.8	1.4%
Petroleum coke	80.6	1.7%
Fuel oil	57.9	1.3%
Kerosene	114.6	2.5%
LPG	448.6	9.7%
Diesel	759.9	16.5%
Gasoline & naphtha	1 492.3	32.3%
Natural gas	528.8	11.5%
Electricity	764.0	16.5%

Source: National Energy Balance 2011 (SENER, 2012a), IEA Energy Balance (IEA, 2013)

Note: TFEC is 4 503 PJ in 2010 excluding international aviation and adjusting consumption for maritime transportation, taken from IEA energy balance (IEA, 2013).

TFEC from kerosene includes energy use for international aviation, which is excluded in the rest of this study.

3.2 Base year energy status

Sectoral breakdown

The base year chosen for all the REmap analysis presented here is 2010. According to Mexico's 2010 national energy balance, TFEC was 4 610 PJ (see Table 4). This was only 0.4% higher than in 2009, when TFEC was 4 590[20].

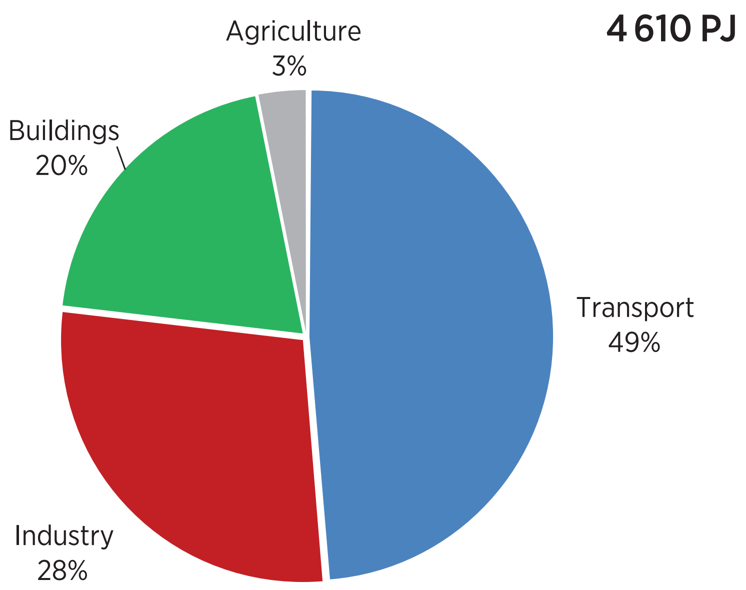
Petroleum products (including condensates) accounted for two thirds of TFEC in Mexico in 2010. Natural gas accounts for another quarter. Modernised forms of renewable energy in national TFEC (excluding international aviation and including electricity consumption from renewables) represented 4.4% or 200 PJ. This share goes up to almost 10% if traditional biomass use is considered. Three quarters of the modern renewable energy proportion is related to renewable electricity consumption. One quarter is biomass use for process heat generation in the industry sector, biofuels (800 million litres of ethanol); and for solar water heaters in buildings (1 078 MW installed capacity).

Transportation was the largest component of TFEC, followed by the industry and buildings sectors. The sectoral breakdown is changing. In the early 1990s, industry and transport sector had similar shares at around 35-40% of TFEC. Since then, transport sector demand has almost doubled. Today the transport sector accounts for about half of Mexico's TFEC while demand for energy in industry remains roughly the same. Over the same period the buildings sector's total energy demand grew by about 35% but still accounts for about the same 20-25% of Mexico's TFEC (SENER, 2012a).

In the transport sector, energy statistics on automotive transport include the energy consumed by transportation for people and freight. Air transportation considers the fuels used by domestic and international flights without including the purchases that any airline makes abroad. Railways include the consumption made by the different train concessions. Marine transportation includes domestic fuels sales to the merchant marine, the army, fishing companies and vessels in general. Electric transport takes into account the total amount of electricity consumed by public transport.

20 TFEC expresses total use of energy resources for energy uses. TFEC includes energy use for international aviation, which is excluded for in the rest of this study.

Figure 5: Total final energy consumption by sector, 2010



Source: Energy Information System, SENER

The transport sector is the largest energy end-user in Mexico, accounting for half of Mexico's TFEC in 2010.

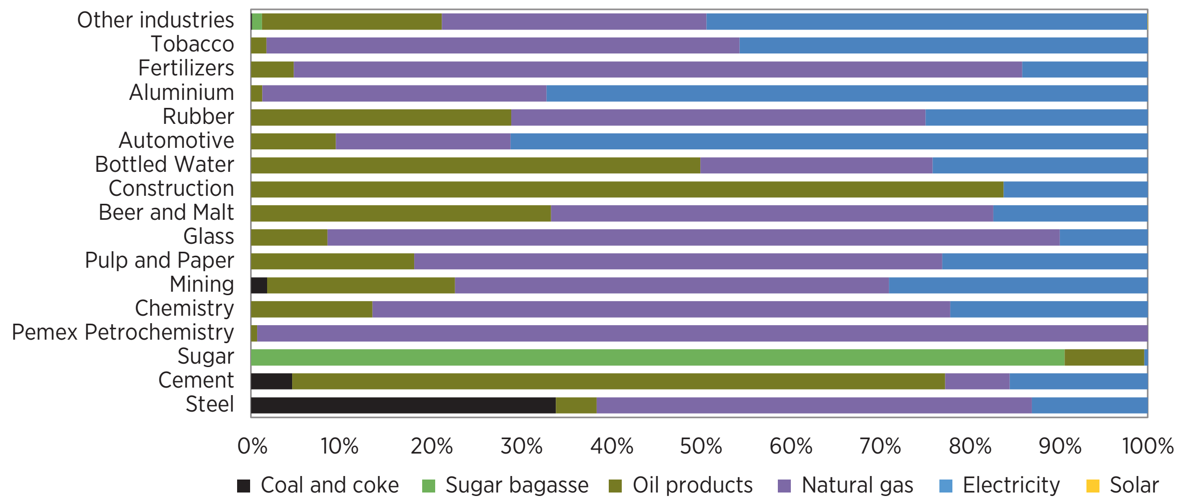
Table 5: Total final energy consumption in the transport sector, 2010

	2010 (PJ/year)	Change (%) 2010/2009	Share (%) 2009	Share (%) 2010
Total Transport[1]	2 245.2	0.9	100	100
Automotive	2 070.3	0.6	92.4	92.1
Liquefied gas	41.4	1.7	2.0	2.0
Gasoline	1 491.4	-0.4	72.8	72.0
Diesel	537.1	3.5	25.2	25.9
Gas	0.5	-7.4	0.0	0.0
Aviation	114.3	3.1	5.0	5.1
Gasoline	0.9	-1.1	0.8	0.8
Kerosene	113.4	3.2	99.2	99.2
Navigation	30.0	-4.4	1.4	1.3
Diesel	28.1	5.7	84.8	93.7
Fuel Oil	1.9	-60.2	15.2	6.3
Railways	26.5	11.0	1.1	1.2
Diesel	26.4	11.0	99.4	99.5
Electricity	0.1	0.0	0.6	0.5
Electricity	4.1	7.3	0.2	0.2
Electricity	4.1	7.3	100	100

Source: National Energy Balance 2010 (SENER, 2011).

1 Data excludes international aviation (IEA, 2013).

Figure 6: Total final energy consumption by industrial subsector, 2010



Source: National Energy Balance 2010, SENER

In 2010, fuel consumption in the transport sector was 2 245 PJ (excluding international aviation). The breakdown by transport mode is as follows: automotive 2 070 PJ; air transport 1 PJ for domestic flights (113 PJ for international aviation); maritime 30 PJ; railways 27 PJ and electric transport 4 PJ.

In 2010, industry's total demand was almost 1.3 EJ. The largest industrial users of energy are steel, cement, petrochemicals, mining and chemicals production. Such bulk materials producers account for nearly 40% of Mexico's industrial TFEC. These sectors require a great deal of heat at high temperatures. This creates obstacles to fossil fuel substitution in these sectors by renewables. Even using biomass, delivering process heat beyond medium temperature conditions (400 degrees Celsius) is difficult.

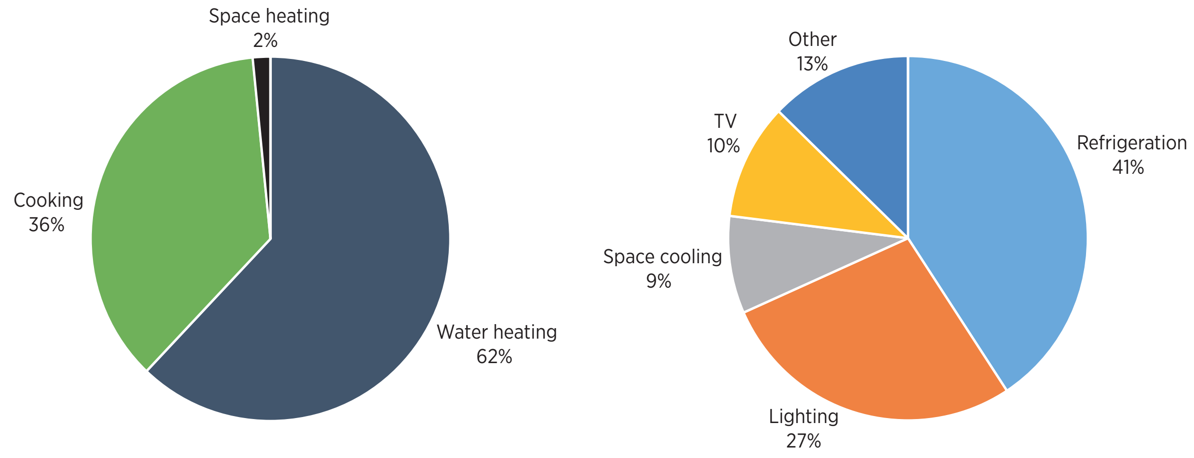
The remainder of Mexico's industrial energy demand is related to the production of food, glass, paper and to the processes of other small industries. These plants generally experience low and medium temperature heat demand (often in the form of steam). This creates a great potential for Mexico to transform its industrial energy mix to renewables.

Figure 6 shows the energy utilisation by source (coal and coking coal, sugar bagasse, oil products, gas, electricity and solar) in each of the main industry subsectors. Oil and natural gas are the main sources of energy to meet industrial demand. Electricity also has a sizeable share (for fans, pumping, compressors etc.). Biomass is the main type of renewable energy consumed in the industry sector. It takes the form of bagasse, a by-product of the sugar industry. Bagasse was mainly consumed for power generation by the industry sector for its own consumption (SENER, 2013b).

Energy consumption in buildings is divided into residential, commercial and public. According to the national energy balance of Mexico, the residential sector accounted for 17% of Mexico's TFEC. The commercial sector accounted for nearly 3% and the public sector less than 1% in 2010. There is data available related to the use of different energy carriers (*e.g.*, coal, solar thermal) in Mexico's buildings sector. On the other hand, data availability for energy use by type of application and other statistics is limited. Thermal energy use is mainly for cooking and water heating. In 2008, water heating accounted for about half total energy demand in the residential sector, and about two thirds of total buildings thermal energy demand. Space heating accounts for a lower share of total thermal energy demand in buildings (about 1% in 2008). This is similar to other countries in the region (SENER & IEA, 2011).

Total demand for electricity in the buildings sector is around 70 TWh (255 PJ). Economic growth and rising

Figure 7: Breakdown of residential sector energy use for thermal applications and electricity, 2008



Source: SENER and IEA (2011)

Water heating in thermal uses and space cooling and refrigeration in electricity use are the applications with the greatest energy consumption in Mexico's building sector

living standards result in an increasing share of electricity in the country's total buildings sector energy mix. This is due to various uses of household appliances as well as space cooling.[21] In 2010, electricity accounted for around 20% of the buildings sector's total energy demand. Average per capita power demand in the residential sector was 420 kWh per capita per year.[22] This masks significant differences. More than 20% of Mexico's population live in rural areas, where those with access to electricity consumes on average 250 kWh power per capita per year. The rest of Mexico's population lives in urban areas and consumes on average 470 kWh electricity per capita per year.

Wood and sugar cane bagasse (by households and industry, respectively) are the basis for thermal biomass applications in the end-use sectors. Households are the main users of wood fuel for cooking and heating, especially in rural areas. These are concentrated in central and southern Mexico. Firewood used for cooking and heating accounts for the vast majority of the biomass consumption. In relative terms this represents one third of Mexico's buildings sector energy use (260 PJ of the sector's 747 PJ TFEC in 2010). The use of wood fuel has created pressure on Mexico's forests. Like agricultural expansion and cattle breeding, it contributes to deforestation (Islas, Manzini, & Masera, 2006). Forests in Mexico today cover around 64.3 million hectares. Annual deforestation, however, is slowing down. It dropped from 0.52% per year in 1990-2000 to 0.3% per year in 2000-10. Mexico today leads in reducing emissions related to deforestation, and in increasing afforestation. This is achieved through a scheme providing financial incentives to prevent deforestation in priority zones (Höhne *et al.*, 2012).

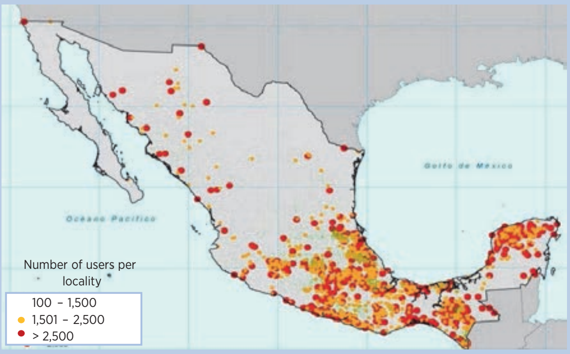
Apart from wood, small amounts of charcoal are used to fuel inefficient earth ovens (12-20% efficiency (REMBIO, 2011)). Total consumption of charcoal was about 2.5 kilotonnes (kt) in 2012, representing 8 terajoules (TJ). Figure 8 shows the geographical distribution of woodfuel users. Most demand is located in the southeastern central zone.

In the early 1990s, PV rural electrification projects were completed, and over 40 000 solar PV systems were installed. Most of these systems were in southern Mexico

21 According to the National Institute of Statistics and Geography, Mexico had 28 million households in 2010 with an average of 3.9 occupants per household (INEGI, 2014).

22 Calculated for the residential sector, considering 49.4 TWh of electricity consumption (SENER, 2012a), 30.3 million electricity users in households (SENER, 2015) and a national average of 3.9 persons per household (INEGI, 2014).

Figure 8: Users of woodfuel per locality



Source: Masera (2011)

(12 000 in the state of Chiapas). Most stalled after only a couple of years, and towards the late 1990s, the PV electrification programme stopped. Problems were mainly due to poor operational performance and poor quality installation. Mexico now has about 80 000 off-grid solar home systems (IRENA, 2013b).

In Mexico, less than three million people (about 675 000 homes) live without access to electricity. These inhabitants are concentrated mainly in southern parts of Mexico. Poverty, distance from the existing grid, and the small size and dispersion of communities, all preclude efficient grid connection (World Bank, 2008). This represents an opportunity for further PV off-grid penetration.

There have been other uses of PV power, such as the installation of more than 1700 solar PV pumping systems in 1994-2005 throughout Mexico with an average system size of 500 watts. These are to be found mainly in the northern deserts of the country that suffer from water shortages. They generate power for water pumping in agricultural applications, and replace traditional diesel/gasoline-engines. These systems are different than the solar home systems described above, which target household electrification. Other off-grid PV systems have also been built. One example is a commercial ice-making system installed in 1999 for use in fisheries in the remote desert community of Chorreras, Chihuahua. This is the first such system in the world. There are also a number of solar PV refrigeration systems, which were first used in Chihuahua and Quintana Roo in 2000 (Cota & Foster, 2010).

In addition to the existing solar home systems, around 500 systems have been installed to date. They provide power to local communities and schools that previously lacked electricity access (around 3 000 people). This is in addition to solar water pumping systems also being deployed (IRENA, 2015a). By 2016, around 40-50 000 rural families are scheduled to receive solar PV electricity. Within the next decade, the government plans to provide electricity to 40-50% of rural communities that lack access to electricity at the moment (Horn, 2011) (Alliance for Rural Electrification, 2013). At least 8% of this will come from renewable energy (Crehueras, 2014).

Within the next decade, the Mexican government aims to provide electricity to the 40-50% of rural communities that lack power access today.

Conventional fuel markets

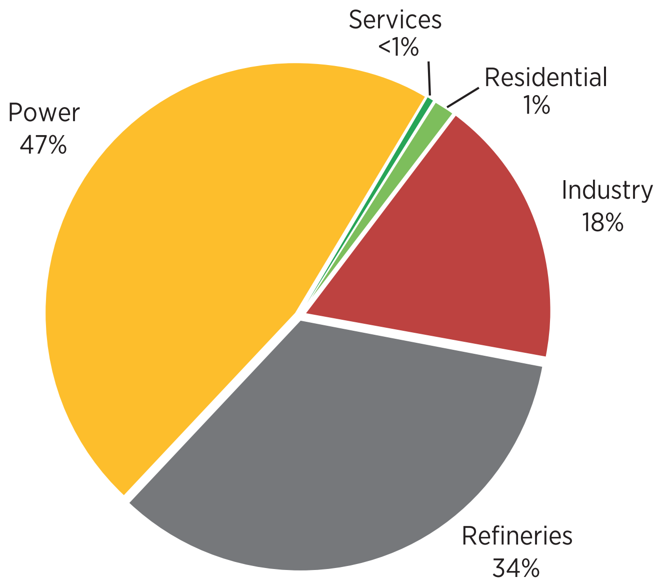
Mexico is the tenth largest producer of oil and natural gas in the world. Crude oil and its products represent 45% of Mexico's total primary energy supply. Mexico is also a net exporter of crude oil. In 2013, oil exports were 2 737 PJ – 47.2% of total crude oil production. Major types of crude exported include Maya (83%), Isthmus (8.6%) and Olmeca (8.3%). Major export destinations include the US (75% of the total), Spain (15%), India (7%) and Canada (2%). Crude imports are marginal. However, in terms of oil products, Mexico is a net importer. It exports 15% of its total refinery output and imports 28% of its total oil product consumption. The net trade balance for primary energy – largely influenced by world oil prices – was around 2 529 PJ in 2013, 7.9% below the 2012 level.[23] The average price of Mexican crude in that year was USD 98.5 per barrel – 3.3% below 2012[24].

Mexico also produces coal and natural gas, but in smaller volumes. In 2013, Mexico imported 217 PJ of coal. Of the total imports in 2013, 48.5% came from Australia, 41.5% from the US, 3.8% from South Africa and the remaining 6.2% from other countries.

23 Oil production in Mexico has steadily decreased since 2005 and reached its lowest level in 2013; production continued to decline in 2014 (EIA, 2014).

24 The potential effects of the changing oil price since late 2014 on the cost-effectiveness of renewables in Mexico is discussed in more detailed in Section 7.

Figure 9: Natural gas demand by sector, 2012



Source: SENER, Natural Gas and Liquefied Petroleum Gas Perspectives, 2013-2027

Demand for natural gas in 2013 was 6 678 million cubic feet[25] per day. In 2002-12, the average growth in demand for natural gas was 4.2% per year. Nearly half is used for electricity generation and one third in petroleum refineries. Much of the rest is used for industrial process heat generation.

Mexico is the world's tenth largest crude oil and natural gas producer, but natural gas imports for power generation are increasing.

Future demand for natural gas will be determined by developments in economic activity and fuel prices. Based on SENER projections, the final price of natural gas is expected to average USD 7 per million Btu by 2030. Gas prices have now broken their historic tie to crude oil prices, and it is unlikely that they will return to that system. The development of transport and distribution infrastructure for natural gas is another important factor affecting future demand forecasts. It is estimated that average annual domestic demand for natural gas will grow by 3.6% from 6 678 million cubic feet per day in 2012 to 11 425 million cubic feet per day in 2027 (SENER, 2013d).

Domestic natural gas production is finding it harder to meet its growing domestic demand. In 2013, natural gas imports equivalent to 993 PJ accounted for one third of Mexico's gross domestic gas supply. Imports came mainly from the US (78%), and the rest from Peru, Qatar, Nigeria, Hungary, Yemen, and Trinidad and Tobago.

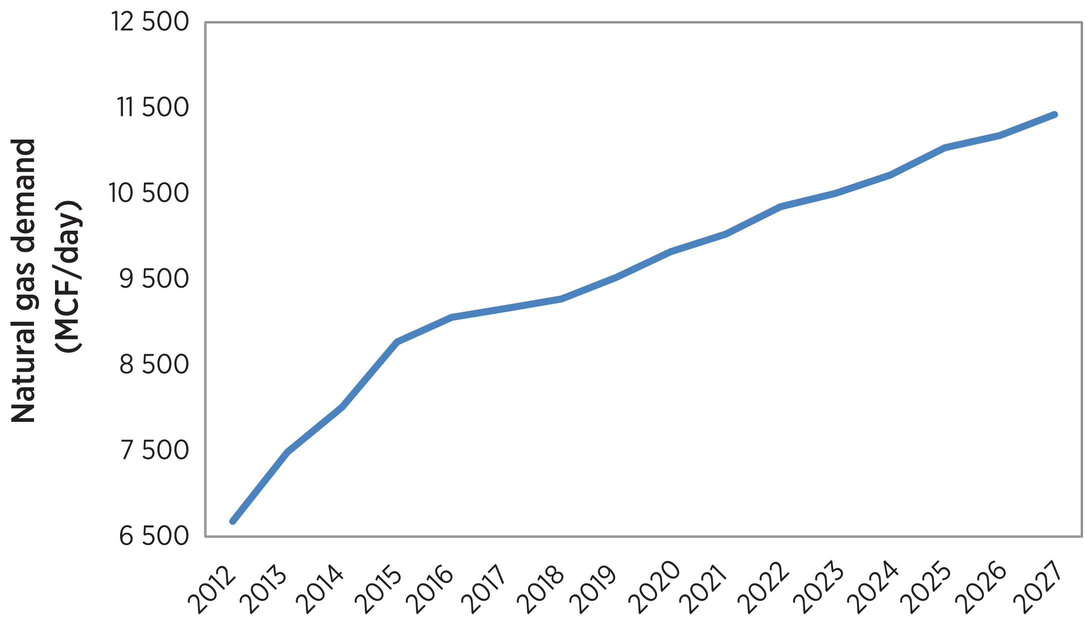
Transmission grids

Mexico has a largely interconnected transmission system. There are also two isolated systems, namely Baja California Norte and Baja California Sur. There are plans to connect these regions to the national grid by 2017 (Baja California Norte) and 2018 (Baja California Sur).

A 400 kilovolt (kV) transmission line 103 kilometres long linking Mexico to Guatemala started commercial operation in 2010. It allows energy transfers to the Central American Electrical Interconnection System countries. This increases the reliability of electric supply and promotes investments in new electricity generating plants to serve the regional electric market. It has an initial export capacity of 200 MW and an import capacity of 70

25 1 million cubic feet of natural gas (dry) = 1 027 000 British thermal units.

Figure 10: Natural gas demand forecast, 2013-2027



Source: SENER, Natural Gas and Liquefied Petroleum Gas Perspectives, 2013-2027 (SENER, 2013d)

Note: One thousand cubic feet (MCF) is equivalent to one million BTU (MMBTU), or approximately 1 055 GJ

MW. Mexico is connected to Belize through a 65 MW capacity transmission line. Mexico has 11 interconnections with the US, all in Texas and California. Their capacities are 36-800 MW. In 2013, 7.4 TWh of electricity was exported, creating a net export of 5.7 TWh. Of the exports, 4.3 TWh (58%) went to the US, 1.6 TWh to Belize (21%) and 1.5 TWh to Guatemala (21%).

The US accounted for nearly 60% of Mexico's total electricity exports in 2013 via 11 interconnections. Mexico's total electricity exports represent 3% of its total consumption.

To meet expected demand growth, national state-owned electric company CFE has identified necessary transmission capacity improvements that will permit the deployment of new renewable energy projects. The energy reform so far has set up the framework and guidelines for energy planning (see Section 5 for further details) to be carried out in future by SENER and by the National Centre for Energy Control (Centro Nacional de Control de Energía, CENACE). According to SENER, future investment needs for system enhancement (*i.e.,* excluding self-generation and off-grid installations) amount to USD 164.4 billion for 2014-28. Approximately 56% of this is for power generation, 21% for distribution, 12% for transmission and 11% for maintenance (SENER, 2013a).

Before the energy reform, the most significant mechanism in Mexico geared to developing transmission for renewable power generation was the "temporada abierta" or open season. This served to reserve transmission capacity for renewable generation connection. The scheme, coordinated by the Regulatory Energy Commission (Comisión Reguladora de Energía, CRE), enables the development of transmission infrastructure. The aim was to meet the needs of CFE and of private developers under the self-supply generation scheme beyond plans in existence at the time. This allowed both grid reinforcement and expansion.

In broader terms, the open season has allowed private generators to reserve transmission capacity by committing to cover transmission costs. These costs are paid proportionally by each participant according to the reserved capacity. The reserved capacity is determined through a complex process, in which developers provided credit guarantees of a specific share of their

Figure 11: Mexico's electricity regions

Source: CFE

costs at a final stage. In this way, CRE ensured that all the participants expressing interest to the transmission capacity are able to meet the associated costs.

The first open season process started in 2006 to allow the deployment of wind in the Isthmus of Tehuantepec in the state of Oaxaca. This first initiative resulted in a plant with 2.6 GW of wind capacity (with an 40% average capacity factor) as well as the requisite supporting transmission capacity. This was equivalent to a total investment of USD 4.5 billion, including generation and transmission capacity (CRE, 2012).

CENACE coordinates the operation of the national power system to ensure economic dispatch, safe operation and reliability of the system. CENACE is now designated as independent system operator (ISO) (see Section 5 for further details). The system is divided into six interconnected regions, which permit the coordination of regional supply, demand and capacity reserves across Mexico's three different time zones. This enables a more efficient and reliable system operation to deal with a range of operational situations. As noted above, the Baja California peninsula regions are an isolated part of the national system (Figure 9).

Energy subsidies

Mexico has subsidies in place for the vast majority of domestic and agricultural electricity consumption, and regulated retail prices for gasoline, diesel and LPG. This sometimes includes a subsidy.

In the power sector, there is a complex electricity tariff structure with different rates depending on consumption level and type of user. The tariffs applicable to the agriculture and residential sectors include subsidies (except for the DAC tariff[19]). Residential subsidies are calculated as a function of consumption based on temperature zones. Consumers in regions with higher temperatures have higher subsidised consumption. Industrial, commercial and DAC tariffs are not subsidised, and they tend to cover total electricity supply costs. In some cases rates are even higher than costs, implying the application of cross-subsidies.

As of June 2014, the average subsidy in the residential and agricultural sectors amounted to 60% and around 74% of total generation costs respectively (CFE, 2015). For commercial and industrial consumers, average prices were 8% above the costs of the energy service they receive (CFE, 2015). The average weighted subsidy for all consumers in the system represented 22% of total generation costs including cross-subsidies (CFE, 2015).

Retail prices for gasoline, diesel and LPG are regulated and set on a monthly basis. The existence of a subsidy is determined by comparing the national regulated price to an average international reference price. Gulf Coast prices are used for gasoline and diesel (SENER, 2013e), and Mont Belvieu for LPG (Monrroy, 2012)). So if the national price is higher, there is no subsidy but if the national price is lower than the international price, the amount of the subsidy per unit is equivalent to the difference between the reference price and the regulated one.

As the energy reform aims to liberalise national energy markets,[26] there are plans to eliminate all producer and consumer subsidies in principle, except for those that apply to low-income consumers. A first step in this direction is the deregulation of retail prices for gasoline, diesel and LPG. This is due to be effective within the next couple of years.

Energy subsidies have been an integral part of Mexico's energy system to support various sectors of the economy. As in other oil-producing countries, this provides the general population with a share in the wealth from national oil and gas production. The energy reforms aim inter alia to reduce market distortions and improve energy efficiency in part by reducing subsidies.

26 For further details regarding the energy reform, refer to Section 5.

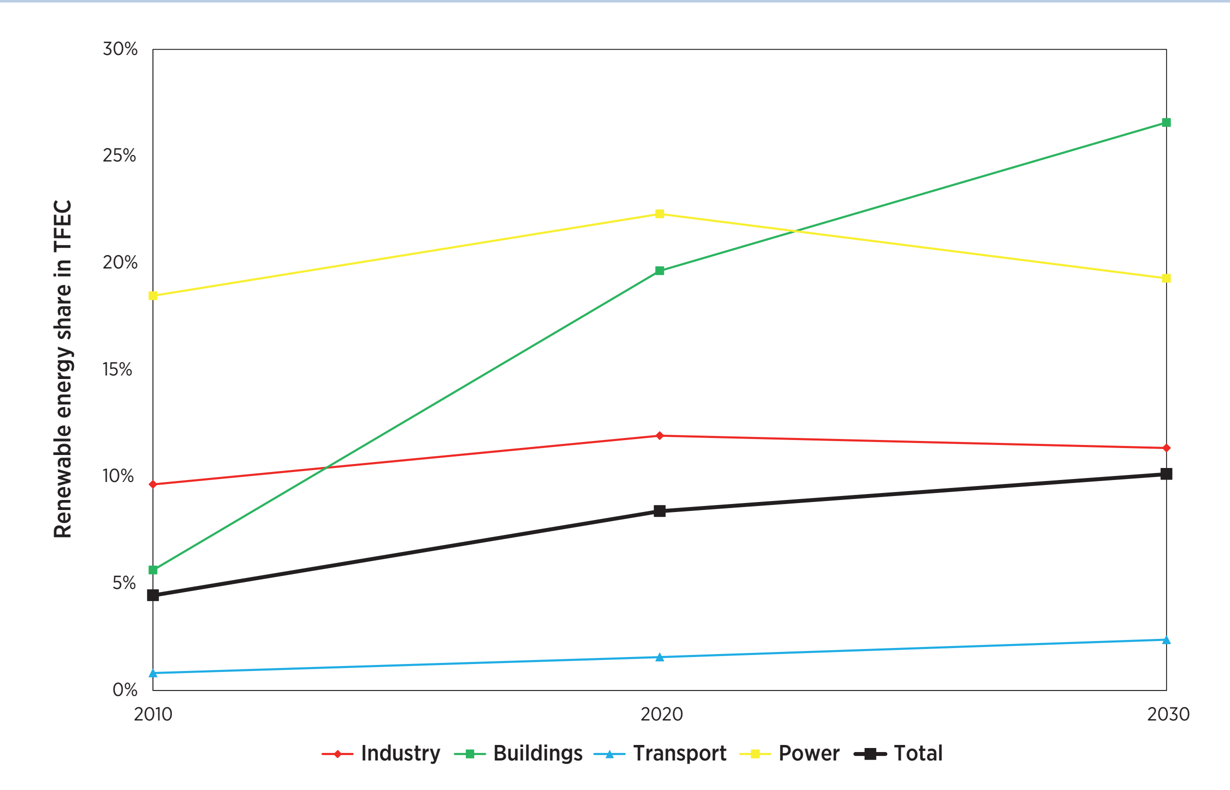
4 REFERENCE CASE DEVELOPMENTS TO 2030

The REmap analysis begins with a Reference Case. This is an assessment of energy consumption projections and the uptake of renewable energy technology in 2010-2030 in Mexico based on current policies. The base year is 2010. This section describes the Reference Case and how it was derived.

Detailed projections by the Mexican government on final energy supply and demand up to 2027 are available. They cover the power sector, the development of solar thermal energy use in buildings and biofuels in transport for 2026 and 2027. These projections in the Reference Case are based on data from two different series of annual reports. These are entitled "Power Sector Perspectives" (Prospectiva del Sector Eléctrico) and 'Renewable Energy Perspectives' (Prospectiva de Energías Renovables). Reference Case projections for end-use sector demand were based on the business-as-usual scenario in the APEC Energy Demand Supply Outlook (APEC, 2013b). This contains energy predictions to 2020 and 2030.

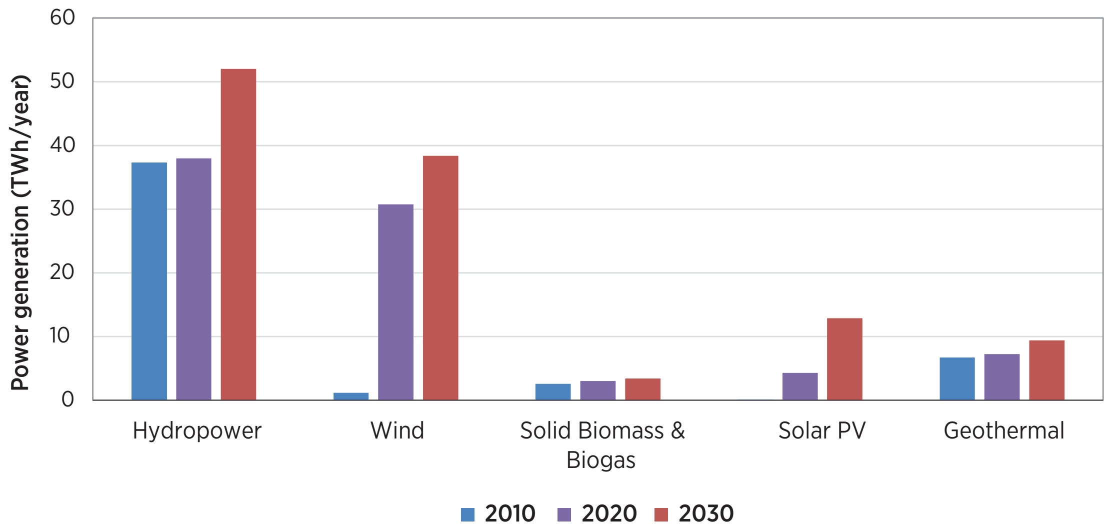
Adding these projections together produces an estimated TFEC of 7.4 EJ by 2030. This is a 64% increase over 2010. Almost 45% of TFEC will be in the transport sector in 2030, a slightly smaller relative share than in 2010. Industry in 2030 accounts for 33% of demand, four percentage points higher than in 2010. The buildings sector demand share remains almost unchanged at 20% of TFEC in 2030. Oil products and electricity continue to be the energy carriers showing the greatest demand in 2030, followed by natural gas and renewables.

Figure 12: Mexico Reference Case, renewable energy shares in TFEC by sector, 2010-2030



The buildings sector experiences the largest growth in renewable energy use in 2010-2030 in the Reference Case.

Figure 13: Reference Case renewable power generation growth, 2010-2030



The share of modern renewable energy in Mexico's TFEC will increase from 4.4% in 2010 to 10% by 2030 in the Reference Case (see Figure 12). Total modern renewable energy consumption in absolute terms grows almost fourfold by 2030, mostly in the power sector. Renewable electricity generation will grow by 140% from 48 TWh/year in 2010 to 116 TWh/year in 2030. Total power generation is expected to grow at a similar rate from 260 TWh/year in 2010 to 602 TWh/year in 2030. Despite the significant increase in renewable power generation, the renewable energy share in power generation remains almost unchanged from 18.5% in 2010 to 19.3% in 2030 (see Figure 12). This is because electricity demand increases at the same rate.

Note that there is a peak in the share of renewable electricity in 2020. This comes from SENER projections which forecast accelerated growth for renewable power in this first period and slower growth in 2020-2030.

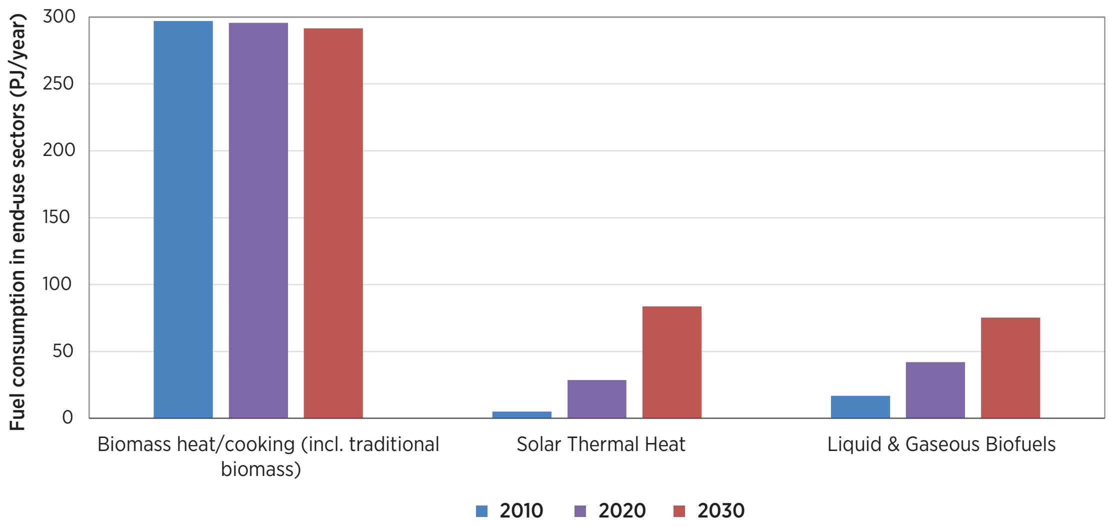
SENER and APEC projections show the share of modern renewable energy in Mexico's energy mix will reach 10% by 2030, up from 4.4% in 2010.

The Reference Case distinguishes energy use by consuming sector, technology and application. It also distinguishes between modernised and traditional renewable energy. The highest demand for modern renewable energy in 2030 will be in the buildings sector – 285 PJ in end-use applications and approximately 105 PJ from renewable electricity consumption. The total (390 PJ) represents 27% of total sector energy demand, up from only 5.6% in 2010. More than half of modern renewables included in TFEC (215 PJ) will be accounted for by bioenergy for heat applications. These are used mainly for cooking purposes. This is driven by the replacement of traditional use of biomass for cooking with efficient cook stoves (Islas, Manzini, & Masera, 2006). A major increase in the use of solar thermal energy for water heating is expected, amounting to approximately 70 PJ in 2030.

Renewable energy in transport included in TFEC will amount to about 75 PJ in 2030. This is mostly liquid biofuels, and is a 350% increase over 2010 when the figure stood at around 17 PJ.

Renewable energy in industry has an 11% share of total sector demand (280 PJ) in 2030, compared to 10% (125 PJ) in 2010. Most of the increase is due to greater use of renewable electricity. Total final use for heat generation remains unchanged, an increase in the use of solar thermal roughly balancing out a decrease in the use of biomass. The latter is partly associated with improvements in energy efficiency in industrial processes (APEC, 2013b).

Figure 14: Reference Case growth of renewable energy use in the end-use sectors, 2010-2030



The forecasts show electricity generation from renewable sources amounts to around 115 TWh/year in 2030, an overall increase of 140% over 2010 (Figure 13). Of this, hydroelectricity accounts for 52 TWh, wind (the preferred technology for new power projects) 38 TWh, solar PV 13 TWh, geothermal 9 TWh and biomass 3 TWh. The contributions of other technologies such as biogas and CSP are fairly small at around 140 GWh and only 15 GWh respectively. Over the same time period, power generation based on natural gas will grow from 120 TWh in 2010 to 400 TWh in 2030. Coal-fired power generation rises from 36 TWh to 54 TWh and nuclear power generation increases from 6 TWh to 26 TWh.

For other renewable energy end-use applications (Figure 14) the Reference Case further differentiates use by technology. For 2030, it shows no change in bioenergy use for heat production (including traditional use of biomass). This remains at around 290 PJ/year, some 90% of which is in the residential sector. This somewhat masks a significant shift from traditional to modern forms of biomass in the residential sector. However, there still remains around 50 PJ of traditional biomass use in 2030. In transport, liquid biofuels use increases from 17 PJ to 75 PJ (equivalent to 3.5 billion litres of ethanol in 2030).

In the buildings sector, solar thermal heat use increases from only around 5 PJ in 2010 to 70 PJ in 2030. The growth in renewables is significant, but these numbers remain modest when compared to the amount of fossil fuels used. This amounts to 590 PJ in 2030.

By 2030, non-electricity use of oil products in all end-use sectors (excluding agriculture) will increase from 2 630 PJ to 4 075 PJ,[27] and non-electricity use of natural gas omit will increase from 529 PJ to 800 PJ.

27 Energy consumption from oil products in the agriculture sector was 145 PJ in 2010 and is projected to be 142 PJ in 2030. No renewable energy option was identified for this sector in the rest of this analysis.

5 CURRENT POLICY FRAMEWORK

KEY POINTS

- Planning and control of the national power system, power transmission and distribution, and petroleum and other hydrocarbon exploration and extraction remain strategic areas whose functions are performed exclusively by the state. However, Mexico's government may now nonetheless enter into contracts with private firms or persons to carry out these responsibilities. This includes extending, modernizing, financing and/or operating the power transmission and distribution networks.

- According to the Electricity Industry Law (LIE by its Spanish acronym), all the participants in the newly created power market will compete under equal circumstances for generation and wholesale market activities. The exception is nuclear power generation, the domain of CFE.

- The new energy legislation creates a wholesale electricity market, enabling the establishment of electricity suppliers that can freely negotiate power supply contracts and tariffs.

- CENACE becomes the ISO managing the transmission and distribution system in coordination with SENER and CRE. CENACE coordinates the wholesale electricity market, with the responsibility to meet electricity demand at lowest cost while guaranteeing the stability of the network.

- No specific framework for the development of geothermal energy by private players existed prior to the energy sector reform. The Geothermal Energy Act now regulates the survey, exploration, development and exploitation stages of geothermal resources for both power and heat generation in line with international best practice.

- Targets to generate a share of total electricity from clean energy technologies have been set at 35% by 2024, 40% by 2035 and 50% by 2050.

- The Bioenergy Interministerial Commission (Comisión Intersecretarial de Bioenergéticos) has been created to analyse and dictate the guidelines for public policy in bioenergy.

- The Bioenergy Law outlines regulations for activities related to biomass, and seeks to contribute to energy diversification and advance sustainable development.

The following section discusses the current renewable energy policy framework. It is important to bear in mind that Mexico has centralised policies that are constitutionally mandatory.

5.1 Energy sector reform

Mexico has recently reformed its energy sector substantially in order to increase the country's productivity. The purpose of two major reforms is to increase investments and jobs and grant PEMEX and CFE more freedom to modernise and work as productive enterprises.

For the oil and gas sectors, the reform aims to foster greater output at more efficient cost, and to foster competitive conditions in refining, transportation and storage activities. It does so by allowing private companies to participate under state regulation. The reform seeks to modernise the power sector, promote lowest reasonable costs of electricity, and deploy cleaner technologies.

In order to achieve these goals, it was necessary to modify certain constitutional articles that limited the potential for competition in the oil and power markets. Specifically, the constitutional reform decreed the following:

Table 6: New regulatory framework

New laws/acts	Modified laws/acts
Hydrocarbons Law	Foreign Investment, Mining and Public-Private Partnerships Acts
Electricity Industry Law	
Coordinated Energy Regulators Act	Federal Public Administration Act
PEMEX Act CFE Act	Federal State-Owned Companies and Procurement for the Public Sector Acts and related laws for civil works and services
National Agency of Industrial Safety and Environmental Protection for the Hydrocarbon Sector Act	
Geothermal Energy Act	National Waters Act
Hydrocarbon Income Act	Fiscal Coordination and Federal Rights Acts
Mexican Petroleum Fund for Stabilisation and Development Act	
	Federal Budget and Fiscal Responsibility Acts

Source: SENER

Note: New regulatory framework including legislative acts passed as of December 2014

- Reform of Article 27: the nation will still own the petroleum and solid, liquid or gaseous hydrocarbons in the subsoil. In this respect no concessions will be granted.
- In order to generate income for the state to support long-term national development, it will carry out the exploration and extraction of hydrocarbons by assigning these activities to its productive enterprises (all previously state-owned companies). Alternatively, it can arrange contracts with these or with private companies. 'State productive enterprises'[28] may themselves contract with private entities. These contracts had not been possible in Mexico since the 1938 oil expropriation.
- Reform of Article 28: planning and control of the national power system, the public service of electricity transmission and distribution, and petroleum and other hydrocarbon exploration and extraction now form part of the strategic areas whose functions are performed exclusively by the state. However, the state can now make contracts with private persons.

28 A state productive enterprise is defined as the exclusive property of the federal government, with its own legal personality and heritage. Furthermore, it is provided with technical, operational and managerial autonomy. This newest term is unique for PEMEX and CFE, both enterprises within the energy sector.

The reforms also created a public trust called the Mexican Fund of Petroleum for Stabilisation and Development. This is to be maintained by the state with the Central Bank (Banco de México) as trustee institution. Its purpose will be to receive, administer and distribute income derived from assignments and contracts indicated in Article 27.

Several secondary laws were recently enacted as a result of these constitutional reforms and the energy reform subsequently adopted in December 2013. Through the Chamber of Deputies and Senate, Congress created or modified 21 laws grouped in nine areas (Table 7). A last piece of secondary legislation, the Energy Transition Law, is still going through the legislative process and should be enacted soon. This law would establish a new legal framework for sustainable energy development and for regulating power sector objectives for clean energy production and emissions reduction (Mexico Chamber of Deputies, 2014). Among others, it replaces the current law regulating renewable energy.[29] [30]

29 However, since this law is still not enacted, the renewable energy policy will be described in this report as mandated by current legislation, including the current law regulating renewable energy. But it should be noted that this is likely to be modified in the near future.

30 When this study was completed in January 2015, some other regulatory measures were not yet published, such as power market rules and the provisions for clean energy certificates.

Planning and control of the national power system, power transmission and distribution, and petroleum and other hydrocarbon exploration and extraction remain strategic areas whose functions are performed exclusively by the state. Mexico's government may now enter into contracts with private firms to carry out these responsibilities including extending, modernizing, financing and/or operating the power transmission and distribution networks.

The main provisions from the recently enacted laws relevant to the development of renewable energy and mainly concerning the power sector are now described in detail. These are the Electricity Industry Law, the creation of an ISO for the power sector and the Geothermal Energy Law.

Electricity Industry Law

The Electricity Industry Law was promulgated on 11 August 2014 to open power sector generation and the wholesale market to competition. The law establishes a new regulatory framework for Mexico´s electricity sector, keeping the planning and control of the national power system as strategic duties of the state. The transmission and distribution of electricity will also be run by the state through the state- owned CFE (SEGOB, 2014a). However, private entities are now allowed to sign a range of different contracts with the state. This potentially contributes technology, financing and expertise to the expansion and improvement of the transmission and distribution networks.

The provisions of the Electricity Industry Law do not particularly refer to renewable energy but rather all forms of clean energy. This includes technologies other than renewables. It establishes a Clean Energy Certificate (CEC) market to foster investments in clean energy and encourage retirement of the less efficient power plants. This is described more fully below**.**

According to the Electricity Industry Law all the participants in the newly created power market will compete under equal circumstances for generation and wholesale market activities. The exception is nuclear power generation, the domain of CFE.

Under the Electricity Industry Law, all generators are guaranteed the right to compete in the wholesale market and to have open access to the grid. They can sign contracts and sell their electricity in the wholesale electricity market. The Electricity Industry Law affirms that the state keeps exclusive authority over nuclear generation through CFE, but all the participants in the newly created power market will compete under equal circumstances for generation and wholesale market activities.

New energy legislation creates a wholesale electricity market, enabling the establishment of electricity suppliers that can freely negotiate power supply contracts and tariffs.

The new law distinguishes two kinds of electricity users according to their level of consumption: qualified and basic users. Qualified users are able to purchase energy in the wholesale electricity market or directly from CFE or other suppliers at previously and freely negotiated rates. Basic supply users will purchase power from CFE at regulated tariffs established by CRE.

The law also permits certain retailers to buy and sell energy in the wholesale electricity market at prices negotiated freely between generators, retailers and qualified users. CFE will buy energy through auctions so it can meet its power needs at competitive prices. In this new scheme, suppliers can offer innovative prices and services to compete for customers, but the Electricity Industry Law does impose low-carbon objectives for the power sector. This takes the form of renewable energy quota obligations for qualified users and retail suppliers to acquire CECs. CRE will regulate transmission and distribution rates and corresponding subsidies to supply basic users.

Independent System Operator

The Electricity Industry Law appoints CENACE as the ISO. It will function as a decentralised public entity under federal public administration, with its own legal personality and assets. CENACE will primarily guarantee the operation of the national electricity system in terms of efficiency, reliability, continuity and safety. It has the responsibility to meet electricity demand at lowest reasonable cost while guaranteeing the stability of the network.

Table 7: Main characteristics of the clean energy certificate scheme

Target setting	The CEC scheme aims to support the achievement of the national clean energy generation goal of 35% by 2024.
Obliged parties	• suppliers • qualified users participating in the power market • end-users who obtain electricity from an isolated supply • holders of Interconnection Agreement Legacies which include a load centre
Eligible technologies	All the clean energy sources as defined by the Electricity Industry Law. Clean generators shall be entitled to receive a CEC for each unit of power they generate without the use of fossil fuels. For efficient cogeneration generators, they will receive a given number of CECs according to the methodology defined by CRE for clean energy accountability for this type of technology. A CEC has permanent validity until it is cancelled to comply with a quota obligation.
Enforcement	Some economic penalty is considered to be in place to enforce compliance. Nevertheless, penalties for non-compliance were still to be determined by the CRE at time of writing.
Start of operation	2018

Source: information based on the Electricity Industry Law (SEGOB, 2014a) and the CEC scheme guidelines (SEGOB, 2014c).

CENACE is now also in charge of ensuring open access to the electricity grid for all market participants without undue discrimination. It will coordinate the wholesale electricity market, ensuring that power plants are dispatched under competitive conditions regardless of the operating entity.

It will also have the power to propose the expansion of the transmission grid to SENER. SENER has the power to authorise the projects, while CRE will design and issue the corresponding regulations in a clear, transparent and equitable manner. Both transmission and distribution expansion will be planned by SENER in coordination with CRE and CENACE.

CENACE becomes the ISO managing the transmission and distribution system in coordination with SENER and CRE. It coordinates the wholesale electricity market, with the responsibility to meet electricity demand at lowest cost while guaranteeing the stability of the network.

Market mechanism to promote renewables in the power sector: Clean Energy Certificates

The Electricity Industry Law creates a clean energy quota obligation scheme to encourage renewable and other clean energy uptake in the power sector. Its purpose is to assure a growing share of total demand for clean generation. It is similar to a tradable green certificate (or portfolio standard) scheme, but is broadened to grant certificates for clean generation as opposed to renewable energy alone. The characteristics of the scheme already defined at time of writing are summarised in Table 9.

The obliged parties must comply with a CEC quota. This will be determined as a desired proportion of clean energy power in total electricity consumed over a specified period at a particular load centre.

The CECs issued to clean generators may be traded by interested parties in bilateral transactions and are valid on condition that monitoring, reporting and verification requirements established by CRE are met (SEGOB, 2014c). Sale agreements of this type are considered commercial acts. Specific trading rules are yet to be defined, as they will be tightly linked to the power market rules. It can be initially inferred that CECs will be traded in the power market either as part of a power purchase agreement or as a separate commodity.

The CEC scheme entails the use of clean energy. When fossil fuels are used in conjunction with it, the 'clean generators' are entitled to receive a CEC for the share of generation accounted for by clean energy. This scenario is primarily relevant to CHP. For these purposes, the proportion of clean energy free from fossil fuel will be determined for each power plant according to a methodology yet to be established by the CRE.

To prevent emissions reduction overestimation, any clean energy generating plant registered under the clean energy obligations scheme may not be registered under any other type of GHG emissions reduction scheme.

CRE will be in charge of certifying the clean energy fraction, issuing certificates, administering and monitoring the CEC scheme. Further detailed rules on how the CEC scheme will operate and how the quotas will be allocated are still to be defined by the CRE[31].

Geothermal Energy Law

The Geothermal Energy Act regulates the survey, exploration, development and exploitation of geothermal resources for power and heat generation in accordance with international best practices. It was promulgated in line with the recent constitutional amendments. Its objective is to use energy contained in the subsurface of the national territory to generate electricity or other thermal uses (SEGOB, 2014a). Before these changes, there was no specific framework for geothermal development, as activities of this kind were constitutionally reserved for the state.

One of the main elements of the Geothermal Energy Act is the definition of hydrothermal geothermal fields in a way that differentiates them from conventional aquifers, thus allowing specialised regulation. The distinction made between geothermal water and water for human consumption is key in this respect. For additional aquifer protection, additions and reforms were made to the Water Act to establish closer coordination between the Ministry of Energy and the National Water Commission. The Geothermal Act establishes binding technical and hydrological requirements for the construction, discharge and environmental impact of geothermal activities. It grants permits for all such activities. Finally, it takes into account efficient measures to maintain the sustainability of the hydrothermal geothermic fields[31].

31 In its 36th article, the Geothermal Energy Law establishes that geothermal water arising from the exercise of a test well for a permit or geothermal concession must be reinjected to the geothermal area. This maintains its sustainability in terms of the applicable provisions yet to be defined.

No specific framework for the development of geothermal energy by private players existed prior to the energy sector reform. The Geothermal Energy Act now regulates the survey, exploration, development and exploitation stages of geothermal resources for both power and heat generation.

5.2 Renewable energy law

The recent evolution of renewable energy policy in Mexico was driven by the Law for the Use of Renewable Energies and Financing the Energy Transition. This was published on 28 November 2008. Its goal was to encourage the use of renewable energy and clean technologies for electricity generation.[32] It incorporated a mandatory policy document known as the National Strategy for Energy Transition and Sustainable Energy Use. This included a discussion of acceptable instruments to finance the energy transition.

The Law for the Use of Renewable Energies and Financing the Energy Transition was adopted to comply with signed international agreements on GHG emissions reduction[33] and clean energy power generation goals. The 2011 amendment to the law established a set of non-fossil fuel generation goals for 2024, 2035 and 2050.[34][35]

The law was meant to define and regulate the use of renewable energy mainly for power generation. It man-

32 Clean energy includes energy sources and power generation processes for which emissions or residues are below a predefined threshold set by national regulation. See footnote 15 for full definition.

33 Mexico has signed agreements for technical cooperation with a number countries including the US and Denmark, as well as international financial institutions such as the Inter-American Development Bank. Mexico has also been supported by international cooperation agencies like USAID and the German Enterprise for International Cooperation (Deutsche Gesellschaft für Internationale Zusammenarbeit).

34 As mentioned above, new legislation to update the Law for the Use of Renewable Energies and Financing the Energy Transition following the energy reform is awaiting approval by the Mexican Congress. This could then be accompanied by the modification of these goals.

35 These goals were also part of the mitigation measures to attain the objectives of the Climate Change Law (Ley General del Cambio Climático), whose objective is to cut emissions by 30% by 2020 and by 50% by 2050 compared to 2000. Fulfilling these aspirational goals is subject to the availability of international financial and technology support mechanisms for developing countries (Congreso General de los Estados Unidos Mexicanos, 2012).

Table 8: Clean power generation goals

	2024	2035	2050
Clean energy goal	35%	40%	50%

Source: SENER

Note: The percentage refers to the total power generation of the national power system. The law does not directly refer to renewables for power generation, in spite of the definition of clean energy.

dated SENER to develop a national renewable energy inventory to provide reliable information on renewable energy resources in Mexico. It established a set of instruments like the Special Program for the use of renewable energy, an energy transition strategy and an energy transition fund, all of which are described below:

- **Special Program for the Use of Renewable Energy:** this introduces specific objectives and goals for the use of renewable energy, as well as renewable energy inclusion goals in electricity generation. It defines the strategies and action needed to achieve these goals, as well as strategies to promote renewable energy projects to generate electricity for rural communities.
- **National Inventory of Renewable Energy:** this is a system of statistical and geographical services financed by the Fund for Energy Transition and Sustainable Use of Energy. It collects information on renewable energy potential and on electricity generation projects using renewable sources and makes the information publicly available. This information is provided through the Mexican Atlas of Biomass Resources for Power Generation, the first section of the National Wave Atlas, the National Atlas of Waves and Wind, the Atlas of Solar Radiation, the National Atlas of Geothermal Resources, and the National Atlas of Small Scale Hydropower Resources.[36]
- **The National Atlas of Feasible Areas:** this atlas provides geographical information needed to locate generation projects and resource potential. This should facilitate the decision-making processes for developing and authorizing renewable energy generation projects.
- **Fund for the Energy Transition and Sustainable Energy Use:** this fund´s objectives are to finance programmes and projects focused on four areas. The first is the use and application of technologies for the use of renewable and clean energy. The second is the promotion of energy efficiency and power savings in the different sectors (residential, industrial, commercial, agricultural). The third funding area is aimed at diversifying energy sources as needed for the energy transition in Mexico. Finally, it funds the collection, generation and dissemination of information about renewable and clean energy potential in Mexico. The fund also promotes power saving and the efficient use of energy in all kinds of processes and activities, from generation to end-use. The fund is formed by four ministries (Energy, Finance, Environment and Natural Resources, and Agriculture) alongside CFE and three research and development institutes. These are the National Council for Science and Technology, the Electric Power Research Institute and the Mexican Oil Institute. The resources allocated to the fund originate from the national budget, amounting to a total of more than USD 500 million in 2009-2014.

36 Available at http://inere.energia.gob.mx/publica/version3.2/

Targets to generate a share of total electricity from clean energy technologies have been set at 35% by 2024, 40% by 2035 and 50% by 2050.

Both the Law for the Use of Renewable Energies and Financing the Energy Transition and the provisions described above are still in force. However, they will be abrogated by the Energy Transition Law still going through the legislative process. It is therefore most likely that the mechanisms described above will be subject to modification.

5.3 Bioenergy legal framework

In February 2008, the Bioenergy Law was published in the Federal Official Gazette. This law states that activities related to bioenergy are considered to be in the national interest, contribute to comprehensive

Table 9: Bioenergy permit types

	Type of Permit
1.	Production and storage of bioenergy such as anhydrous ethanol and biodiesel.
2.	Commercialisation of bioenergy such as anhydrous ethanol and biodiesel
3.	Transportation of bioenergy such as anhydrous ethanol and biodiesel.
4.	Notice of production and storage of bioenergy exception.*

Source: SENER

Note: This table is based on the sixth of a number of guidelines for the grant of permits for producing, storing, transporting and commercialising bioenergy such as ethanol anhydrous and biodiesel. This is directly related to the permit of production and storage of bioenergy.

** According to the Bioenergy Law, exception notices are given when the maximum production capacity of any given plant reaches 500 litres, and maximum storage reaches 1000 litres.*

national development and help guarantee sustainable development of the rural sector. This legal framework is regulated by articles 25 and 27, fraction XX of the Mexican constitution. The Bioenergy Law contributes to the goals of energy diversification and sustainable development. It does so by promoting the production of inputs for biofuels and the production, commercialization and efficient use of the biofuels themselves.

The Bioenergy Law created the Bioenergy Interministerial Commission (Comisión Intersecretarial de Bioenergéticos), composed of the heads of relevant ministries with different interests in the matter. This commission designs and dictates guidelines for public policy related to bioenergy for further implementation by competent authorities.

The Bioenergy Interministerial Commission has been created to analyse and dictate the guidelines for public policy in bioenergy.

The regulatory framework established by the Bioenergy Law defines the requirements, procedures and periods for granting permits for the production, storage, transportation and commercialisation of bioenergy. It specifies the measures that must be followed to protect the environment during the industry's development, and dictates sanctions for the different offences as stipulated in the legal framework. Failure to comply with permitting requirements may mean a permit is revoked. Guidelines defining the binding requirements for biofuel permits are shown in Table 9.

The Bioenergy Law outlines the regulation for activities related to biomass, and seeks to contribute to energy diversification and sustainable development.

Following the energy sector reform published in the Federal Official Gazette, nine related laws were enacted and 12 other laws were modified because they are linked directly or indirectly with bioenergy. The laws directly related to the bioenergy sector are the Coordinated Energy Regulators Act, creating CRE, and the National Agency of Industrial Safety and Environmental Protection for the Hydrocarbon Sector Act. This created a new agency, the National Agency for Industrial Safety and Environmental Protection of the Hydrocarbons Sector. This is better known as the Agency for Safety, Energy and Environment. This national agency is an administrative body separate from the Environment and Natural Resources Ministry. It is authorised to regulate and supervise the production, transportation, storage and industrial distribution of biofuels when they are directly related to diesel and/or gasoline mixing or preparation processes. SENER is specifically authorised by the Bioenergy Law to grant and revoke permits related to production, storage, commercialisation, transportation and biofuels distribution through pipelines (the latter in conjunction with CRE).

6 RENEWABLE POTENTIALS AND COSTS

Table 10 provides an overview of the possible capacity of certain renewable energy technologies for power generation. The table separately indicates the probable capacity for geothermal and small hydropower (SENER, 2014a).

If probable capacity is considered, both geothermal and small hydropower (< 30 MW) offer a major resource opportunity. According to the journal Hydropower & Dams, the theoretical potential for hydropower in Mexico is 49 GW. However, the economic potential is estimated at about half that at 27 GW based on today's capacity factor as calculated from a total generation potential of 72 TWh/yr. This economic potential is more than twice the installed capacity in 2013. Thus another 15 GW could be utilised. In Mexico today hydropower capacity of at least 3.8 GW is planned (SENER, 2013a). In addition to the values shown in Table 10, the estimated tidal energy potential in the Gulf of California amounts to 26 GW (SENER, 2012c).

The estimated bioenergy supply potential in Table 11 for 2030 is based on a study (REMBIO, 2011) prepared by REMBIO and IRENA estimates (IRENA, 2014b). According to IRENA, Mexico's total sustainable biomass supply potential (only including residues and excluding cultivated biomass) through to 2030 is 626-1012 PJ/year. The REMBIO estimate of 3569 PJ is much higher – 1063-1515 PJ/year. This is because it also includes 1063 PJ of energy crops and 1515 PJ of forest products in addition to residues. According to REMBIO estimates, forests present the highest bioenergy potential. Dedicated energy crops based on food crops are not considered in the IRENA analysis in view of the competition with land and increasing food demand in Mexico to 2030. Given Mexico's efforts to reduce deforestation, only the residue and waste streams of the forest products are accounted for in the IRENA analysis.

The supply cost of biomass depends on the resource type, where the resource is located, where it is delivered and in which form it is transported. According to IRENA estimates, biomass supply costs for Mexico (including transportation costs of USD 2-3/GJ) range from USD 2.4/GJ for processing residues and biogas to around USD 4.6/GJ for harvesting residues. Wood residues and waste are estimated to cost around USD 3.3/GJ in 2030. However, given the size of the country and resource

Table 10: Renewable energy resource potential for power generation

	Possible		Probable		Installed capacity (June 2014) (MW)	Generation (GWh/year)
	Capacity (MW)	Generation (GWh/year)	Capacity (MW)	Generation (GWh/year)		
Geothermal	7422	52013	5730	45175	823	6168
Large hydropower (>30 MW)	5630	4504	-	-	12038	36559
Small hydropower (<30 MW)	-	-	9243	39060	436	1753
Wind	50000	87600	-	-	1899	4546
Solar PV	5000000	6500000	-	-	66	34

Source: National Renewable Energy Inventory (SENER, 2014a)

Note: The methodology used to determine this potential follows a similar approach to that employed to assess hydrocarbon reserves. Therefore probable capacity is not a share of possible reserves. Instead, the potential is cumulative. It does not include the potential for which generation permits have been granted nor resource already being exploited. It is estimated as follows:

- *Possible capacity refers to theoretical potential for power generation based on indirect studies and generic assumptions that do not state any technical or economic feasibility.*
- *Probable capacity denotes sites where some field studies have been carried out, but are not sufficient to prove technical and economic viability.*

Table 11: Breakdown of total biomass supply potential in 2030

	IRENA[1] (PJ/year)	REMBIO[2] (PJ/year)
Biogas	304	70
Energy crops	-	1063
Harvesting residue	129-350	427
Processing residue	55-216	494
Wood forest	-	1515
Wood residue	92-93	-
Wood waste	46	-
Total	626-1012	3569

Source: IRENA (2014b) & REMBIO (2011)

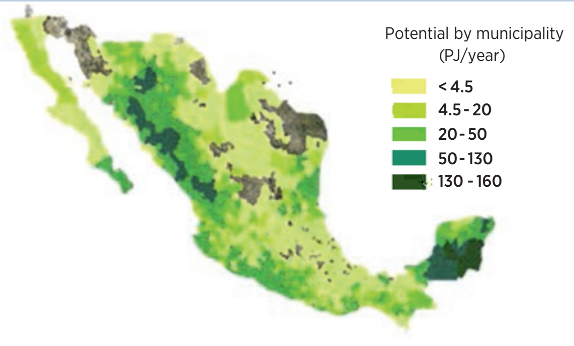
1 The difference between the low and high supply potential from IRENA estimates is due to different assumptions of factors such as development in non-disturbed area allowed or not, land recovery rates, proportion of residues from food consumption; land development rate, etc. (For further details, consult the Bioenergy Energy Paper (IRENA, 2014b)).

2 Technical potential for sustainable biomass-to-energy production.

distribution, transportation costs may be higher in reality than the assumed average value for the 26 countries analysed in REmap.

The potential of sustainable wood supply is distributed throughout the country. It is more concentrated in the peninsular area in the South and in the Sierra Madre Oriental and Sierra Madre Occidental mountain ranges in north-eastern and western Mexico (see Figure 15). These biomass resources are thus convenient to most areas of demand.

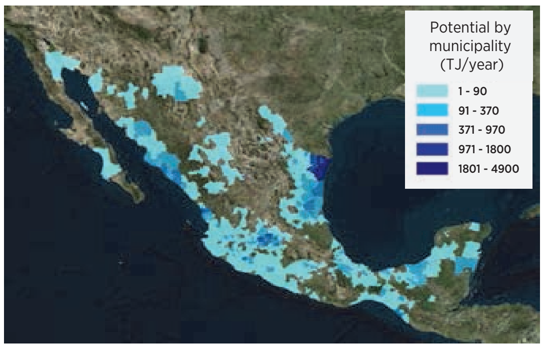
Figure 15: Sustainable wood supply potential for energy



Source: National Renewable Energy Inventory (SENER, 2014a)

According to REMBIO, dedicated energy crops are the second largest source of biomass after wood. These include eucalyptus, sugar cane, sugar beet, sweet sorghum, palm oil and jatropha curcas – all resources highly suitable for biofuels production. Figure 16 shows the distribution of dedicated energy crops in Mexico.

Figure 16: Dedicated energy crop supply potential



Source: National Renewable Energy Inventory (SENER, 2014a)

Note: Energy crops include jatropha curcas, palm oil, sugar cane, sugar beet, eucalyptus and sweet sorghum. The assessment of the potential is based on the existing crops, assuming that all the production could be dedicated to biodiesel or bioethanol production. The estimates should therefore be viewed with caution as no consideration of alternative commercial uses for these crops has been taken into account.

7 REMAP OPTIONS FOR MEXICO

KEY POINTS

- There is high quality wind resource potential for up to 30 GW of onshore wind in 2030 with an average capacity factor of 35%.
- Given Mexico's major solar resource potential, installed solar PV capacity could rise from 5 GW in the Reference Case to 30 GW in 2030 under REmap 2030. This consists of 60% utility-scale and 40% rooftop installations.
- Compared to the Reference Case, significant solar thermal potential is available for further deployment, especially in industry, which benefits from an additional 45 PJ under REmap Options.
- In REmap 2030, total biomass use would be three times as high as in 2010. Biomass in TFEC would account for more than half total renewable energy use.
- Heating applications account for half total biomass demand in Mexico in 2030, with the other half related to transport and power generation.
- Compared to very limited use today, a quarter of Mexico's total heating sector energy demand could be supplied from modern renewables.
- Options have been identified that can triple Mexico's total final renewable energy use from around 0.5 EJ in 2010 to 1.5 EJ by 2030.
- Implementing REmap Options provides the opportunity to reduce Mexico's total coal demand by 62%, natural gas by 21% and oil by 6% in 2030 compared to the Reference Case. This means natural gas demand would grow by 115% between now and 2030. Under Reference Case, this demand rises by 175%.
- Installed solar PV and wind capacity account for 74% of the REmap Options identified in the power sector.
- Mexico could be on track to meet its clean energy objectives *i.e* 35% of power from clean technologies by 2024 and 40% by 2035.
- The major renewable energy potential for heating can be realised and result in savings at the same time given the availability of low-priced biomass residues and waste, and cost-competitive solar water heaters.
- Compared to equivalent new capacity using conventional generation, accelerating Mexico's uptake of renewable energy could result in savings of USD 0.1/GJ (USD 0.4/MWh) using the business perspective. It could result in savings of USD 2.0/GJ (USD 7.2/MWh) using the government perspective.
- Onshore wind, utility-scale solar PV and geothermal would be cost-competitive with natural gas power plants in 2030. However, this will depend on the trajectory of natural gas prices.
- REmap Options would reduce Mexico's CO_2 emission growth between 2010 and 2030, from 70% to 40%, or to 513 Mt CO_2 emissions instead of 615 Mt CO_2 in 2030.
- A 21% renewables share results in annual net savings of USD 1.6 billion in Mexico's total energy system by 2030. If savings from improved human health from reduced air pollution and lower CO_2 emissions are also taken into account, they amount to USD 4.6-11.6 billion annually.
- Adequate long-term planning for grid development is critical to meet the wind and solar power generation potential under REmap 2030.
- If Mexico fulfils its distributed electricity and heating generation potential, 22% of the 38 million homes predicted for 2030 would have solar water heating systems and 10% solar PV rooftops by 2030.
- Biomass supply potential needs to be fulfilled and a biomass market created to connect supply and demand in order to obtain the 810 PJ of primary biomass estimated under REmap Options for 2030.
- Adequate long-term planning for grid development is essential to meet the wind and solar power generation potential under REmap 2030.

The REmap analysis for Mexico uses a REmap tool developed internally. This incorporates forecasts from two sources, namely SENER for power sector and APEC Energy Demand Supply Outlook 2013 business-as-usual scenario (APEC, 2013b) for the Mexican end-use sectors. The REmap analysis allows for commodity and fuel prices specific to particular countries, as well as localised renewable and conventional technology costs and performance characteristics. The data, assumptions and approach used have been summarised in Sections 2 and 4. The tool allows IRENA to enter additional renewable energy options in the industry, buildings and transport end-use sectors as well as power generation and district heat. However, the latter was excluded from the scope of the present analysis as there is no district heating in Mexico.

The procedure for using the tool to create REmap Options is as follows:

1) A Reference Case was created for 2020 and 2030. For 2010-2030, it was based on the business-as-usual scenario in the APEC Energy Demand Supply Outlook 2013 for Mexican end-use sectors, as well as projections from SENER for the power sector.
2) Fuel prices were forecasted based on SENER national reports (for fuels other than biomass) and IRENA estimates (for biomass).
3) Local technology cost and performance criteria (*e.g.,* capital costs and capacity factors) were based on SENER reports and IRENA's own estimates.
4) Additional renewable energy options for all end-use sectors and the power sector were analysed and entered into the tool as appropriate.

The following studies have been used to identify additional renewable energy options beyond the Reference Case:

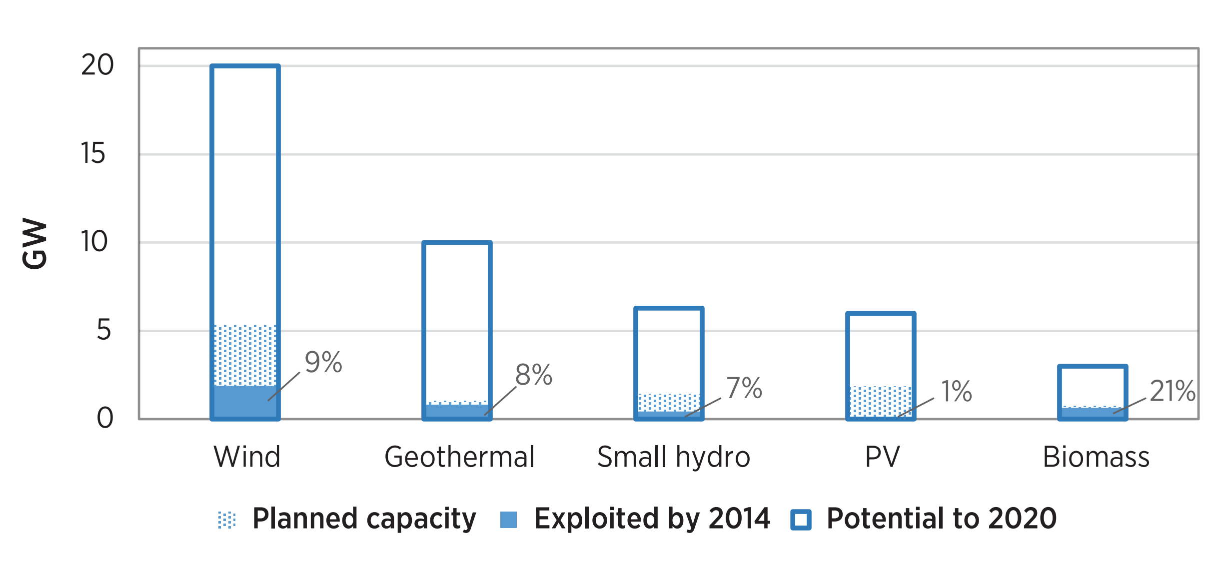
- Renewable Energy Perspectives 2012-2027 (SENER, 2013b) and CONUEE study for the promotion of solar water heaters in Mexico (CONUEE, 2007). These were used to set the potential for additional solar water heating in a high penetration scenario in the buildings sector.
- National Energy Strategy 2013-2027 (SENER, 2013c) was used to assess the economic potential of wind, geothermal and solar PV power by 2020.
- Power Sector Perspectives 2013-2027 (SENER, 2013a) was used for additional wind developments by 2027 according to the alternative (high renewable development) scenario. This aims for a 35% power generation share using clean technologies by 2024.
- National Renewable Energy Inventory (SENER, 2014a) was used to assess the technical potential of solar, wind, geothermal power and small hydropower.
- Hydropower & Dams, World Atlas 2014 (Hydropower & Dams, 2014) to establish the economic potential of hydropower.
- Biomass supply potential and cost estimates originate from IRENA for power and heat generation and biofuel production (IRENA, 2014b) (IRENA, 2013a).
- Bioenergy in Mexico, Current Status and Perspectives (REMBIO, 2011) was the reference for biomass supply potential.
- The IRENA Renewables for Industry Roadmap (IRENA, 2014c) was used for total heat generation and solar and geothermal heat generation in Industry.

The following section is divided into five subsections. Section 7.1 discusses the potential of different renewable energy technologies in Mexico, as well as the regions with greatest renewable resource availability. Section 7.2 provides a survey of the REmap Options. In Section 7.3, detailed cost projections are provided, while Section 7.4 presents cost/supply curves for the REmap 2030 energy mix. Section 7.5 discusses these findings, challenges and alternative cases.

7.1 Renewable energy technologies in 2030

Mexico has significant and diverse renewable energy resource potential (see Section 6). The National Energy Strategy 2013-2027 (SENER, 2013c) outlines the economic potential of renewable energy for the power sector that could be realised by 2020. Figure 17 shows the current status of renewable energy deployed and planned as of June 2014.

Figure 17: Renewable energy economic potential for power generation by 2020, planned capacity and capacity deployed by June 2014



Source: National Energy Strategy 2013-2027 (SENER, 2013c), INERE (SENER, 2014a)

Note: Planned capacity is based on the proven potential according to INERE data (SENER, 2014b), which corresponds to power capacity from generation permits approved for renewable energy projects. There is no guarantee that the projects related to such planning would ultimately be deployed.

The potential, distribution and characteristics of each renewable resource available for power, heat and biofuels production are described in the following paragraphs on specific technologies.

Wind

Onshore wind potential in Mexico is located mainly in three regions: the Isthmus of Tehuantepec (southern region), the states of Tamaulipas (eastern region) and Baja California (northwestern zone). According to INER, the total theoretical wind potential amounts to 50 GW (SENER, 2014a), while the economic potential by 2020 amounts to 20 GW, as shown in Figure 17 (SENER, 2013c). The resource available in some zones with high potential, like the Isthmus of Tehuantepec in Oaxaca, is estimated to be capable of producing at a capacity factor of more than 40%. Of the total 50 GW theoretical capacity, 20 GW of potential capacity could be deployed with an average capacity factor of 35%. Another 10 GW could be deployed at an average capacity factor of 27%. The remaining 20 GW could be deployed with a 20% average capacity factor (PWC, Climate Works Fundation, IMERE and WWF, 2013).

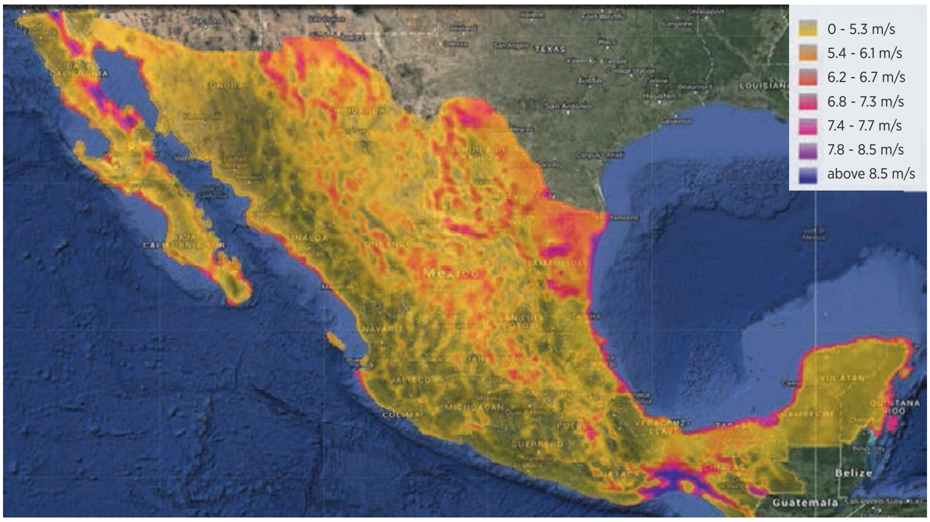
As shown in Figure 18, wind projects are being deployed in locations with high wind resource potential. The Reference Case assumes the continuation of this trend to 2030 with 11 GW onshore wind capacity, where plants with capacity factors of 40% are being deployed. An additional 19 GW capacity is assumed under REmap 2030. This option is derived from the alternative scenario in the Power Sector Perspective 2013-2027 (SENER, 2013a), which increases onshore wind power capacity penetration to around 30 GW by 2030. About half the total capacity in REmap 2030 is assumed to be deployed in low wind resource areas averaging a capacity factor of about 27% with the other half in areas averaging a capacity factor of 35%. This represents 60% of Mexico's total theoretical wind potential of 50 GW as outlined in Section 6 of this report.

REmap 2030 also assumes 1 GW offshore wind is deployed in the Gulf of Mexico.

Solar PV/CSP

Mexico's geographical location is ideal for the exploitation of solar resources. The daily average solar irradiation stands at 5.5 kWh/m^2.

Figure 18: Annual mean wind speed at 50 metre height



Source: Global Atlas (IRENA, 2015b)

Note: In legend "m/s" is the annual mean wind speed in meters per second

There is a high quality wind resource potential for up to 30 GW of onshore wind in 2030 with an average capacity factor of 35%.

The solar PV resource potential is shown in Figure 19 with specific sites identified where solar developments could be economically feasible. Northwestern Mexico shows major potential for solar power generation. Daily average irradiation in the region can exceed 8 kWh/m^2 in spring and summer (SENER, 2014a). Levels in the region are similar to southwestern US, where many utility-scale solar power plants are being built today. The central region also has abundant solar resource, as does the Baja California peninsula.

To date, solar resources in Mexico are barely exploited on any large-scale or commercial basis. The Reference Case considered an increase in solar PV capacity of only 5.6 GW by 2030, of which around 60% is utility-scale and the remaining is rooftop solar. This represents an annual growth of 300 MW in 2010-30, already much higher than the annual installations of 31 MW in 2013 and 17 MW by September 2014 (CRE, 2014)[37].

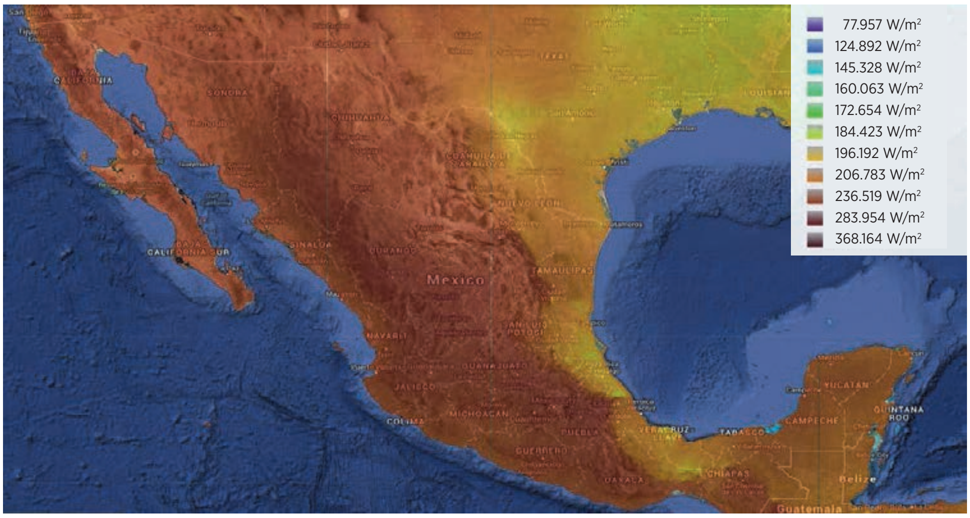
37 The low deployment of solar PV observed that year may have been influenced by the series of regulatory changes initiated in Mexico.

The REmap Options include an addition of almost 25 GW of solar PV capacity, assuming the same share of 60% utility-scale and 40% residential/commercial applications as in the Reference Case. Total solar PV capacity reaches 30 GW in REmap 2030. This capacity is assumed to be deployed to a large extent in northwestern Mexico which is distant from the most populated areas in Mexico. Demand is in the centre and the southern parts of the country. This distance between supply and demand means planning will be needed for transmission infrastructure in coordination with solutions for grid integration of renewables.

REmap also adds 285 MW solar PV rural electrification systems to the Reference Case to arrive at a total of 860 MW. Some of these systems provide electricity to households without access to grid power. Other systems are mini-grids used to provide power for street lighting, agricultural pumping, mobile phone towers etc. in addition to residential needs.

Solar resources for CSP power generation are abundant. However, as yet no sizable additions of this technology

Figure 19: Solar resource



Source: Global Atlas (IRENA, 2015b)

are included in the Reference Case. By contrast, REmap took into account an increase of 1.5 GW in CSP capacity.

Given Mexico's major solar resource potential, installed solar PV capacity could rise from 5 GW in the Reference Case to 30 GW under REmap 2030. This consists of 60% utility-scale and 40% rooftop installations.

Geothermal

Geothermal energy is also a major potential resource for both electricity and heating projects. Mexico has the fifth largest installed geothermal power capacity after the US, the Philippines, Indonesia and New Zealand (IRENA, 2015c). Although it is expected that new projects will go on-stream in the near future, some units are also due to be decommissioned (GEA, 2013). Thus a substantial net increase in capacity requires greater effort. Considering the probable capacity alone means neglecting a considerable amount of untapped geothermal energy for both electricity and heat generation, as described in Section 6. The resource potential is spread throughout the country, but concentrated in the central, eastern and southern regions, as shown in Figure 20.

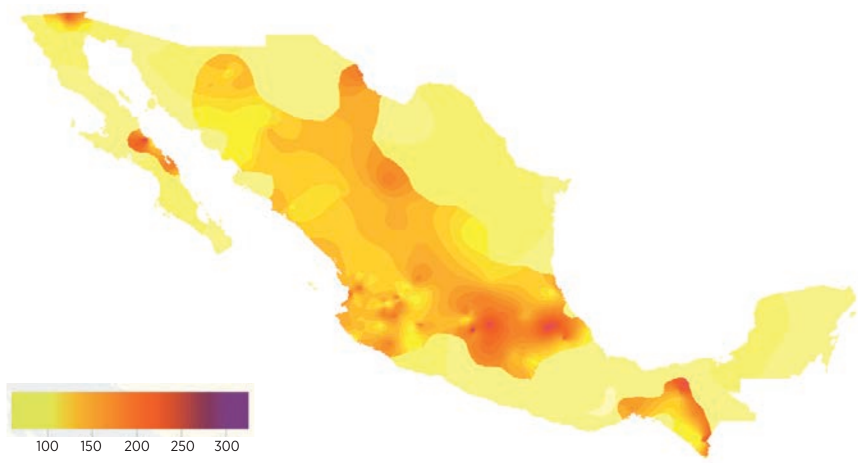
The REmap Options assume 3.2 GW in geothermal electricity generation capacity in addition to the 1.1 GW accumulated installed capacity envisaged in the Reference Case. In REmap 2030, total geothermal capacity reaches 4.3 GW.

Mexico's Electric Power Research Institute estimated probable reserves of geothermal high-enthalpy reservoirs suitable for power generation at a minimum of 3.3 GW (Birkle, 2006). To achieve REmap 2030, all of this would have to be utilised.

Biomass

The REmap Options for 2030 for power generation from bioenergy amount to 2.8 GW, an addition of almost 1 GW to the Reference Case. Approximately 1 GW of this increase corresponds to biomass co-firing in coal plants and 1.8 GW of CHP located on site at industrial plants. Biomass use at industrial CHP plants is halved between bagasse and a range of solid biomass sources. The total installed capacity in REmap 2030 is similar to the economic potential for the year 2020.

Figure 20: Geothermal resource potential



Source: National Renewable Energy Inventory (SENER, 2014a)
Note: Scale corresponds to subsoil temperature in °C.

Hydropower

Off-grid and distributed power is the most extensively explored energy solution for most of Mexico's isolated communities. Small hydropower shows significant untapped potential for this segment.

Hydroelectricity in Mexico is expected to continue to grow both from large hydropower facilities and small, mini and micro hydro projects (<30 MW) under construction or planned. An additional 6.5 GW is anticipated for large hydropower, based on the economic potential presented in the report Hydropower and Dams (Hydropower & Dams, 2014). The estimated potential for small hydropower lies mainly on the rivers of the Pacific Rim and in the states of Veracruz, Oaxaca and Chiapas (SENER, 2014a). Mexico has a gross estimate of 3.2 GW in small hydropower potential (up to 10 MW)[38]. However, much of the economic potential has been already developed or is in the pipeline. REmap 2030 therefore retains the 1.8 GW of total installed capacity from the Reference Case in 2030.

In the Reference Case, around 17 GW of large hydropower and 1.8 GW of small hydropower are considered. Total installed capacity reaches 25.3 GW in REmap 2030.

Potential in end-use sectors

Solar and geothermal use for heating and cooling, and modernised forms of biomass in end-use sectors all offer further potential.

For process heat generation, 80% of total solar thermal REmap Options (10 GW) is to be found in the manufacturing industry. It serves 5% of total energy demand for industrial process heat generation (IRENA, 2014c). Two thirds of this potential would mainly be deployed in sectors with low temperature heat demand, such as food and textile production processes, as well as in certain chemical production processes. The rest is mainly for medium temperature applications for chemical production processes using solar thermal concentration technologies. Mexico has recently started to deploy this technology, with some 600 kW of thermal capacity in operation. This is used mainly in the food sector (AEE INTEC, 2014).

Potential for solar cooling in industrial applications is estimated as 23 MW. This would provide about 2-3%

38 This value is based on inferences from international statistics and not on a resource assessment.

of power demand in food production, replacing power demand for refrigeration (IRENA, 2014c).

The remaining additions for heat concern solar water heating in buildings. Water heating energy demand accounts for 10% of buildings total thermal energy use in Mexico in 2030. The Reference Case already considers a significant addition of solar thermal – around 17 GW from almost no use in 2010. A small addition of 1.5 GW is included in REmap 2030, based on an extrapolation of a high penetration scenario for solar water heating systems (SENER, 2013b). Around 90% of the buildings sector potential is in households, and the remaining 10% in the service sector (SENER, 2012c). An addition of about 4 GW solar cooling can be a substitute for split air conditioning use. This would replace about 1% of total building electricity demand, or 5% of total electricity demand for cooling. Total solar thermal capacity in buildings thus amounts to more than 23 GW by 2030.

In total, solar thermal capacity estimated for both industry and buildings amounts to almost 33 GW in REmap 2030. This would require around 2 GW of annual solar thermal capacity additions in 2010-2030, a level ten times higher than the annual additions in 2010-2012.

Compared to the Reference Case, significant solar thermal potential is available for further deployment, especially in industry, which benefits from an additional 45 PJ under REmap Options.

Low/middle temperature direct-use applications for generating heat for industry, buildings or agriculture offer a greater potential for expanded geothermal use than is the case for power generation. However, very little is happening at present in these promising applications. An addition of around 800 MW of geothermal heat for the industry sector is considered under REmap Options (about 1% of Mexico's total energy demand for process heat generation). This potential is realisable because a major part of deployable geothermal resources for direct heating are close to manufacturing facilities in Mexico.

Several forms of biomass could be used in Mexico, including wood and wood products, agricultural and forest residues, and biogas from urban waste and manure. The largest additional biomass use in 2030 takes place in the transport sector in the form of liquid biofuels and in the manufacturing sector for process steam and power generation. These amount to 53 PJ and 175 PJ, respectively, beyond the Reference Case. Within manufacturing, 29 PJ would be in cement manufacturing. The biomass and waste component of this industry's fuel would rise by 20%. Combined with other measures, this would put Mexico's cement industry on a path to reducing its clinker production emissions by 45% compared to 2010 (IEA, 2009). One third of the remaining 146 PJ is related to steam generation in boilers and two thirds to CHP for various production processes.

Fuel blending in the transport sector in both gasoline and diesel was taken into account for REmap Options. This assumes a 6% ethanol blend in gasoline, equivalent to 86 PJ consumed per year in REmap 2030 versus 53 PJ in the Reference Case. A 5% biodiesel blend was assumed[39] for diesel. This is equivalent to 41 PJ/year in REmap compared to 22 PJ in the Reference Case. A 30% blend of biokerosene in jet fuel for air transport was assumed for domestic aviation only. However, the definition of local transport varies greatly among different sources and needs to be improved. As a result of these REmap Options, total primary biomass demand in the transport and industry sectors reaches 257 PJ and 200 PJ, respectively in 2030.

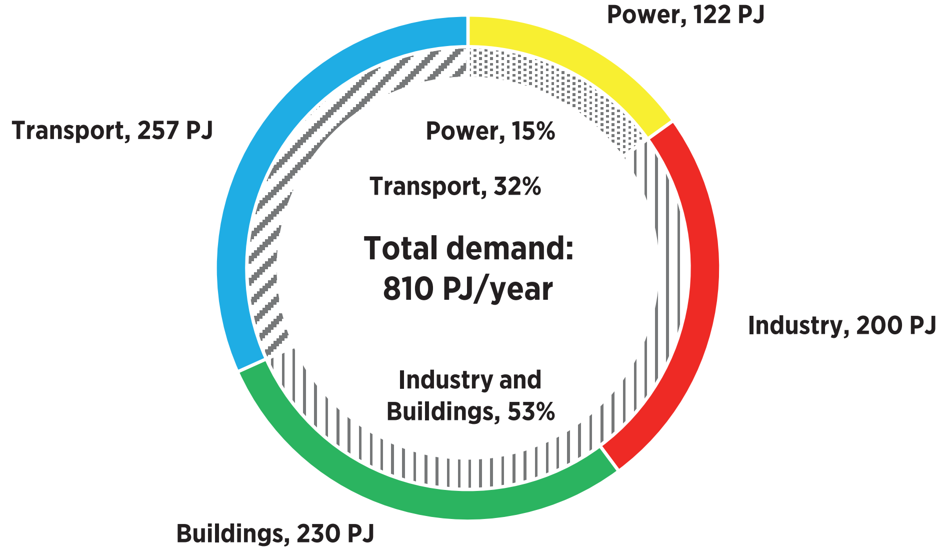
REmap 2030 also replaces fossil fuels through transport sector electrification. It includes a fleet of over 350 000 plug-in hybrid electric vehicles (PHEVs) and around 60 000 two-wheel EVs. This results in new electricity demand of 1.5 TWh (assumed to be sourced from renewable energy) and raises the sector's electricity demand by 40% compared to the 2030 Reference Case. It replaces almost 9 PJ in oil products in 2030 based on a 1% market penetration of the total motorcycle and passenger vehicle stock estimated in 2030 (World Bank, 2009)[40].

All traditional use of biomass remaining in the buildings sector in the Reference Case is replaced by modern types of bioenergy. In total, 15 PJ of modern bioenergy replaces 51 PJ of traditional biomass use. Around 4 PJ of this potential is biogas and the remainder is solid bio-

39 The earlier 1% blend targeted for biodiesel has already been achieved in the Reference Case and was therefore revised.

40 Total road vehicle stock is predicted to reach over 70 million units in 2030, of which 50% are sedan cars and almost 10% are motorcycles.

Figure 21: Primary bioenergy demand by sector in REmap 2030



Heating applications account for half total biomass demand in Mexico in 2030, with the other half related to transport and power generation.

mass. This adds another 590 000 modern cook stoves to over 7 million considered in the Reference Case.

The total supply potential for biogas is about 300 PJ. This mainly takes the form of urban waste across the country, and manure in the northern and central western regions. In the Reference Case, biogas use reaches 60 PJ in 2030 in the buildings and industry sectors. In REmap Options, an additional 4 PJ is assumed for cooking, and about another 20 PJ for process heat generation. This amounts to a deployment of around one third of the total biogas supply potential.

Total biomass demand in end-use sectors as liquid biofuels and for heating/cooking reaches 810 PJ in REmap 2030. This is almost halfway between IRENA minimum and maximum estimates of total supply potential discussed above.

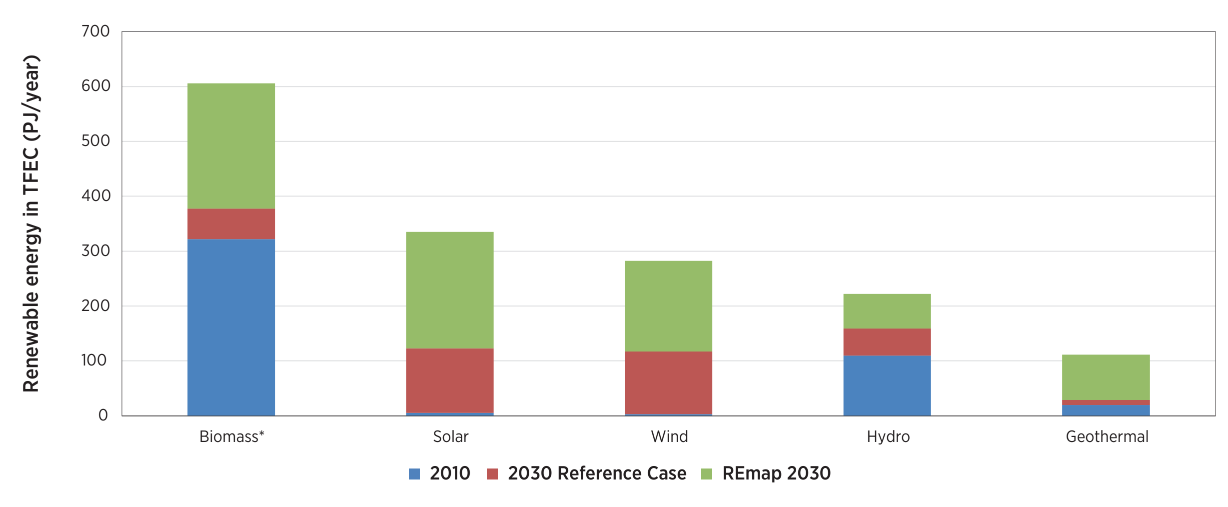
In REmap 2030, total biomass use would be three times as high as in 2010. Biomass in TFEC would account for more than half total renewable energy use.

Biomass is used as a source for power, transport fuels and heat technologies, therefore providing energy services in all sectors. Figure 21 shows the distribution of primary energy between end-use and power sectors. The transport sector accounts for almost a third of total demand followed by the buildings sector. Industry is projected to consume about a quarter of total biomass usage and the remaining is for power generation.

7.2 Roadmap table

REmap 2030 results in a significant increase in the amount of renewable energy use in TFEC. In 2010 around 200 PJ of modern renewable energy was used in Mexico (about 460 PJ including traditional use of biomass). In the Reference Case for 2030, about 748 PJ originates from modern renewable energy, while REmap Options amount to almost 790 PJ. Biomass remains the largest source of renewable energy in REmap 2030. However, solar PV shows the largest increase both in absolute terms and in growth rate, with a fivefold increase in generation between the Reference Case to REmap 2030. This is followed by wind, which almost doubles. Renewable energy in TFEC could nearly double to 1.5 EJ compared to the Reference Case (748 PJ). Figure 22 shows the anticipated Remap 2030 increase for each renewable energy resource.

Figure 22: Increases in renewable energy consumption in TFEC by resource



Note: Biomass includes traditional biomass uses of 260 PJ in 2010 and 51 PJ in the 2030 Reference Case.

Note: Incl. electricity consumption.

Table 12 and Figure 23 show the estimated breakdown of renewable energy end-use by consuming sector for 2010 and 2030 for both the Reference Case and REmap 2030.

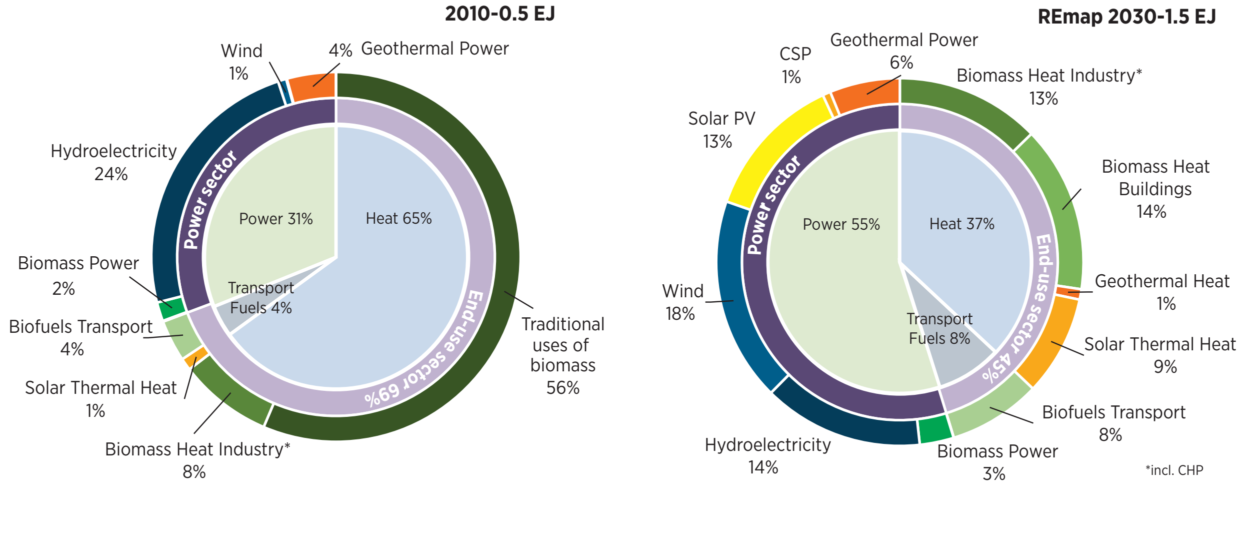
Mexico's heating sector shows considerable potential for renewables. The modern renewable energy share of the buildings sector has the largest potential for increase. It rises from about 6% in 2010 to 39% in 2030 under REmap 2030 as a result of significant deployment of solar thermal and modernised cooking/heating appliances using biomass. In the case of biomass, geothermal and solar thermal, the industry can triple its share of renewable energy use in the same time period. By contrast, the transport sector experiences limited growth in renewable energy share with the implementation of REmap Options. Nevertheless, the renewable energy share it can achieve under REmap 2030 is significant compared to 2010. Given the sector's total energy use

Table 12: Breakdown of renewable energy share by sector

			2010	2030 Reference Case	REmap 2030	RE use REmap 2030 (PJ/year)
Industry	Heat	Heat consumption	4.6%	3.2%	22.7%	273
	incl. renewable electricity	Sector TFEC	9.6%	11.3%	34.4%	841
Buildings	Heat only	Heat consumption	0.7%	30.9%	34.8%	311
	incl. renewable electricity	Sector TFEC	5.6%	26.6%	38.9%	558
Transport	Fuels	Fuel consumption	0.8%	2.3%	3.9%	128
	Fuels & electricity	Fuel TFEC	0.8%	2.4%	4.2%	136
Power		Generation	18.5%	19.3%	45.7%	1003
Total		**TFEC**	**4.4%**	**10.1%**	**20.9%**	**1536**

Compared to very limited use today, a quarter of Mexico's total heating sector energy demand could be supplied from modern renewables.

Figure 23: Breakdown of renewable energy use by application and sector in final energy in 2010 and under REmap 2030



Options have been identified that can triple Mexico's total final renewable energy use from around 0.5 EJ in 2010 to 1.5 EJ by 2030.

in Mexico's TFEC, even low shares of renewable energy make a significant impact in the country's total renewable energy use.

The share of renewable energy in the power sector more than doubles in REmap 2030 compared to the Reference Case and compared to 2010. It increases from just under 19% to almost 46%, or around 116 TWh and 280 TWh of renewable power generation respectively.

All the above renewable energy developments mean the modern renewable energy share in TFEC reaches 21% in REmap 2030 compared to 4.4% in 2010. This suggests Mexico could be in line to meet its clean energy objectives to obtain 35% of power from clean technologies by 2024 and 40% by 2035. Under REmap 2030, these targets can be achieved with renewables alone.

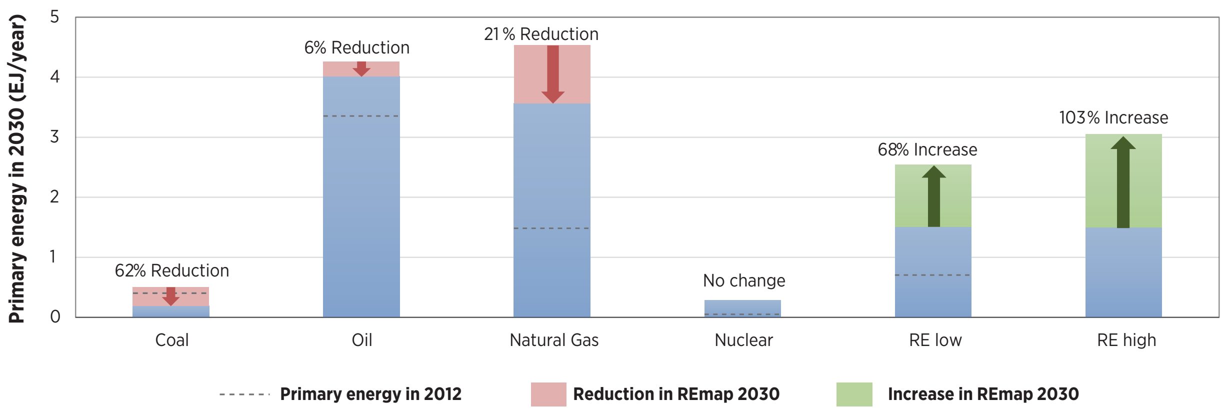
Renewable power represents 54% of total renewable energy used in Mexico in REmap 2030. The other 46% is related to end-use sector demand. Of this, around 82% is for heating and cooling applications in industry and buildings, and 18% in transport biofuels. This differs from 2010, when heating applications represented two thirds of renewable energy use and renewable power just under one third.

Various forms of bioenergy in power and end-use sectors account for nearly 40% of the total renewable energy use in REmap 2030. This is followed by solar PV and solar thermal with 23% and wind with 18%. Solar PV accounts for about 60% of the total solar use. Solar thermal accounts for most of the rest, with CSP technology providing less than 1%. The remainder consists of 14% hydropower and 6% geothermal, virtually all of which is dedicated to power generation. The most obvious changes from 2010 include a decline in the share of traditional biomass to zero in 2030 from almost 60% in 2010. Meanwhile, the contributions of solar thermal, solar PV and wind energy rise significantly.

Figure 24 shows how REmap Options would change the primary[41] energy fuel mix in 2030, with renewable energy replacing conventional energy sources. There are different ways to calculate the primary energy equivalent of renewables, resulting in a range of esti-

41 As shown in Figure 24, primary energy use estimates are based on TFEC and primary energy use in power generation, including energy derived from blast furnace and coke ovens. They exclude non-energy uses, as well as energy for industry's own use and for oil and gas extraction.

Figure 24: Renewables offset against fossil fuels as primary energy source, REmap 2030 compared to Reference Case



Implementing the REmap Options provides the opportunity to reduce Mexico's total coal demand by 62%, natural gas by 21% and oil by 6% in 2030 compared to the Reference Case. This means natural gas demand would grow by 115% between now and 2030. Under the Reference Case, this demand rises by 175%.

mates.[42] The high renewable calculation uses the Energy Information Administration partial substitution method while the low calculation uses the IEA physical energy content method. These do not represent different cases or different levels of renewable energy consumption, but rather differences in converting renewable electricity and heat into primary equivalents.

In primary terms, renewable energy use in Remap 2030 increases by 68-103% over the 2030 Reference Case. Coal demand falls most in relative terms by 62% (174 PJ) to remain the lowest fossil fuel contributor to Mexico's primary energy mix. Natural gas – now the dominant fuel for power generation – sees the largest reduction in absolute terms (950 PJ), but only a 21% drop in relative share. This is because gas-fired generation is replaced by renewable power. Oil retains the largest share of primary energy (a little larger than natural gas) and sees only a 6% reduction compared to its total consumption in the Reference Case in 2030. Renewables take third place as primary energy resource after oil and natural gas if renewable technologies and uses are aggregated under REmap 2030 as described above.

Table 13 provides more detail about the evolution of the energy system envisioned in this study. It shows the analysis base year 2010, the Reference Case for 2030 and REmap 2030. The renewable energy share in TFEC grows from 4.4% in 2010 (200 PJ) to 10% in 2030 (748 PJ) in the Reference Case. The renewable share more than doubles under REmap 2030, in which total renewable energy use is 1536 PJ/yr by 2030. This consists of 128 PJ as liquid biofuels, 584 PJ as heat in buildings and industry, and 824 PJ as renewable power consumption.

Figure 25 provides an overview of capacity developments for the REmap Options in the power sector in 2013 (the year with the most recent data available), the 2030 Reference Case and REmap 2030. For each technology, there is a significant gap between the 2030 Reference Case and REmap 2030. This indicates that the level of potential renewables use is significantly higher than projected in current plans. Under Remap 2030, solar PV would have the largest renewable power generation capacity by 2030 and would require the largest

42 Different methods are applied to estimate total primary energy demand. The two applied in this study are the physical energy content and substitution methods. The physical energy content method is used by IEA and Eurostat. These count renewable electricity and biofuels as primary energy at the same value as they appear in the form of secondary energy. Meanwhile, geothermal, CSP and nuclear are counted by converting average process efficiencies into primary energy equivalents. The substitution method converts renewable electricity and heat to primary energy. This method uses the average efficiency of the fossil fuel power and heat plants that would otherwise be required to produce these quantities.

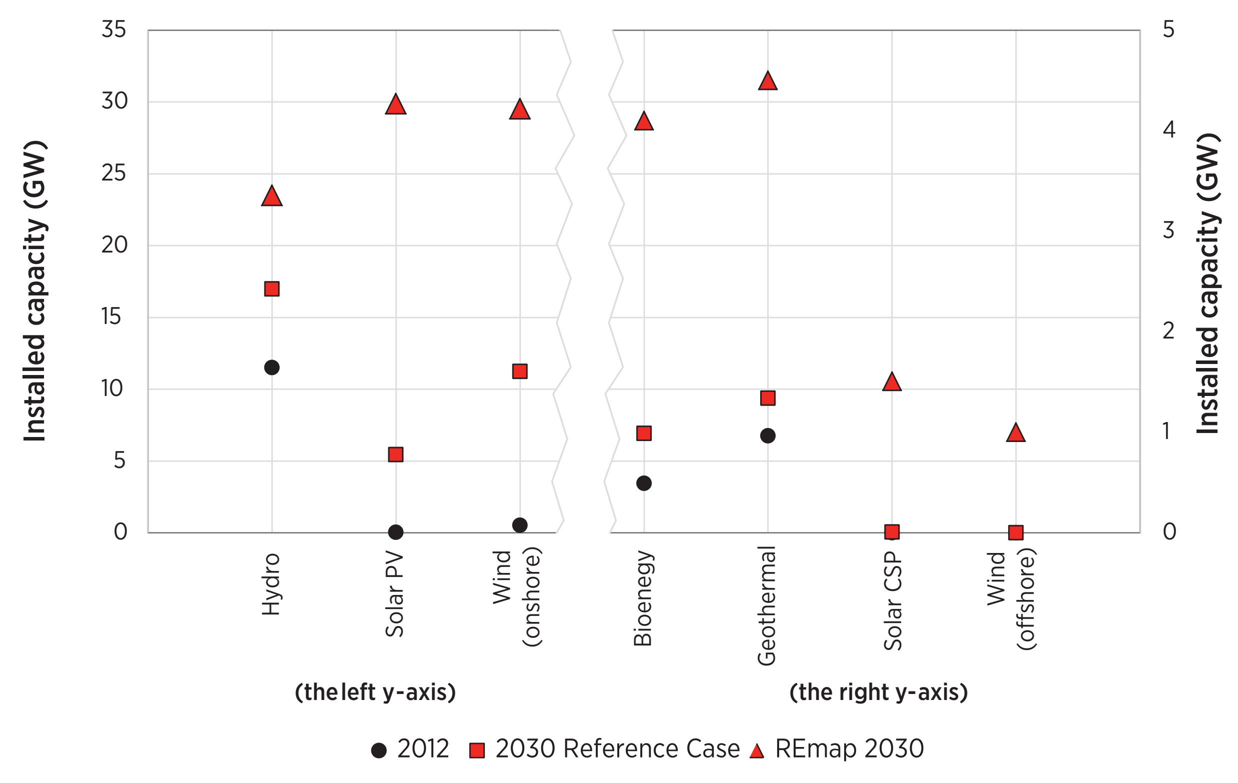
Table 13: Mexico REmap 2030 overview

1. Electricity		Unit	2010	Reference Case 2030	REmap 2030
Power capacity	**Renewable energy**	**GW**	**13.0**	**37.8**	**95.8**
	Hydropower	GW	11.5	19.0	25.5
	Onshore wind	GW	0.1	11.1	29.4
	Offshore wind	GW	0.0	0.0	1.0
	Bioenergy (incl. CHP)	GW	0.42	0.9	3.8
	Solar PV – utility	GW	0.0	3.5	18.9
	Solar PV – rooftop	GW	0.1	2.1	11.4
	Solar CSP	GW	0.0	0.01	1.5
	Geothermal	GW	1.0	1.2	4.3
Electricity Generation	**Renewable energy**	TWh	**47.9**	**116.2**	**279.1**
	Hydropower	TWh	37.3	52.0	72.0
	Onshore wind	TWh	1.1	38.4	88.0
	Offshore wind	TWh	0.0	0.0	3.5
	Bioenergy (incl. CHP)	TWh	2.7	3.5	15.0
	Solar PV – utility	TWh	0.0	8.1	44.5
	Solar PV – rooftop	TWh	0.1	4.8	21.0
	Solar CSP	TWh	0.0	0.01	3.6
	Geothermal	TWh	6.7	9.4	31.5
2. Heat					
Solar heating (buildings)		PJ	1	70	77
Solar cooling (buildings)		PJ	0	0	4
Solar heating (industry)		PJ	0.2	13	58
Solar cooling (industry)		PJ	0	0	0.2
Geothermal heat (industry)		PJ	0	0	14
Biomass buildings (modern)		PJ	0	216	230
Biomass industrial		PJ	38	25	200
Total		PJ	**39**	**325**	**584**
3. Transport					
EVs		Mln	0.0	0.0	0.4
		TWh	0.0	0.0	1.5
Biofuels		PJ	17	75	128
4. Ratio of electricity generation					
Gross power generation		TWh	259	602	610
Generation ratio of renewables		%	18	19	46
5. TFEC					
TFEC		PJ	**4 503**	**7 383**	**7 337**
All renewable energy		PJ	200	748	1536
Renewable heat and fuel		PJ	59	400	712
Renewable power		PJ	141	348	824
Ratio – renewables/TFEC		%	**4.4%**	**10%**	**21%**

growth in capacity deployment to 2030. Onshore wind would rank second in installed capacity followed by hydropower.

With the addition of 163 TWh of renewable power generation in REmap Options, renewable power generation grows to 280 TWh by 2030, a 46% share of total generation. This is more than double the Reference Case. Annual renewable generation consists of 65 TWh in

Figure 25: Power capacity development by renewable energy technology



Installed solar PV and wind capacity account for 74% of the REmap Options identified in the power sector.

solar PV, 92 TWh in wind and approximately 23 TWh in geothermal, making a total 32 TWh.

Hydropower contributes a total 72 TWh in REmap 2030, including an additional 20 TWh for large hydropower installations (greater than 30 MW). Bioenergy options for power generation show a 11 TWh increase in addition to the 3.5 TWh in the Reference Case. Finally there is practically no use of CSP in the Reference Case, but CSP power generation amounts to almost 4 TWh in REmap 2030.

Total power generation in REmap 2030 includes a significant share from variable renewables (wind and solar) amounting to 26% – or 157 TWh per year. The challenges associated with intermittent power sources of these kinds are discussed in Section 7.4.

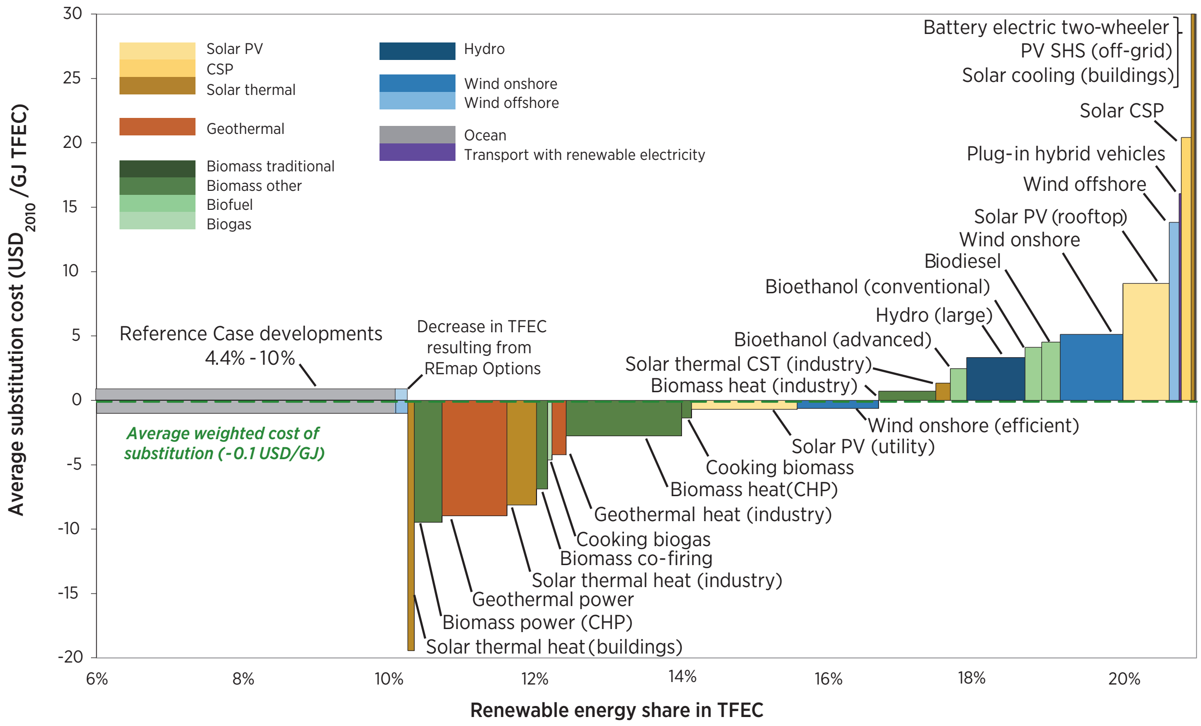
Mexico could be on track to meet its clean energy objectives i.e. 35% of power from clean technologies by 2024 and 40% by 2035.

7.3 Summary of REmap Options: cost-supply curves

Previous sections have discussed the technology options available for accelerated renewable energy development in Mexico by 2030. In this section these options are coupled with their respective technology costs and ranked in terms of cost-effectiveness. This aggregation represents an overall cost-supply curve of the achievable renewable energy deployment under REmap Options.

The REmap Options represent a portfolio of technologies considered applicable for accelerated renewable energy deployment in the power and end-use sectors (buildings, industry and transport). This is based primarily on technical factors and resource availability. This portfolio is not an allocation of the global additional potential based on Mexico's GDP or on the experience of the other 25 REmap countries, nor does it represent extrapolations. Further technology portfolios can be

Figure 26: REmap Options cost-supply curve, business perspective, by resource



Note: The renewable energy share in the Reference Case increases from 4.4% in 2010 to 10% in 2030. However the Reference Case bar in this figure starts at 6% in order to show REmap technology options more clearly.

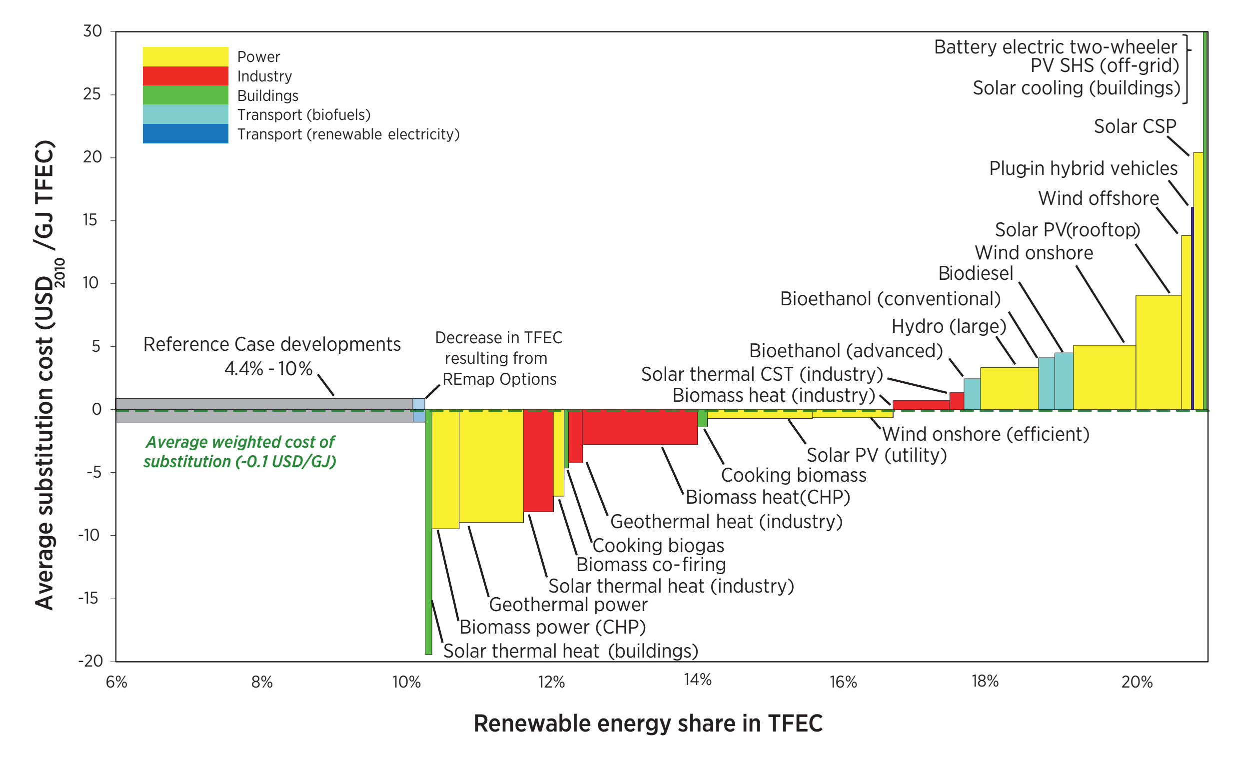
generated on the basis of a different understanding of the parameters that constitute REmap Options or other studies looking at the specific case of Mexico.

The cost-supply curves discussed in this section are an approximate representation of the realistic economic potential of renewable energy technologies – the REmap Options – which can be deployed by 2030 in addition to the Reference Case. The cost-supply curve is not used *a priori* to develop the REmap 2030. Instead, it is an *ex post* representation of the REmap Options taken.

The results of the analysis are shown in the cost-supply curves in Figure 26 through Figure 29 are based on local technology costs and technical performance characteristics (capacity factors, conversion efficiencies etc.) There are two sets of curves. One is based on national costs – the business perspective. It incorporates the national cost of capital using a 10% discount rate, energy commodity prices including national taxes,[43] as well as subsidies. The second is the government perspective. This is based on standard international energy commodity prices. For coal and natural gas, a distinction is made between export and import countries. The government perspective uses a fixed 10% discount rate. The business perspective reflects factors likely to influence private investment decisions. The government perspective considers factors more relevant to government decisions on policy and spending. The national cost-supply curves are used to examine the costs and savings related to increased renewable energy uptake. The standard international curve is used when considering research and development needs. It compares renew-

43 A carbon tax for fuels is included in these national parameters. It is equivalent to USD 0.007/litre for gasoline, USD 0.009/litre for diesel and USD 0.004-0.005 for natural gas.

Figure 27: REmap Options cost-supply curve, business perspective, by sector



Note: The renewable energy share in the Reference Case increases from 4.4% in 2010 to 10% in 2030. However, the Reference Case bar in this figure starts at 6% to show REmap technology options more clearly.

able potential and costs across regions or globally and provides insight into cost differences between Mexico and global markets resulting from policy decisions like energy taxation.

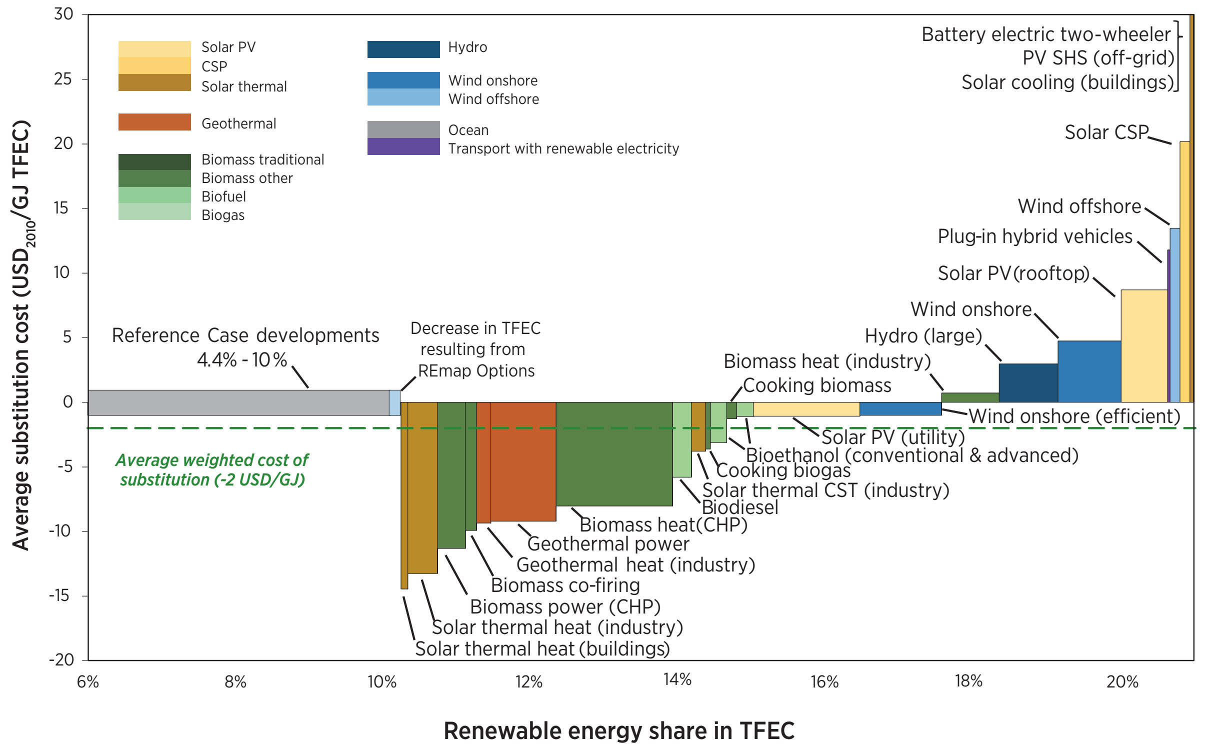
Decision-makers will be tempted to pick low-cost options from the left end of the curve and to skip high-cost options on the right side. However, the cost curves should not be misinterpreted as a series of steps from left to right showing costs in isolation that can be chosen or rejected. Rather, there are synergies and interactions, and all of these options need to be exercised together to achieve the indicated level of costs and renewable energy shares. The figure therefore gives a perspective of the entire country and energy mix.

Nor should decision-makers assume that options represented by individual blocks in the supply curve are homogenous in terms of substitution costs. Rather, the blocks represent average values based on the deployments assumed in the REmap 2030. For instance, some options produce savings or improvements in efficiency that help reduce the costs of more expensive options even further below those that would exist otherwise. The focus on the cheapest individual options will not result in the least expensive overall transition. That outcome requires a holistic approach. This study finds that only when all these options are pursued simultaneously can the share of renewables in TFEC in Mexico be raised to 21% by 2030.

The cost-supply curves for the business and government perspective are presented twice. They are coloured once by resource and once by sector. In Figure 27 and Figure 29, the cost-supply curves are displayed with the technologies coloured by sector. These show that most of the identified potential involves renewable energy options in the power sector.

In the REmap cost-supply curves, the Reference Case growth in renewable energy in 2010-2030 is shown by the first horizontal bar in grey. The results of the REmap analysis and accelerated deployment of renewable energy (the REmap Options) are plotted on the curve as

Figure 28: REmap Options cost-supply curve, government perspective, by resource



Note: The renewable energy share in the Reference Case increases from 4.4% in 2010 to 10% in 2030. However, the Reference Case bar in this figure starts at 6% to show REmap technology options more clearly.

coloured bars. The x-axis shows the additional potential of each technology, while the y-axis shows the average incremental cost of substitution for deploying that technology in lieu of a conventional variant.

Cost-curve results by sector and technology

The results in Figure 26 are dependent on projections of technology costs and fuel prices. An overview of the assumptions underlying these projections is available in Annexes A and E[44]. The technology option mix and costs vary according to sector. Costs associated with the Reference Case are not quantified because they are part of expected energy system developments and are outside the boundaries of the REmap analysis.

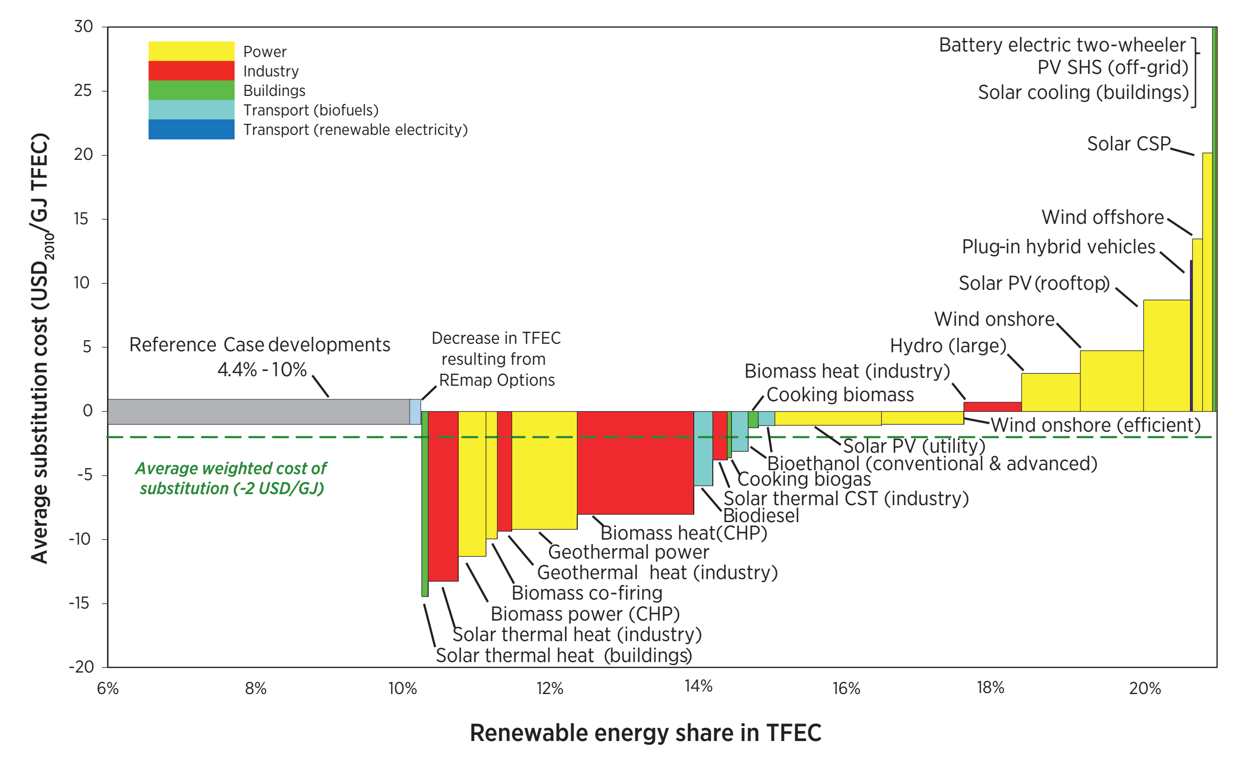
When viewed from business (national prices) and government perspectives (international prices) the REmap cost-supply curves show that a big share of REmap Options could be deployed with cost savings compared to conventional technology alternatives.

The least expensive renewable energy options are derived from biomass and geothermal sources. The cost-competitiveness of industrial CHP using biomass arises partly from an assumption that the corresponding REmap Options use biomass residues. These are very inexpensive (USD 2-5/GJ). Efficient combustion of biomass residues in CHPs (including bagasse from sugar cane production) can be a cost-effective alternative to fossil fuels and a good way to phase in renewable power. Furthermore, a mix of bioenergy, solar thermal and geothermal can replace petroleum products in the industry sector. These are typically used for process heat generation in Mexico.[45]

44 These estimates are based on 2030 capital cost projections for energy technologies and assume an average increase in fossil fuel prices of 50% in 2010-2030.

45 If the REmap Options were to be compared using the fall in the oil price experienced as this report was in progress, they would come out as less cost-effective. This is particularly the case for industry and transport, where petroleum products are being replaced.

Figure 29: REmap Options cost-supply curve, government perspective, by sector



Note: The renewable energy share in the Reference Case increases from 4.4% in 2010 to 10% in 2030. However, the Reference Case bar in this figure starts at 6% to show REmap technology options more clearly.

Substitution costs are also cost-competitive for heating in both building and industry sectors. This is because solar water heaters in Mexico have low capital cost and high capacity factors. They are assumed to replace conventional heating boilers mostly fed by expensive LPG at forecast oil prices. Solar water heat would also be cost-competitive if used in Mexico to replace natural gas in process heat generation. However, petroleum products rather than gas are typically used for this process in Mexico. Biomass and waste used in clinker production to replace coal is also nearly cost-competitive with the identified renewable energy technology options. In the buildings sector, solar water heaters show a similar cost advantage as process heat generation in the industry sector. Replacing traditional biomass use with biogas and residues is also cost-effective due to the high efficiency of modern cook stoves and the low price of biomass feedstock. However, solar cooling used to replace electricity for air conditioners has a high substitution cost due to the high capital costs and low annual utilisation rates of solar cooling units.

The outlook for biofuels and EVs in the transport sector is more problematic. SENER forecasts that gasoline and diesel prices will increase to around USD 30/GJ (around 30-40%) by 2030 compared to the 2010 level. These projections incorporate an end to present subsidies on petroleum products. This is in line with fuel market liberalisation. However, price projections and assumptions on technology development show biofuels are still expected to be slightly more expensive in 2030 than their petroleum equivalents. This is described in the appendices to this report.

The major renewable energy potential for heating can be realised and result in savings at the same time given the availability of low-priced biomass residues and waste, and cost-competitive solar water heaters.

Average substitution costs are positive for power generation (*i.e.* above the average cost of conventional power) even though they encompass a range of tech-

Table 14: Overview of the average cost of substitution for the REmap Options

	Business perspective (national prices) (USD/GJ)	Government perspective (international prices) (USD/GJ)
Industry	-2.4	-6.3
Buildings	-2.0	-0.5
Transport	4.3	-2.8
Power	0.6	0.1
Average of all sectors	**-0.1**	**-2.0**

Compared to equivalent new capacity using conventional generation, accelerating Mexico's uptake of renewable energy could result in savings of USD 0.1/GJ (USD 0.4/MWh) using the business perspective. It could result in savings of USD 2.0/GJ (USD 7.2/MWh) using the government perspective.

nologies including low-cost biomass. This is in part because several of the various REmap Options (solar PV rooftop, offshore wind, CSP) have fairly high capital costs. They are assumed to replace inexpensive natural gas generation. However, power from biomass, geothermal, utility-scale PV and onshore wind (in zones with high resources) can save costs. The positive or negative effects that the integration of this renewable energy capacity would have on the system are not analysed in this study.

Table 14 shows the average cost of substitution for each end-use sector. Accelerating Mexico's uptake of renewable energy could result in savings. These amount to USD 0.1/GJ (USD 0.4/MWh) in the business perspective and USD 2.0/GJ (USD 7.2/MWh) in the government perspective compared to developing the equivalent new capacity with conventional generation.[46] The savings in the government perspective would equate to 9% of the cost of natural gas power generation in 2030.

If viewed by technology, the substitution cost drivers are evident. Table 15 provides an overview of the current and projected LCOE for new capacity power plants. This is based on technology and exploitation costs alone without accounting for any type of incentive. According to REmap 2030, around 15-20 GW of onshore wind capacity in high wind resource sites (approximately 40% of the technical potential for wind) will be cost-competitive with natural gas by 2030. In addition, utility-scale solar PV, geothermal and power installations fed with biomass residues are also expected to be cost-competitive with natural gas generation in 2030. This cost-competitiveness means that no economic incentive is provided. All other technologies are estimated to be more expensive than coal and natural gas, although onshore wind with lower resource potential and large hydropower are almost cost-competitive by 2030.

It is worth noting that rooftop PV is one of the only technologies that can produce electricity directly at point of consumption. A comparison with generation costs (*e.g.,* LCOE) of alternative large-scale fossil fuel technologies is therefore not the most appropriate. Rather, if viewed from a 'plug-parity perspective' *i.e.,* compared to the retail price of electricity, rooftop solar PV (whose generation cost is estimated to average USD 0.11/kWh) would provide savings. They need to be compared to retail electricity tariffs of around USD 0.16-0.19/kWh including the energy rate but excluding fixed charges. As for any of the other technologies, the impact that distributed solar PV could have on-grid costs (related to power losses, flows or infrastructure) is not considered in the analysis.

The costs of assuring system reliability for intermittent power and variable renewable energy are also outside the scope of this study. However, they could have a

46 SENER projections for installed power capacity and generation in 2027 show coal power generation is run at a capacity factor of 60% (SENER, 2013a). This value has been considered as input for performance data for coal generation. Given that some renewable energy technologies are replacing this fossil fuel, average costs of substitution would slightly increase, from USD -0.1 to USD 0.3 per GJ in the business perspective, and from USD -2.0 to USD -1.6 per GJ in the government perspective. This assumes the capacity factor is increased to 80%.

Table 15: Comparison of national levelised costs of power generation in REmap 2030

	LCOE in 2030 (USD/MWh)
Large hydropower	95-120
Onshore wind, low wind resource	85-115
Onshore wind, high wind resource	70-90
Offshore wind	115-145
Solar PV (rooftop)	100-125
Solar PV (utility)	70-90
Solar PV home systems (off-grid)	310-370
Solar CSP (no storage)	155-195
Biomass co-firing (residues)	65-80
Biomass CHP (residues)	40-50
Geothermal	55-75
Coal	90-110
Natural gas	70-90
Diesel gen-set	185-220

Note: The LCOE assumes a national discount rate of 10%. In the case of utility-scale and rooftop PV, LCOE is higher than costs in the US, for instance, in zones with similar solar irradiance. This is due to higher discount rates in Mexico, combined with the fact that it is a young market. Thus the annualised capital costs are higher (around 20-30% when compared the US).

Onshore wind, utility-scale solar PV and geothermal would be cost-competitive with natural gas power plants in 2030. However, this will depend on the trajectory of natural gas prices.

major effect on power generation cost rankings. This is especially true for Mexico where the variable renewable energy share could reach 26% by 2030. External costs related to fossil fuel power generation are not accounted for in these LCOE calculations.

Benefits of REmap Options

Economic arguments for increased renewable energy are accompanied by strong environmental arguments. The REmap Options would result in an estimated annual reduction in CO_2 of 102 million tonnes (Mt) per year by 2030 (Table 16) from over 615 to 513 million tonnes. Reductions in the power sector of 78 million tonnes represent three quarters of total mitigation. If all REmap Options were deployed, Mexico could reduce the growth of CO_2 emissions in 2010-2030 from 70% (in the Reference Case) to 40%.

Socio-economic benefits are also anticipated from increasing the renewables share in Mexico. Various sources focusing on Mexico show the employment

Table 16: Avoided CO_2 emissions resulting from REmap Options

	2010 (Mt/yr)	2030 Reference Case (Mt/yr)	REmap 2030 (Mt/yr)	Avoided (Mt/yr)
Power	122	254	175	78
Industry	53	75	57	19
Transport	155	233	229	4
Buildings	29	42	42	0
Total	367	615	513	102

REmap Options would reduce Mexico's CO_2 emission growth in 2010-2030 from 70% to 40%, or to 513 Mt CO_2 emissions instead of 615 Mt CO_2 in 2030.

Table 17: Overview of job estimates related to renewable energy in Mexico

Recent developments	
160 MW wind project built in 2012[1]	500 jobs during construction phase of 2 years, plus 60 permanent jobs
Woodfuel production of 12 000 millions of Mexican pesos per year[2]	417 000 jobs as of 2009
Projections in 2012-2030	
1.5 GW solar PV power additions[3]	12 400 jobs
12 GW wind power additions[4]	48 000 direct and indirect jobs
1 GW biomass power additions[5]	31 000 jobs
2.2 GW geothermal power additions[6]	36 700 jobs
Bioethanol 6% blend (812 million litres per year)[7]	21 230 permanent jobs

Sources: 1 Wood et al. (2012); 2 REMBIO (2011); 3 SENER (2012d); 4 SENER (2012e); 5 SENER (2012f); 6 SENER (2012g); 7 SAGARPA (SAGARPA, 2013).

Table 18: REmap Options financial indicators based on government perspective

Changes in costs of the energy system (in 2030)	**(USD bn/yr)**
Incremental system cost	-1.6
Reduced human health externalities	-1 to -2
Reduced CO_2 externalities	-2 to -8
Net cost-benefits	-4.6 to -11.6
Incremental subsidy needs	0.4
Investments (average between today and 2030)	
Incremental investment needs	6.6
Total investment needs (REmap Options)	6.9
Total renewable energy investment needs (REmap Options and Reference Case)	11.8

impacts already experienced as a result of renewable energy (see Table 17). With increasing renewable energy deployment, the total number of people employed in the sector will continue to rise. SENER estimates that 175 000 direct, indirect and induced jobs could be created in all renewable energy technologies combined by 2020 (IRENA, 2013b). At the same time, however, it must be recognised that jobs would be lost in the conventional energy sector.

Furthermore, implementing all REmap Options could halve Mexico's total coal demand by 2030 compared to 2010. Based on steam coal national prices, this would result in annual savings in Mexico's energy bill of USD 1.4 billion by 2030. This is equivalent to the amount all sectors paid for coal purchases in 2010. The savings on expenditures for oil products in 2030 could be as high as USD 4.2 billion per year, 60% of that in the industry sector. Savings in natural gas consumption by the power sector could be USD 6.6 billion per year accompanied by decreasing dependence on imported natural gas. These estimates assume no fossil fuel backup power capacity is needed. If accounted for, this would otherwise reduce these fuel savings.

From a government perspective REmap Options identified in Mexico show a negative incremental system cost[47], or cost savings of around USD 1.6 billion in 2030 (Table 18). This does not include benefits related to air pollution reductions affecting health and CO_2 emissions. If such externalities were to be included, and depending on how these are valued, full deployment of the REmap Options could result in annual estimated reduced health costs of USD 1 – 2 billion by 2030. These avoided exter-

47 Net incremental system costs are the sum of the differences between capital and operating expenditures of all energy technologies based on their deployment in REmap 2030 and the Reference Case in 2030.

Table 19: Valuation of human health externalities for power generation technologies

<table>
<tr><th></th><th>Total (SENER) (USD/MWh)</th><th>Total (World Bank) (USD/MWh)</th><th>Total (IRENA) (USD/MWh)</th></tr>
<tr><td>Coal</td><td>1.3</td><td rowspan="4">5-36</td><td>5-14</td></tr>
<tr><td>Fuel oil</td><td>2.3</td><td rowspan="2">12-35</td></tr>
<tr><td>Diesel</td><td>1.0</td></tr>
<tr><td>CCGT</td><td>0.05</td><td>1-3</td></tr>
</table>

Source: SENER (SENER, 2013b), (World Bank, 2014)

Note: All data is expressed in real USD for 2013. IRENA analysis included $PM_{2.5}$ emissions as opposed to PM_{10} which are included by the SENER and the World Bank analyses.

nal costs result from a reduction of health complications caused by air pollution from fossil power plants, fuels in the transport sector and biomass in the buildings sector. Power and buildings enjoy 45% of the benefits, and less than 10% goes to the transport sector.

If the emissions reductions of 102 million tonne CO_2 are taken into account, an additional USD 2-8 billion per year could be saved by 2030.[48] About three quarters of these reductions are related to the power sector.

The aggregated benefit is an energy system cost reduction of USD 4.6-11.6 billion per year. Increasing the share of modern renewable energy from 4.4% in 2010 to 21% by 2030 produces significant savings if external costs of fossil fuels are included. This depends on how these are valued.

Modern forms of biomass result in similar emissions when combusted. However, they are negligible compared to the externalities from indoor air pollution caused by traditional biomass use. In the case of power generation, a considerable share of renewable power originates from renewable energy sources that do not result in any direct emissions. This includes solar PV, wind or geothermal compared to coal or natural gas. Despite the fact that modern forms of biomass also create external costs, these avoided externalities from fossil fuel combustion related to human health can be considered realistic. Nevertheless, a comprehensive estimate of replacement costs viewed from the government perspective would need to net out external renewable and fossil costs. Although this study only considers external costs related to air pollution, both renewables and fossil fuel also use water and land. These concerns could be included in a more detailed and exhaustive external cost review.

According to a 2014 World Bank analysis, external costs related to SO_2, NO_x and PM_{10} emissions from power generation have been estimated in other studies to range from as low as USD 0.005/kWh to USD 0.027 – 0.036 kWh. These values arise in the critical pollution zones of Salamanca and Tula, respectively. This depends on the methodology used (see Table 19 for a comparison of the values by SENER, the World Bank and IRENA). On an annual basis these external costs would amount to USD 0.8-4.5 billion in 2030, given that unit external costs exceed the REmap estimates. The low end of this range is close to the REmap estimates of USD 0.4-1 billion per year for the power sector. SENER has published preliminary estimates of external costs of power generation emissions (SENER, 2013b), based on a CEPAL externalities study (CEPAL, 2007). This is shown in Table 19.

Table 18 also shows that a 21% renewable energy share in renewable energy technologies by 2030 would require an average annual investment of USD 11.8 billion through to 2030.[49] Of this, USD 6.9 billion would come from the REmap Options and USD 4.9 billion from investments taking place in the Reference Case. Since the REmap Options investments eliminate a USD 0.3 billion investment in conventional energy variants, the incremental annual investment[50] needed would be USD 6.6 billion.

48 Efficient mitigation assumes that the cost of prevention does not exceed the cost of the damages prevented.

49 Investments refer to gross rather than incremental investments for all renewable energy technologies deployed between now and 2030.

50 Net incremental investment needs are the difference between the annual investment needs of all REmap Options and the investment needed otherwise for conventional technologies.

The table also shows that an annual subsidy of USD 0.4 billion would be required. This would make REmap Options technologies with positive substitution costs 'competitive' with fossil technologies.

A 21% renewables share results in annual net savings of USD 1.6 billion in Mexico's total energy system by 2030. If savings from improved human health from reduced air pollution and lower CO_2 emissions are also taken into account, they amount to USD 4.6-11.6 billion annually.

7.4 Discussion of REmap Options and implementation challenges

The energy generated in REmap 2030 draws on a variety of renewable resources for electricity, heat and biofuels, and includes a small contribution from electrification in the transport sector. Renewable energy climbs to almost 21% of the general energy mix and more than doubles to 46% in the power sector. Realising this potential means overcoming economic, deployment and system integration challenges. This is particularly relevant for technologies that make a major contribution to renewable energy use. These are biomass (38% of total final renewable energy use), solar power/heating (23%) and wind (18%). The rest of this section covers the main issues for each resource and for final use that could arise from deploying REmap 2030.

Wind

Wind power is the dominant renewable energy technology for power generation in REmap 2030 (92 TWh/year in 2030). Total installed capacity in 2030 would be 31 GW. Total installed capacity for onshore wind in 2013 (the most recent year for which data are available) is 1.7 GW (SENER, 2014a). This would require an average installation rate of 1.7 GW/year to realise the REmap 2030 potential. This would include exploiting 12 GW already estimated to be economically feasible by 2020 (IEA Wind, 2012), as developed in the Reference Case. It would include an additional 18 GW under REmap Options by 2030. Around 50% (9 GW) of these additions are considered cost-effective compared to power generation based on natural gas in 2030.

The area with the largest onshore wind resource is in the Isthmus of Tehuantepec in the state of Oaxaca where the economically feasible potential is calculated to be over 6 GW by 2020 (IEA Wind, 2012). La Rumorosa in the state of Baja California is another area with great resources. It benefits from more than 5 GW of potential that could be deployed (Secretariat of Economy, 2013). Exploitation of wind in these two regions would already represent a third of the total capacity targeted in REmap 2030.

Two obstacles need to be overcome. One is the need for transmission capacity both in zones with high wind potential and where investments are economically feasible. The second is the implementation of measures to integrate renewables into the power system. This will be partly influenced by how cost sharing is worked out for new connections and by grid expansion planning in new legislation. The new regulatory framework permitting the Mexican government to contract with private firms is expected to alleviate the challenges of integrating wind into the power grid.

Some measures have already been implemented to expand the grid. Transmission lines have been recently extended (IEA Wind, 2012) for the Isthmus of Tehuantepec under the open season scheme (see section 3). A subsequent open season round was run to add 2 GW of transmission capacity in this zone and over 3 GW in the Baja California and Tamaulipas states. This is still under construction, and is to be deployed in the next few years.

The subsystem for Baja California still lacks an interconnection with the national grid, despite a long-stated plan to complete one. At the moment, the first phase of the interconnection is due to be ready by 2017 (SENER, 2013a) but expected capacity will be limited to around 300 MW (SENER, 2012h). Challenges arising from local features in the landscape would also need to be accounted for in planning, since not all high resource areas will be easily accessible.

About 200 companies in Mexico are capable of supplying some of the components of wind turbines. Experienced engineering and construction firms (IEA Wind, 2012) in Mexico could become wind project developers or work on engineering, procurement and construction.

The government has created an inclusive national initiative for innovation in wind technology, the Mexican Centre for Energy Innovation in Wind (Centro Mexicano de Innovación en Energía). This is one of several energy innovation centres. This centre's main research areas include wind turbines, grid integration capacity development, aerodynamics and aeroelasticity, wind resource, artificial intelligence and mechatronics. The country's growing knowledge of both project and technology development will be essential to realise the large wind power potential.

Solar PV

In order to achieve the 30 GW of installed solar capacity proposed for REmap 2030, an average 1.5 GW needs to be installed each year between now and 2030. This installation rate is 15 times higher than for similar recent additions in Mexico. Specifically, annual additions of 1 GW are forecast to 2020, accelerating to 2 GW/year in 2020-2030. This would allow annual installations estimated at about 76 GW to make up 2-3% of total peak demand in 2030. This is half the level of around 5% seen in Germany in recent years. Experience in Germany showed that these levels can be reached without significant grid integration problems.

According to REmap 2030 estimates, distributed PV generation (rooftop solar and off-grid solar home systems could account for 11.3 GW – 7% of total 2030 generation capacity. Off-grid solar home systems to meet rural electrification needs will consist of less than 300 MW. If all the remainder were rooftop solar PV, panels would be needed for less than 10% of total building roof space. Opportunities will arise in new houses/buildings in particular. Given the large capacity of solar thermal already assumed for buildings in Mexico, it will be necessary to consider competition with solar thermal for roof availability. It is estimated that one in every six homes will have solar water heater systems by 2030. This falls to one in five if only households with firm rooftops are considered, as discussed below.

In 2010, there were three international solar PV module producers and two national companies assembling modules in Mexico. Total module production capacity of these manufacturers, operating at 84% capacity, was 275 MW. This was mostly aimed at the export market (Huacuz & Agredano, 2011; IEA, 2010). Total production capacity is now more than 300 MW, the highest among Latin American countries (Secretariat of Economy, 2013). Under these circumstances, 60% of solar PV modules needed to achieve REmap estimates will need to be imported (at least 90 million) unless local industry is developed to meet this demand.

Solar thermal

Solar thermal is now the third largest renewable heat resource after wood and sugar cane bagasse (SENER, 2013c). Yet current deployment is still low. In order to achieve long-term development in line with REmap 2030, particular issues need to be considered in the industry and buildings sectors.

The 14 GW solar thermal increase for manufacturing uses by 2030 starting from a very low base in 2010, means the annual installation of approximately 700 MW in solar thermal capacity in 2010-2030. Total solar thermal generation would represent more than 4% of industry's total heating demand. An IRENA study on the manufacturing industry (IRENA, 2014c) indicates around 45% of heat demand in industrial processes corresponds to low temperature heat that could be provided by solar thermal technologies. It estimates a techno-economic potential of about 3% worldwide for solar thermal. A slightly higher share for a country with high solar irradiation is thus found to be realistic. The potential estimated solar cooling in food production processes is less than 1% of total power demand in 2030. Assuming about 5-10 MW capacity per production plant, this would require about 1500-3000 production facilities to be equipped with solar thermal plants. Solar thermal heat has high installation costs, especially if built with concentrated solar thermal collectors. These are now partly subsidised by more general national financing programmes not specifically aimed at renewables developments. More targeted financing for renewables is one of the challenges to be resolved to fulfil the REmap potential.

Solar thermal energy in buildings for solar water heating systems is expected to experience significant growth even in the Reference Case. The economics of solar water heating systems are based on fuel savings. These are a function of the price of the fuel being replaced as well as installation costs. LPG is the main fuel used for water heating, while Mexico enjoys high solar irradiation. It already makes economic sense, therefore, to install solar thermosiphon systems for water heating.

Under REmap 2030, 23% of total energy demand for water heating (320 PJ) can be met by solar thermal energy.[51] This would imply adding 1.5 million m^2/year of collector area in 2015-2030 (a fivefold increase when compared to the 300 000 m^2 added in 2011) for a total cumulative capacity of 32 million m.[2] According to a CONUEE study, a solar thermal collector area of about 4 m^2 is enough for the average household (CONUEE, 2007). This would imply installing 370 000 solar water heaters per year in the residential sector in 2013-2030). This is equivalent to equipping 20% of all homes with a structurally sound roof with solar thermal (or approximately 5.5 million households) by 2030.[52] Around ten million new homes dwellings are expected to be constructed in 2010-2030. This creates the opportunity for direct solar water heater integration instead of retrofit.

Realizing this potential will mean embedding technology standards, certification and control of solar water heater systems and installation. This is necessary to assure quality performance and to attain maximum efficiency of installation. At present a wide range of systems exist with greatly varying quality and performance. On occasions, unqualified developers undertake projects.

Two barriers need to be overcome on the users' side. The first relates to awareness of the economic opportunity and benefits of solar water heating. The second concerns finance availability to facilitate initial investment by households. The government's 'green mortgage' programme in place since 2010 addresses this issue. It aims to promote the use of clean and efficient technologies in households, including water and energy services. Although it applies to all sectors, it is intended mainly for low-income families. These can make savings on their water and energy bills, reducing costs while protecting the environment (BSHF, n.d.). The programme provides both information and financial assistance to potential consumers of solar energy in end-use sectors for purposes other than power generation.[53]

If Mexico fulfils its distributed electricity and heating generation potential, 22% of the 38 million homes predicted for 2030 would have solar water heating systems and 10% would have solar PV rooftops by 2030.

Biomass

In REmap 2030, total primary biomass use reaches 810 PJ, which would exceed the low supply potential estimates of 600 PJ. In order to ensure that demand is met, Mexico may need to import biomass, reduce demand needs through energy efficiency programmes or deploy its full energy crop and forest wood potential. These two biomass sources are not fully considered in this low supply potential estimate. Energy crops, whose potential is excluded from this study, could have further potential for various uses in Mexico, either to generate power/heat or as feedstock for liquid biofuels production. However, the sustainability of energy crops is a major concern, as is the ever-present potential competition with food production for land and water resources.

Most biomass used for power generation is sugar cane bagasse used in the sugar industry. In 2013, this accounted for nearly 90% of all biomass power generation, followed by biogas power produced from agriculture, industry and urban residues (SENER, 2013b). Industrial CHP accounts for 50% of all biomass power generation in 2030. Half of this is from bagasse and the other half a mix of other solid biomass and waste. Today about half the total bagasse generated is used for power generation. REmap 2030 assumes that all bagasse generated would be efficiently utilised in industrial CHP plants.

Biomass use in buildings is virtually unchanged in 2030. However, there is a significant shift to more efficient biomass resource use in the most modern household woodfuel cook stoves and in improved earth ovens for charcoal production. The Reference Case still includes

51 Solar thermal for water heating in 2010 provided 3% of energy consumption.

52 This has been calculated using a 1.5% cumulative average growth rate in dwellings (SENER, 2013c), which generates the total number for households for 2030. This is a conservative estimate compared to the 2% historical cumulative average growth rate in 2000-2010 (INEGI, 2014). Structurally sound roofs, which are capable of accommodating solar water heating equipment, are estimated in 70% of homes (SENER, 2013b). If all households are considered, the total share of households with solar water heating declines to 15%.

53 The 'green mortgage' is a "housing finance scheme developed by the Institute for the National Workers' Housing Fund." Families purchasing homes using this fund are given an additional 'green' mortgage of up to USD 1250 to cover the cost of additional eco-technologies." This is a credit on top of the actual mortgage credit (BSHF, n.d.).

20% of traditional biomass use in buildings for cooking, while REmap 2030 requires all households burning wood to install efficient wood cook stoves. It is most likely that achieving 100% efficient biomass use will need a certain level of government intervention to provide information, training and technical assistance as well as financing. Several such government initiatives to promote the increased use of the most modern cook stoves are already underway[54].

Biomass use in transport under REmap 2030 is rather conservative. Studies assessing biomass resource potential estimate that the technical maximum sustainable potential[55] for dedicated energy crops for ethanol and biodiesel production amounts to 540 PJ and 180 PJ per year, respectively (REMBIO, 2011). In these studies, only 30% of sugar cane and sweet sorghum primary supply potential for bioethanol is exploited. In the case of biodiesel, 40% of palm oil and jatropha curcas potential would be utilised. Most of these dedicated energy crops are spread along the coast of the Gulf of Mexico, where flat land is accessible, and precipitation is favourable (REMBIO, 2011). The bioenergy supply chain will need to be improved by 2030. For liquid biofuels, production plants can be constructed close to feedstock sources. Since liquid biofuels will still need to be transported to demand centres, advanced biofuel plants producing high value biofuels will be needed to assure economic transport and profitability.

In REmap 2030, nearly 90% of the total biomass supply potential is related to agricultural residues and biogas. Agricultural activity and cattle breeding are spread across the country, but agricultural residues are mainly located in the western and northern regions. They will need to be transported for use in manufacturing located mainly in central and southern regions, at least in part for power co-generation. Transportation costs reported in the literature range from as low as USD 2-3/GJ. This may account for up to half the total supply costs of biomass transported in long distances. For local use of biomass and for short distance transportation, the contribution of transport costs to the total supply cost is much lower.

Biogas from animal manure is generated mainly in the northern and central parts of Mexico. It therefore has limited potential to replace traditional biomass use, centred mostly in Southern Mexico. A more likely replacement there will come from urban waste and local forestry residues.

Biomass supply potential needs to be fulfilled and a biomass market created to connect supply and demand in order to obtain the 810 PJ of primary biomass estimated under REmap Options for 2030.

Renewable electricity integration challenges

The development of renewable energy in the power sector will result in socio-economic and strategic benefits. There are also benefits to the power system, such as the increase in overall power supply security arising from grid expansion. At a certain level of penetration, distributed generation can have a positive impact on congestion due to changes in power flows. Nevertheless, deploying high shares of variable renewables in power systems poses simultaneous challenges to integration in the existing energy mix, grid connection, and system and market operation. These factors vary by country, and there is no one-size-fits-all solution for integrating renewable electricity into the power system.

Adequate long-term planning for grid development is essential to meet the wind and solar power generation potential under REmap 2030.

REmap 2030 is a macro-level analysis that provides technology options for Mexico to 2030. It does not model the power system as a whole. To accelerate renewable energy uptake in Mexico, REmap estimates need to be supported with system-wide modelling to understand how a share of variable renewable energy estimated at 26% of total power generation in 2030 can be accommodated in Mexico's power system. No quantitative studies have yet been completed to assess the impact of variable renewable energy in Mexico. This

54 These programmes have been in place for some decades already. They address different issues, such as the design of more efficient woodfuel cook stoves, awareness-raising programmes among users, training for construction and subsidizing the total or a share of the required investments (Masera, Díaz, & Berrueta, n.d.).

55 Sustainable supply is based on adequate land for harvesting each of the specified crops. It excludes land with food crops, areas covered by forest and tropical rainforests, natural conservation areas, terrain with gradients over 4-12% depending on the crop, and land that would require irrigation (REMBIO, 2011).

makes it difficult to estimate the effects of 26% of variable renewable energy on the power system. Some available measurements related to the impacts of variable renewable energy penetration in the system, particularly from wind, are included points below.[56] These are based on the experience of other countries whose renewable power penetration has reached significant levels. Putting REmap results into context will be particularly necessary for long-term power system planning in Mexico. They will determine optimal solutions to ensure security of generation supply, grid development and system balancing. This concerns interrelated requirements from long-term system adequacy until system reliability secures real-time system operation. This translates into having enough generation and transmission capacity in place to efficiently meet demand needs. System balancing covers unexpected disturbances, variability and forecast errors. The main challenges arising from these and creating corresponding solutions are summarised below.

1) To ensure generation adequacy, an adequate level of reserve margin[57] needs to be maintained, as electricity demand increases by 2030 and so will peak demand. It will therefore be necessary to have enough available firm generation capacity to cover peak demand, along with using other solutions such as demand-side management or larger interconnection capacity.

   Capacity credit/value is typically used when discussing available firm capacity. This is the value associated with the reliability of a technology to generate during peak load. It is expressed as a percentage of installed capacity to cover the peak load. Peak demand in 2012 reached 38 GW and is estimated at 77 GW in 2030[58] (SENER, 2013a).

   In Mexico, wind capacity credit can reach to 20-25% at low penetration levels (GIZ, 2014). Capacity credit decreases as penetration of wind power increases. In REmap 2030, penetration reaches 18%. Therefore, the capacity credit associated with this level of penetration could be set at around 10%. To maintain the reserve margin set in the Reference Case, a backup generation capacity of 6 GW would be needed. Assuming that this is built with gas, this implies an additional investment of around USD 300 million per year (less than 3% of total renewable energy investment needs of REmap 2030). This has not been considered in the cost/benefit analysis in REmap 2030.

   No capacity credit values were available for solar PV. Given the 13% penetration level for total installed solar PV, it can be expected that the additional costs for backup generation capacity will not be large when compared to total system costs. This is the case for wind.

   Appropriate market signals are needed to incentivise the construction of conventional power plants to reach the required reserve margin given the renewable energy share increase under REmap 2030. They would be needed to cover peak load, and would therefore experience lower hours of operation.

2) Transmission capacity expansion will have a major impact on integrating variable renewable energy into the grid. Additional transmission capacity will be needed for wind and solar PV in northern and western Mexico, sparsely populated areas remote from industrial activity. Effective transmission expansion planning will be necessary where supply and demand are far apart. Construction and investments required for new capacity can take a long time.

   IEA estimates the incremental costs of renewable integration into the grid at USD 2-13/MWh. This is a minor increase of 2-15% compared to LCOE for wind generation, to which costs of this type are allocated. Typically a transmission system operator (TSO) would consider three drivers for grid expansion: renewable interconnection, market condition improvement and supply security.

56 These results should be treated carefully as they are not representative of Mexico. Rather, they indicate the implications that other countries have had to take into account when integrating variable renewable energy.

57 The reserve margin is the difference between effective available capacity and peak demand, expressed as a percentage of peak demand.

58 Assuming the same in 2010 provided 3% of energy consumption. This has been calculated using a 1.5% cumulative average growth rate of 4.1% for peak demand in the national interconnected system based on SENER (2013a) forecasts for the 2012-2027 period

These are not necessarily driven by resources but they aim to meet consumer demand in the most reliable and affordable way. The grid is used by all types of power generation technologies. Hence, additional costs would be allocated among both conventional and renewable forms of power generation.

3) Grid codes will need to be defined on the services renewable power generators should provide to the network. Examples are fault ride-through capabilities,[59] reactive power supply or contribution to system operation with output and ramping[60] controls.

CENACE will need to cope with planning and operating more complex physical systems, including wind and solar PV generation forecasts. This is particularly important given challenges to ensure grid stability and potential balancing costs. Describing experience in other countries, IEA Wind Task 25 estimates the increase in short-term reserve requirements (from hourly to day-ahead) at a 20% penetration (Holttinen *et al.*, 2013). This is similar to Mexico. Requirements differ widely. They are 1% in Germany where forecast errors are considered one hour ahead. In the UK, where no forecasting is performed and the analysis considers variability[61] four hours ahead, they are as much as 19% Thus far, this increase in short-term reserves does not imply additional generation capacity. It is purely a matter of how existing power plants are utilised.

Balancing cost increases can be less than USD 1/MWh for a wind penetration of 20%, as is the case in Scandinavia. By contrast, they are almost USD 6/MWh in the US. These costs are minimal and would represent 1-7% of average onshore wind production costs.

59 This is an electrical device capability, especially for wind generators, and allows them to operate through periods of lower grid voltage.

60 Ramping is the ability to rapidly increase or decrease generating levels to maintain system stability when generation from other sources drops off unexpectedly.

61 The increment in short-term reserves significantly increases when no wind is forecast as part of system operation (Holttinen *et al.*, 2011). This should give an idea of the level of complexity and variation of these estimates for different power systems. This points to the need to carry out similar studies for Mexico.

4) It is important to adjust system and market operation rules to prevent them obstructing renewable energy incentives. These include curtailment rules, penalisation for deviations from committed supply, and unit commitment time windows.[62]

5) The technical adequacy of existing and future generation plant design needs to be assessed. This informs planning for particular plant types, such as highly efficient power plants or plants with more ramping flexibility – especially in the case of gas power. This is particularly important as PV will have a large share of capacity. In Mexico, this stops generating some time before the evening peak. It is therefore crucial to ensure the system has enough flexibility to handle high upward ramping needs. As most of this capacity in REmap 2030 is added to the Reference Case, it will be necessary to adjust long-term flexibility considerations to put optimal solutions in place.

To summarise, grid integration creates challenges. Flexible operational practices, flexible generation and demand side management are potential solutions. Important solutions relating to system operation include greater interconnection capacity and balancing areas, lower gate closure time frames, accurate forecasting systems, and subhourly dispatch schedule updates.

The high penetration of renewables in the power system in REmap 2030 will raise challenges related to generation supply, grid development and system balancing. The integration and related solutions will largely be a matter of adequate planning, and would not entail significant integration costs.

Given Mexico's large geographical area and dispersed communities, mini-grids and rural electrification will also play a crucial role. This will help limit grid integration challenges and transmission capacity expansion. In urban areas, distributed generation on building rooftops will also play a major role. Both of these have major potential under REmap 2030. The expected deployment of distributed generation will necessitate the management of new challenges related to distribution grid

62 Implementing shorter intervals for unit commitment and dispatch lowers the forecast errors.

operation. It will mean finding the best way to make use of electricity generated by self-suppliers. This includes the design of net-metering schemes, the potential use of storage etc.

Electrification

The REmap analysis showed that biomass resources in Mexico play an important role in increasing the renewable share. Bioenergy is responsible for more than a third of the additional potential, primarily in the end-use sectors. However, affordable and sustainable biomass sourcing remains an important question. Deploying alternative and complementary renewable energy resources can help reduce potential dependence on biomass.

Alternatives in heating are limited, especially for high temperature process heat generation in the manufacturing sector. Thus far, this has only been generated from biomass or fossil fuel. In the buildings sector, solar thermal, heat pumps and geothermal are alternatives to biomass, although onsite land availability, costs and access to resources could be constraints.

There are many options in the power sector. Solar PV, onshore/offshore wind, CSP, hydropower, geothermal and marine technologies all have further potential beyond the REmap 2030 estimates.

In the transport sector, liquid biofuels play the most important role in raising the sector's renewable energy share. Next to the use of biofuels, the contribution of EVs is substantial, providing around 40% of the additional renewable energy potential from a passenger-kilometre perspective. In REmap 2030 no additional modal shifts are assumed for transport beyond the Reference Case. However, electrification options are commercially viable and their deployment could be accelerated instead of or alongside liquid biofuels growth.

An additional set of REmap Options was created called REmap-E to further explore and clarify the additional electricity potential in end-use sectors. This considers a more radical electrification scheme than REmap 2030. It replaces most biomass with electricity from renewables. In REmap-E, three technology strategies are used to reduce biomass dependency and increase the share of electricity in end-use sectors. Heat pumps instead of biomass deliver the required heat in the buildings sector and low temperature process heat for industry. In the transport sector, modal shifts (public trams, electric buses and trains) replace liquid biofuels. The increased electricity demand from these end-use sectors is supplied by additional solar PV and on/offshore wind capacity. Additional solar PV and wind generation could also replace power that would otherwise have been generated by biomass.

In 2030, annual electricity demand rises from around 20 TWh to 27 TWh. This is the result of electrification in the manufacturing industry and a switch from biomass to heat pumps. In the transport sector a switch to different forms of electric mass transit results in an increased annual demand for electricity of 3 TWh. In buildings the increased use of heat pumps results in an additional annual electricity demand of 5 TWh.

In REmap-E, TFEC in 2030 is 6.8 EJ compared to 7.3 EJ in REmap 2030. This saving of almost 7% is due mainly to the higher technical efficiency of electrification technologies over combustion energy systems when viewed in terms of final energy. For example, the efficiency of a heat pump to deliver heat is three to four times higher than that of a steam boiler. Efficiency differences relating to modal shift are even higher. They may be as much as ten times higher when an electric tram is compared to an internal combustion engine. REmap-E results in almost 100 PJ less of renewables than REmap 2030 due to reduced biomass consumption. Yet the lower TFEC means the relative share of renewables is similar (20% versus 21%). This still amounts to a nearly fivefold increase in renewables share in 2010-2030.

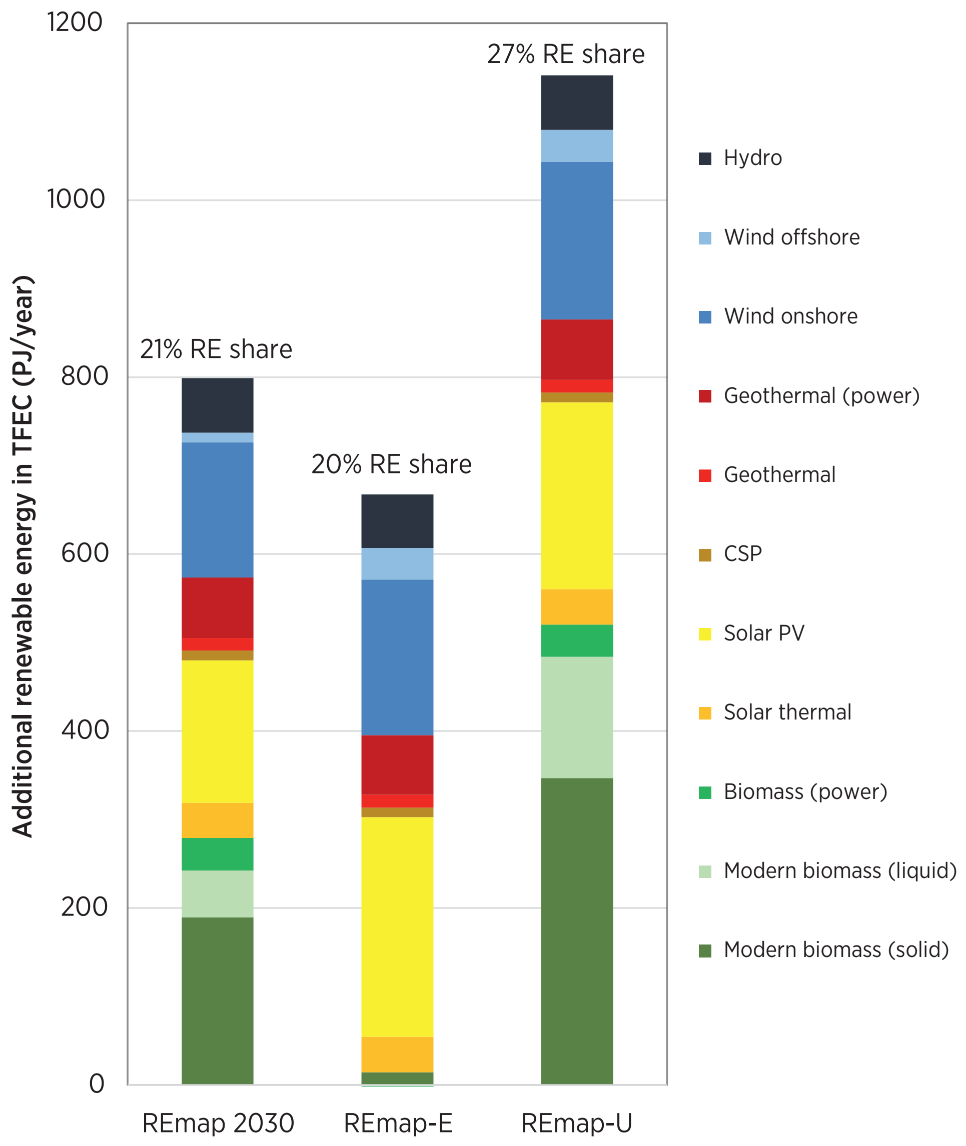
REmap-U presents an alternative case to REmap 2030. It assumes all countries approach a 30% renewable energy share by 2030 regardless of where they stand today. It does not include individual national goals, but assumes a broad mix of different renewable energy technologies. In their Reference Cases, some countries would need to substantially increase their renewable energy shares to approach 30%. However, others would meet or even exceed this level. Not all countries need to achieve exactly 30% to contribute to the global 30% renewable energy share in REmap-U is met. For instance, Mexico only achieves 27%.

A number of technology options and strategies are required to meet this global goal of 30%. According to REmap-U, the first strategy in all countries is to reduce energy demand by implementing energy efficiency measures. The reduction potential would differ for each country, varying with the growth of energy consumption and the present level and distribution of energy intensity. For Mexico, an energy saving potential of 5% was assumed over 2030 consumption levels.

The second strategy involves using increased electrification technologies in countries that do not achieve a 30% renewable energy share after both REmap Options and energy efficiency improvements are exhausted. This is the case for Mexico. The electrification technologies chosen for Mexico are those used in REmap-E. Finally to increase renewable energy even further, an annual increase in both solid and liquid biomass imports of around 240 PJ is assumed (wood fuel for heating and biofuels for transport). As shown in Figure 30, REmap-U takes the Mexican renewables share to 28%, a significant increase over the 21% in REmap 2030.

Figure 30 compares the renewable energy share in Mexico's energy mix of 2030 under three possible fu-

Figure 30: Renewable energy technology options under REmap 2030, REmap-E and REmap-U, 2030



tures for 2030. REmap 2030 and REmap-E are both specific to Mexico. REmap-U shows how a 30% renewable energy share could be achieved on a global basis if every country were to deploy even higher shares of renewables than envisaged in REmap 2030.

Figure 30 also shows only minor additions of biomass use in REmap-E. By contrast, the additions to solar PV (yellow bars), onshore and offshore wind are higher than under REmap 2030. This is due to electrification in end-use sectors. The total capacity of solar PV and wind reaches 25-30 GW and 38-42 GW, respectively in REmap-E. This also further raises the variable renewable energy share, implying that even more efforts will be required to ensure grid stability compared to REmap 2030.

The substitution costs of REmap-E and REmap-U are estimated to be somewhat higher than for REmap 2030. Among the three cases, REmap-E is the most expensive. Its cost depends on the mix of renewable power technologies employed to increase electrification, and on the potential need for supporting infrastructure. The cost increase is also driven by higher installation or infrastructure costs for electrification technologies (EVs, electric public transport and heat pumps). Under REmap-U, the cost of substitution is higher than under REmap 2030 but lower than under REmap-E. A lower increase in REmap-E total electrification is realised in REmap-U, and this explains the lower cost. In addition, the assumed energy efficiency improvements yield cost savings, since less renewable energy capacity is required.

8 BARRIERS AND OPPORTUNITIES FOR A RENEWABLE ENERGY TRANSITION

KEY POINTS

- In the last decade, Mexico had a strong preference for natural gas power plant construction. This trend can be altered in the future with policy support that improves the business case for renewables.

- The lack of transmission capacity in areas with high renewable energy resource potential has acted as one of the major obstacles to large-scale renewables deployment. The open season has started to alleviate this problem, and it is expected that investments in transmission will follow more easily now that energy reforms have been made.

- Renewable energy projects are in many cases not profitable. Prior to the reforms there were no economic incentives to promote the development of renewable energy technologies.

- Regulatory certainty underpins the foundation of a clear and transparent framework for power sector operation, particularly since the energy reforms.

The discussion that follows in this section introduces the main barriers encountered so far in renewable power development. This is practically the only sector that has made any headway so far. Renewables use in the heat and transport sectors was so far limited. By contrast, power generation is the main focus of renewable energy expansion in Mexico today. These barriers to renewable energy development need to be resolved in order to foster renewable energy uptake. Specific recommendations to overcome them are presented in the next section. It is worth mentioning that some of these are already the subject of provisions in the energy reforms. Once the liberalised energy markets are operational, some barriers not affected by new regulations may well be lowered. On the other hand, new barriers may arise.

Barriers and opportunities in the power sector

In the last 15 years Mexico has increasingly used natural gas for power generation instead of oil or coal. However, oil and gas reserves are diminishing, and imports continue to increase (EIA, 2013). This makes energy production from fossil fuels more expensive, and supply alternatives potentially more attractive. The 2013 energy reform opens the oil, gas and electricity markets to foreign and private investors and to alternative forms of generation, ending the monopolies of state-owned utilities PEMEX and CFE. This highlights the need to establish a transmission system operator that assures electricity market access to all generators.

Both the energy reform and national energy strategy stress the importance of creating mechanisms and incentives for renewable energy. They aim to create appropriate opportunities for renewables deployment in Mexico. However, low-priced natural gas power generation will continue to provide economically competitive, low-cost electricity. This paves the way for politically attractive tariffs but may limit investment in renewables deployment.

The CEC scheme described above is a leading measure designed to accelerate renewable energy development. In principle this scheme should encourage fossil fuel power replacement with renewables. Yet it is unclear how these certificates will work. This may now present problems given the dominance of CFE in the market at the moment. It is equally difficult now that the electricity market is being opened up, but for different reasons.

Historical developments also affect the future of renewables. Both fossil fuel and nuclear power plants have long plant life expectancy. In 2011, the average age of Mexico's coal and natural gas plants was 17 and 13 years, respectively. This reflects the strong preference for gas in new plant construction in the last decade. It is likely that little of the natural gas capacity added before 1980 (about 2.5 GW) can be retired by 2030, assuming a lifetime of 50 years. The coal capacity that can be retired by 2030 is about 6-7 GW. Hence, the replacement of fossil fuel power plants by renewable technologies in REmap 2030 does not assume fossil-fired capacity is retired early. Nonetheless planned retirements permit more than 2 GW of natural gas capacity to be included in REmap 2030.

In the last decade, Mexico had a strong preference for natural gas power plant construction. This trend can be altered in future with policy support that improves the business case for renewables.

One of the main obstacles to the development of large-scale renewable energy lies in the lack of transmission capacity in areas with high renewable resource potential. Grid expansion plans for both CFE and project developers have historically been blocked by legal restrictions on how CFE should carry out investment in new transmission. Project developers needed assured transmission availability to commit to building a plant. Under the prior regulatory framework in Mexico, plans for transmission expansion required up to ten years. This is longer than the time required for deploying an average power plant. Some provisions in the energy reform concern transmission expansion. It is therefore expected that transmission planning schedules will be more consistent with the needs of investors planning additional generating capacity, especially in renewable energy zones with high potential.

However, as noted in Section 3.2, nearly 2000 MW of wind power was deployed under the open season mechanism[63] (Wood, Lozano, Romero-Hernandez, & Romero-Hernandez, 2012). Before this, there were no clear and transparent rules on renewables grid connection and cost-sharing, which contributed to their limited deployment. Final rules have not yet been established, but should further direct these access and cost-sharing concerns to prevent discrimination. The Ministry of Energy will now develop transmission expansion plans in cooperation with CENACE and CRE. This will include long-run expansion plans based on the principles of sustainability and economic viability.

The government can now contract with private firms to extend, modernise, finance and/or operate its transmission projects, as well as modernise distribution networks. This eases the path of renewable energy deployment. New transmission lines can now be constructed either with federal funding or by private sector concession, thus relieving pressure on the federal budget.

Risk allocation is every bit as important to investors as cost-sharing. Risk allocation is a problem common to all IPPs. For this reason, project finance is often used for private investment in off-grid power generation. A few other financing arrangements to limit risk and guarantee profitability include long-term power contracts, high credit ratings for power contract offtakers and engineering, procurement and construction contracts with highly ranked firms. Some IPPs may seek to contract with a group of industrial users under the rubric of electricity generation associations. This permits larger and possibly more efficient projects that benefit from economies of scale and allow greater cost and risk-sharing.

The lack of transmission capacity in areas with high renewable energy resource potential has acted as one of the major obstacles to large-scale renewables deployment. The open season has started to alleviate this problem, and it is expected that investments in transmission will follow more easily now that energy reforms have been made.

Some non-utility and small-scale power projects may experience difficulties in qualifying for or negotiating reasonable finance despite the fact that installing these systems creates major energy savings. Even if the energy reform foresees a wholesale market, at least in the short to medium term, renewable energy developers would thus still tend to establish bilateral contracts assuring profitability. It is hoped that eventually they can compete on a more efficient basis.

Equally lacking is the public and political drive to comprehensively develop a national renewable power in-

63 See the part of "Transmission grids" in Section 3.2 for further details.

dustry. This would include a certain amount of domestic renewable generation component manufacturing and national renewable power technology development, particularly for wind and solar PV. Spain, Germany and Denmark have all taken this route (Juárez-Hernández & León, 2014). Equipment production capacity exists today to deliver technology and its components. However, this would not suffice to meet growing demand, even in the Reference Case, unless its growth were aligned with plans for future renewable energy development in Mexico. Staggering investments would be required for Mexico to build its own entire equipment supply industry capable of raising solar PV module production from 300 today to 90 million. However, it might also be appropriate to import a proportion of PV panels and at the same time continue to build system design and installation expertise at home.

Renewable energy development is slow for a number of reasons, including the fact that many projects simple are not profitable or cost-competitive when compared to conventional generation technologies or reference electricity prices. Only further improvements to its economic efficiency or new economic incentives will alter this. Renewable energy could not compete on cost prior to the energy reform, when regulations limited the potential for private investment in renewable power. Even after the reform, they still cannot compete. Only a few projects today are profitable. Some projects that acquire permits for construction and generation cannot not be deployed because they are not always economically viable without any further subsidy or financial support. Investorts would be reluctant to invest in schemes that do not return the investment profitably.

Renewable energy projects are in many cases unprofitable. Prior to the reforms there were no economic incentives to promote the development of renewable energy technologies.

Since the energy reform was enacted, new investments are on hold. This is due to uncertainty and lack of information about the rules of the wholesale market and specific regulations to be issued following the Electricity Industry Law and the Energy Transition Law. In every case, regulatory certainty is essential for clear and transparent framework underpinning power sector operations.

The above sections dealt with the general characteristics of Mexico's energy system today, some major administrative concerns, and particular cost and financing questions. All of these could create obstacles to renewable energy expansion. The next section discusses barriers to specific technologies, both by technology and by resource.

Regulatory certainty underpins the foundation of a clear and transparent framework for power sector operation, particularly since the energy reforms.

Wind

Wind power experienced the fastest growth in recent years, largely under self-supply schemes, as large energy-intensive companies find some of these projects economical. Nevertheless, much of the high quality resource potential identified remains untapped, mainly due to the lack of transmission capacity. The new regulations for expansion planning conferred on CENACE should help improve economic potential in windy regions.

Wind power plant construction, particularly in southern Mexico, has not always fully considered the interests of indigenous communities in the area. This has thwarted the construction of some approved wind projects. This is because information and consent on contracts, land lease agreements and compensations was withheld from local communities.

Solar PV

Solar PV technology is still under development, and its cost-competitiveness in most cases is limited. Nevertheless, solar PV electricity is used in some projects in Mexico. As of 2013, distributed PV capacity made up 40% of total installed solar PV capacity, or around 26 MW.

One of the main barriers to further penetration of distributed PV has been the lack of awareness among both types of users. People in towns may lack information on the benefits of solar PV rooftop installation, including potential energy bill savings. Meanwhile, rural and off-grid communities may lack information about the possibilities for off-grid or mini-grid electrification. Net-metering is included in the incentives remaining after the energy reform. This emphasises the need to draw up a specific plan for deploying smart grids to increase the beneficial services self-suppliers can provide to the system. This would help cut down barriers to rooftop solar PV.

Biomass

Supply constraints are the main barrier to power or heat generation from biomass. This starts with the complex and slow procedures for authorizing wood resource exploitation (REMBIO, 2011). Owners of wood resources, particularly in community schemes, do not have the training and organisation required to carry out the necessary studies to apply for wood exploitation permits. They may need to bear the extra cost of contracting services from third parties.

Another barrier is the high cost of long-distance transport, often making biomass unprofitable. This is exacerbated by the limited range of technologies for processing solid biomass. These need to be capable of producing biomass (chips, pellets etc.) with high calorific value, and would make transport more economical. At present there is a lack of finance for technology adaptations of this type in Mexico (REMBIO, 2011). Agriculture residues are susceptible to uncertainties due to variable seasonal availability. They may also be diverted to other non-energy uses such as fertilisers or livestock feed (REMBIO, 2011). Forest resource management in most parts of Latin America needs to improve, as Central America has the weakest record in sustainable forest management (FAO, 2010) in the world. Mexico has made substantial progress against deforestation. However, this is still a critical issue if further natural resource degradation is to be avoided and sustainable feedstock supply improved.

Action needs to be taken to stimulate demand as well as sustainable and affordable biomass supply. Without clear and appropriate policies and targets, Mexico's end-use sectors will easily continue to rely on fossil fuels. Hence realistic target-setting and new policies are required to take full advantage of this growing potential market for biomass and other renewables.

Geothermal

The main barrier to geothermal energy development is the high exploration costs, especially those associated with perforating wells needed to assess the technical and economic potential of estimated resources.

Private geothermal development is now feasible. Prior to the energy reform, geothermal exploration and production were reserved exclusively for the state, and private participation was restricted to obtaining concessions. Environmental standards for water quality were not clear or conducive to geothermal development. The Geothermal Energy Law enacted as part of the energy reform drew a distinction between geothermal and drinking water supplies. It set a framework for private entities to explore and exploit geothermal resources. This will create a new opportunity for geothermal energy deployment.

Small hydropower

Small hydropower projects face several barriers. One example is the lack of reliable assessments of generation potential. Another is high hydrological uncertainty caused by the lack of adequate basic meteorological and hydrometric information.

Administration and red tape gets in the way of permit acquisition for small hydropower projects. This is coupled with requirements for preliminary and feasibility studies, and long and complex multiple licensing procedures with federal, state and municipal authorities. The cost of adequate pre-feasibility studies is another concern, yet such studies are absolutely critical to clarifying the economic and environmental viability of a project before making an investment.

9 SUGGESTIONS FOR ACCELERATED RENEWABLE ENERGY UPTAKE

This report has discussed the present energy situation, existing policy framework and barriers to renewables in Mexico. It has identified the potential to raise Mexico's renewable energy share to 21% of TFEC by 2030. Based on these findings, this section provides a list of policy recommendations in five areas after consulting the national experts. They are listed below.

- establishing transition pathways for renewable energy
- creating an enabling business environment
- ensuring smooth renewables integration into the system
- creating and managing knowledge
- unleashing innovation

Planning transition pathways

Renewable energy development and use is a high priority for Mexico. The government has set clean energy generation and GHG emission reductions targets. The goals mandated by law for clean energy in the power sector are as follows:

1) no more than 65% supply of total power generation using fossil fuels by 2024
2) a 40% minimum of total electricity from clean energy by 2035
3) no more than 65% supply of total power generation using fossil fuels by 2050.

The first national targets for electricity generation by the various renewable sources were established by the Special Programme for the Development of Renewable Energies 2009-12 and 2014-18.

The national energy strategy is the main instrument for long-term planning in Mexico's energy sector, prepared jointly by the National Energy Board (Consejo Nacional de Energía (CNE) and its Advisory Forum. It is subject to approval by Congress. By law, this document is updated every year, always with a 15 year time horizon.

Mexico's energy policy went through a fundamental redesign at the end of 2013, and a progressive policy was put in place to accelerate renewable energy growth in the power sector. The present study shows there is potential to raise the share of modern renewable energy to 21% in TFEC by 2030.

Mexico is actively pursuing clean energy policies, mainly in the power sector, but this means overcoming an array of challenges and barriers. Long-term planning for the transmission grid is a major issue, especially as some of the additional renewables potential is in areas distant from the main national interconnected system. Moreover, annual installation rates for different technologies estimated according to REmap 2030 are significant. Equipment needs and the time required to install these capacities should be planned in tandem with related infrastructure development. This is especially important given the long distances between solar and wind resources and demand centres. Mexico has limited capacity of equipment manufacture today, a large share of which is geared for export. At the same time, Mexico imports a fair share of its renewables plant components. With the anticipated growth in demand for new equipment, it is hoped that domestic supply industries will broaden out, and that this trade balance will change. However, this will require massive investment. Policies and planning will be essential to developing competitive local players in the global market that base their growth on innovation and a skilled workforce.

A complete transition to clean energy needs to cover both the power and end-use sectors. As REmap 2030 demonstrates, end-use sectors also show major renewable energy potential. Three quarters of Mexico's TFEC is still related to energy use for heating and transport. Decisive investments in renewable technologies for end-use applications are increasingly possible as businesses invest in new manufacturing capacity, building stock and new kinds of passenger vehicles. But appropriate policies and incentives are needed to take advantage of this growing potential market.

A considerable share of total renewable energy use in 2030 will rely on modern forms of biomass, which can meet multiple industrial and residential energy needs. Under Remap 2030, the traditional biomass predominantly used for cooking and water heating in Mexico will be fully upgraded. The findings of this report yield the suggestions listed below for planning transition pathways to 2030 in Mexico.

These incentives and special arrangements should in principle only work during a transitional period and should not create a permanently privileged class of energy producers. The final objective is a permanently competitive and profitable renewables industry.

Recommendations

- Ensure that the Special Program for the Use of Renewable Energy targets is pursued as a first step to realizing REmap 2030 potential.
- Develop an adequate, ambitious and timely electricity transmission plan that guarantees potential renewable power deployment.
- Reinforce the recently enacted Geothermal Energy Law with appropriate requirements for sustainable long-term geothermal resource exploitation, incorporating the vast experience developed in geothermal exploitation by CFE.
- Incentivise industry development to improve local expertise and increase the national supply of renewable energy technology components and equipment.
- Expand the current short-term modern cook stove programme to a long-term strategy to accelerate the full replacement of traditional biomass, with an emphasis on financing schemes for low-income users.
- Set more ambitious liquid biofuels targets and create programmes to create a business case for EVs.
- Set up a supportive policy, planning and regulatory framework to foster significant and affordable biomass supply for industrial CHP and solar water heating.
- Foster and extend policies that ensure the sustainable development and use of biomass resources.
- Integrate green energy policies in regulations for new buildings construction to facilitate the extended adoption of PV and solar water heating in this sector.

Creating an enabling business environment

Policy support to improve the cost-effectiveness of renewable energy technologies is a key step in supporting their deployment during the transition period from now until 2030. Improving cost-effectiveness can start with the efficient reduction and allocation of costs and risks and the related uncertainties in renewable energy investments. Policy frameworks that create appropriate conditions conducive to efficient investment will increase the confidence of investors implementing projects and attracting sources of finance at both national and international levels. The most important considerations in the long run are the need for efficient investment and for renewable energy to truly compete with fossil fuels without special considerations on either side. Until such conditions predominate, a number of measures could be taken during the transition period to increase renewable energy attractiveness and engineer a larger renewables market share by targeted policy choices.

It will be important to ensure adequate conditions are created for integrating small-scale projects into the market and for diversifying ownership structure in the energy sector. This will create local jobs and benefit consumers. The financing challenges for smaller capacity projects will need to be resolved in the short term as an increasing share of investments is likely to be needed for such capacity.

Appropriate subsidies are a sensitive issue when defining the business environment. At the moment, diesel and petrol used in transport, LPG, some renewables and most electricity tariffs are in some way subsidised. A policy rationale of some kind has been used to justify each of these subsidies. For a country trying to expand renewable energy deployment, the balance of existing subsidies is a matter of concern. The government is planning to revise its subsidies. If this revision results in an economic balance, as considered in the REmap 2030 business perspective, this would make a significant impact on the business case for renewables in Mexico.

Recommendations

- Through effective economic, financial and/or fiscal incentives, establish a market where renewables are cost-competitive to realise the medium and long-term renewable energy objectives (*i.e.* clean energy targets to 2018, 2024 etc.)
- Ensure that the recently created CEC scheme is fully up and running and effective to achieve the targets set.
- Design power exchange rules that support the efficient participation of renewable energy generators and ensure grid access for all technologies.
- Draw up adequate rules for grid connection, access and cost-sharing to guarantee renewable power development.
- Ensure that clear and publicly available information on administrative procedures for renewable energy development is effectively communicated across the whole stakeholder spectrum.

Ensuring smooth integration of renewables into the system

Particular attention needs to be paid to the large-scale integration of different renewable energy technologies in different sectors. Three main challenges emerge here. The first is the high share of variable renewables (wind and solar PV) reaching about 25% of total power generation in REmap 2030. The second is the high share of distributed solar PV capacity and solar thermal that would require planning for the most effective use of rooftops on Mexican buildings. The third is related to ensuring an fully operational supply of modern biomass, and its substitution for traditional biomass use.

Expanding transmission capacity will be essential to deliver utility-scale generation from remote northern areas rich in resources to demand hubs in central and southern Mexico. Infrastructure related to grid integration of variable renewables in Mexico has not been studied in detail using power system models. This will need to be rectified in the years to come as the share of variable renewables grows. Technological solutions, suitable measures and the requisite policy support appropriate to Mexico's specific character need to be better understood.

REmap 2030 estimates that up to three out of ten roofs in Mexico by 2030 would need to be covered by either a solar PV or solar water heating unit. This is an ambitious share. However, if the right policy support and planning is provided, and space efficiently shared between the two technologies, it can be realised for new build between now and 2030.

Mexico's total renewable energy mix does not include much modern biomass. However, REmap 2030 shows that it could account for one third of the total renewable energy use. Some of this is due to the substitution of traditional biomass use with modern solid biomass and biogas. The other factor is combined process heat and power generation in the manufacturing industry or in stand-alone separate heat and power generation systems. This level of demand for modern biomass applications does not exist in Mexico at the moment. Effective and efficient use of modern biomass is largely limited to plants whose byproducts are used on site (*e.g.,* bagasse). Unless new policies are put in place, the cost-effective potential estimated in 2030 would most likely not be deployed. Policies are also needed on the supply side to address sustainable and affordable biomass sourcing. The supply potential of bioenergy, limited to biogas and a mix of agricultural and forest residues, has been conservatively estimated. It would be grossly insufficient to fully utilise the estimated volume of biomass use potential by 2030 identified in this study. Instead, dedicated and sustainably grown energy crops would need to supplement this residue supply potential. This in turn would require an integrated policy approach starting from water and land use planning to changing agricultural practices. Policies would need to orchestrate input from a variety of industries producing relevant byproducts. Another strategy to make the best use of limited biomass supply potential is to reduce thermal energy demand by improving energy efficiency or to increase the efficiency of renewable electricity technology alternatives.

Recommendations

- Build grid infrastructure that can accommodate variable renewable energy shares up to 26%, and secure the necessary financing for this task.
- Set clear rules for power system operation, including grid codes, rules for dispatch and curtail-

ment, ancillary services etc. that foster better renewables deployment and dispatch.

- Adjust power system operational practices to give greater flexibility, implementing accurate renewable generation forecast systems, shorter gate closure timeframes, larger balancing areas and subhourly updates of dispatch schedules.
- Ensure the isolated Baja California and Baja California Sur power systems are connected to the national grid to make their solar and wind potential fully available.
- Strengthen decentralised power generation through appropriate legislative frameworks. These need to allow diverse ownership structures and self-supplier involvement, simplified administrative procedures, net-metering/billing schemes and advanced metering infrastructure.
- Draw up legislation and power market rules that allow new players to participate in the energy service market, permitting aggregation of generation, demand-side and storage.
- Develop a working biomass feedstock market to ensure sustainable and affordable supply by considering the nexus between sectors that (jointly) produce, transport and use these feedstocks. Develop the infrastructure to utilise the major biogas potential to its full extent locally.

Creating and managing knowledge

Mexico is beginning to shape its energy system so that it accepts more renewables. Policy changes and long-term targets give great hope that Mexico's large solar, wind and bioenergy potential will be significantly utilised. However, the sustainable transition to renewable energy, planning for renewables integration, and the creation of a business environment conducive to renewables require good knowledge management. This means modern intelligence on renewable technologies, market conditions and economic realities alongside well-managed research. Knowledge and analysis of this calibre is required for the entire renewables value chain. This ranges from resource to impact assessments on the environment or the economy.

Recommendations

- Improve awareness of potential renewable energy use and energy efficiency in buildings among manufacturers, users and project developers/installers.
- Develop a network integrating capacity-building skills and human resources, linking and expanding the science/technology/business axis.
- Develop power system models incorporating higher shares of variable renewable energy in power generation, transmission and system operation. This yields an understanding of the optimal solutions for ensuring security of power generation supply in the long and short term.
- Critically assess the socio-economic and environmental impacts of renewable energy projects, and communicate this clearly to all stakeholders.
- Embed technology standards, certification and control for component and equipment supply and installation.
- Improve the assessment of renewable energy potential presented in INERE to ensure the best data available by accounting for technical, economic and sustainability constraints.

Unleashing innovation

Under REmap 2030, Mexico's modern renewable energy share can reach 21% with existing technologies. This compares with 4.4% for 2010. This is an impressive growth potential, especially since it can be reached using existing technologies alone. However, there is no guarantee that 21% will be attained by 2030, which in any case is not the final goal. There is potential to exceed this. Technology innovation will play a key role in realizing the REmap 2030 potential. Innovation can lead to new technologies with more efficient processes, enduring and better quality equipment that can help improve the profitability of renewable energy projects. Technology innovation can also help commercialise new and emerging renewable energy alternatives like advanced biofuels or energy and wood crops in various end-use applications. Little or no potential for these has been identified thus far.

Recommendations

- Improve government support for innovation, research and development to cut renewable energy costs and improve technical efficiencies.
- Provide incentives for research and development in renewables and extend the Energy Sustainability Fund (Fondo Sectorial en Sustentabilidad Energética, FSE) to exploit capacity building and innovation in renewable energy
- Continue consolidating partnerships for innovation in wind, solar and geothermal.
- Promote the activities of the various Mexican Energy Innovation Centres. These investigate scientific and technological solutions for administrative, logistical and economic problems affecting sustainable energy expansion in Mexico.
- Develop technologies to increase sustainable energy crops and forest wood supply.
- Improve energy efficiency and the electrification of end-use sectors to reduce dependency on biomass.

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LIST OF ABBREVIATIONS

Abbreviation	Description
°C	degrees Celsius
AD	anaerobic digestion
ASEA	National Safety, Energy and Environmental Agency (Agencia de Seguridad, Energía y Ambiente)
ANSIPA	National Agency of Industrial Safety and Environmental Protection for the Hydrocarbon Sector Act (Agencia Nacional de Seguridad Industrial y de Protección al Medio Ambiente del Sector Hidrocarburos)
APEC	Asia-Pacific Economic Cooperation
bbl	barrel
BoE	barrel of oil equivalent
CCGT	combined cycle gas turbine
CCS	carbon capture and storage
CEC	clean energy certificate
CEMIE	Mexican Centre for Wind Energy Innovation (Centro Mexicano de Innovación en Energía)
CENACE	National Center for Energy Control (Centro Nacional de Control de Energía)
CEPAL	Economic Commission for Latin America and the Caribbean
CF	capacity factor
CFE	Federal Electricity Commission (Comisión Federal de Electricidad)
CHP	combined heat and power
CNE	National Energy Board (Consejo Nacional de Energía)
CO_2	carbon dioxide
CONACYT	National Council for Science and Technology (Consejo Nacional de Ciencia y Tecnología)
CONUEE	National Commission for Efficient Energy Use (Comisión Nacional para el Uso Eficiente de la Energía)
CRE	Regulatory Energy Commission (Comisión Reguladora de Energía)
CSP	concentrated solar power
CTCP	total short-term cost (costo total de corto plazo)
DAC	residential high consumption electricity tariff (doméstico de alto consumo)
DOF	Federal Official Gazette (Diario Oficial de la Federación)
EIA	Energy Information Administration
EJ	exajoule
EPC	Engineering, procurement and construction
ETC	evacuated tube collector
EU	European Union
EV	electric vehicle
FOTEASE	Fund for Energy Transition and Sustainable Use of Energy (Fondo para la Transición Energética y el Aprovechamiento Sustentable de la Energía)
FPC	flat plate collector

Abbreviation	Description
FSE	Energy Sustainability Fund (Fondo Sectorial en Sustentabilidad Energética)
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies
Gcal	gigacalories
GDP	gross domestic product
GHG	greenhouse gas
GHI	global horizontal irradiation
GIS	Geographical Informations System
GIZ	German Federal Enterprise for International Cooperation (Deutsche Gesellschaft für Interna-tionale Zusammenarbeit)
GJ	gigajoule
Gt	gigatonne
GW	gigawatt
GW_e	gigawatt-electric
GW_{th}	gigawatt-thermal
HHV	higher heating value
IDB	Inter-American Development Bank
IEA	International Energy Agency
IGCC	integrated gasification combined cycle
IIASA GAINS	International Institute for Applied Systems Analysis (IIASA) Greenhouse Gas and Air Pollution Interaction and Synergies (GAINS)
IIE	Electric power research institute (Instituto de Investigaciones Eléctricas)
INEGI	National Institute of Statistics and Geography (Instituto Nacional de Estadística y Geografía)
INERE	National Renewable Energy Inventory (Inventario Nacional de Energías Renovables)
INFONAVIT	National Workers’ Housing Fund (Instituto del Fondo Nacional de la Vivienda para los Traba-jadores)
IPCC	Intergovernmental Panel on Climate Change
IPP	independent power producer
IRENA	International Renewable Energy Agency
ISO	independent system operator
km	kilometre
kt	kilotonne
kV	kilovolt
kW	kilowatt
kW_e	kilowatt-electric
kWh	kilowatt-hour
LAERFTE	Law for the Use of Renewable Energies and the Financing for the Energy Transition (Ley para el Aprovechamiento de las Energías Renovables y el Financiamiento de la Transición Energé-tica)
LANSIPA	National Agency of Industrial Safety and Environmental Protection for the Hydrocarbon Sector Act (Ley de la Agencia Nacional de Seguridad Industrial y de Protección al Medio Ambiente del Sector Hidrocarburos)
LCOE	levelised cost of electricity
LHV	lower heating value

Abbreviation	Description
LIE	Electricity Industry Law (Ley de la Industria Eléctrica)
LNG	liquefied natural gas
LPDB	Bioenergy Law (Ley de Promoción y Desarrollo de los Bioenergéticos)
LPG	liquefied petroleum gas
LORCME	Coordinated Energy Regulators Act (Ley de los Órganos Reguladores Coordinados en Materia Energética)
m^2	square metre
MATS	Mercury and Air Toxics Standard
MBtu	million British thermal units
Mln	million
MCF	thousand cubic feet
Mt	megatonne
MW	megawatt
MW_e	megawatt-electric
MWh	megawatt-hour
MW_{th}	megawatt-thermal
MXN	Mexican peso
NO_x	mono-nitrogen oxide
O&M	operation and maintenance
OECD	Organization for Economic Co-operation and Development
p-km	passenger-kilometre
t-km	tonnes-kilometre
PEAER	Special Program for the Use of Renewable Energy (Programa Especial para el Aprovechami-ento de Energías Renovables)
PEMEX	Mexican Petrolums (Petróleos Mexicanos)
PHEV	plug-in hybrid electric vehicles
PJ	petajoule
PM	particulate matter
PPA	Power Purchase Agreement
PTC	Parabolic trough collector
PV	photovoltaic
R&D	research and development
RD&D	research, development and deployment
REMBIO	Mexican Network for Bioenergy (Red Mexicana de Bioenergía)
SAGARPA	Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food (Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación)
SE4All	Sustainable Energy for All
SEMARNAT	Secretariat of Environment and Natural Resources (Secretaría de Medio Ambiente y Recursos Naturales)
SENER	Ministry of Energy (Secretaría de Energía)
SHS	solar home system

Abbreviation	Description
SIEPAC	Central American Electrical Interconnection System (Sistema de Interconexión Eléctrica de los Países de América Central)
SO_2	sulphur dioxide
SWH	solar water heating
TFC	total final consumption
TFEC	total final energy consumption
TJ	terajoule
toe	tonnes of oil equivalent
TPED	total primary energy demand
TSO	transmission system operator
TWh	terawatt-hour
UN	United Nations
USD	United States dollar
VRE	variable renewable energy
yr	year

ANNEX A:

Energy prices

Commodity	National energy price in 2030
Crude oil (USD/GJ)	21.9
Steam coal (USD/GJ)	4.4
Electricity (buildings) (USD/kWh)	0.19
Electricity (industry) (USD/kWh)	0.10
LPG (buildings) (USD/GJ)	19.3
Natural gas (power generation) (USD/GJ)	7.3
Petroleum products (fuel oil) (USD/GJ)	12.1
Diesel (USD/GJ)	33.0
Gasoline (USD/GJ)	27.9
Kerosene (USD/GJ)	43.6
Biodiesel (USD/GJ)	37.5
Conventional bioethanol (USD/GJ)	31.4
Second generation bioethanol (USD/GJ)	29.7
Biokerosene (USD/GJ)	52.6
Primary biomass (forest surplus) (USD/GJ)	9.3
Biomass residues (harvesting residue) (USD/GJ)	4.6
Biomass residues (processing residue/biogas) (USD/GJ)	2.4
Biomass residues (wood waste) (USD/GJ)	3.3
Traditional biomass (USD/GJ)	1.5
Nuclear fuel (USD/GJ)	0.5
Discount rate (%)	10

ANNEX B:

Technology portfolio

	Renewable energy deployment	Reference Case	REmap 2030
Power sector (incl. CHP) (TWh/year)	Total electricity production	602	610
	Hydropower	52	72
	Geothermal	9	32
	Solar PV	13	65
	CSP	0.01	4
	Wind	38	92
	Bioenergy	4	15
Industry (PJ/year)	Total consumption	2450	2448
	Electricity consumption	1243	1244
	Bioenergy	25	200
	Solar thermal	13	59
Transport (PJ/year)	Total consumption	3278	3276
	Electricity consumption	13	18
	Liquid & gaseous biofuels	75	128
Buildings (PJ/year)	Total consumption	1475	1434
	Electricity consumption	548	541
	Bioenergy (modern biomass)	216	230
	Solar thermal	70	80

ANNEX C:

Data for cost-supply curve from the business and the government perspective

Business perspective

REmap Option	Potential (TJ /year)	Substitution cost (USD_{2010}/GJ TFEC)
Water heating: solar (thermosiphon)	6,300	-19.4
Self-suppliers, CHP electricity part (solid biomass)	28 027	-9.5
Geothermal	65 507	-9.0
Solar thermal	30 000	-8.1
Biomass co-firing (retrofit)	10 838	-6.9
Solar cooling	180	-5.6
Cooking biogas from anaerobic digestion	4 250	-4.6
Geothermal heat	14 358	-4.2
Self-suppliers, CHP heat part (solid biomass)	117 253	-2.8
Solid cooking biomass	10 250	-1.4
Solar PV (utility)	107 594	-0.7
Wind onshore (efficient)	82 814	-0.6
Biomass boilers	58 000	0.7
Solar thermal	15 000	1.3
Second generation bioethanol (passenger road vehicles)	16 601	2.5
Large hydropower	59 118	3.3
First generation bioethanol (passenger road vehicles)	16 601	4.1
Biodiesel (passenger road vehicles)	19 286	4.5
Onshore wind	63 880	5.1
Biofuels (passenger aviation)	422	9.0
Solar PV (residential/commercial)	46 810	9.1
Offshore wind	10 357	13.8
PHEV	2 389	16.1
Solar CSP PTC no storage	10 485	20.4
Self-suppliers: solar	3 562	30.0
Self-suppliers: offgrid PV	1 189	48.5
Battery electric two-wheeler (passenger road vehicle)	10	57.5

Note: 1 TJ = 1 000 GJ; 1 MWh = 3.6 GJ

Government perspective

REmap option	Potential (TJ /year)	Substitution cost (USD_{2010}/GJ TFEC)
Solar water heating (buildings)	6 300	-14.4
Solar thermal heat (industry)	30 000	-13.3
Self-suppliers, CHP electricity (solid biomass)	28 027	-11.3
Biomass co-firing (retrofit)	10 838	-9.9
Geothermal heat	14 358	-9.3
Geothermal power	65 507	-9.2
Self-suppliers, CHP heat (solid biomass)	117 253	-8.0
Biofuels (passenger aviation)	422	-6.3
Biodiesel (passenger road vehicles)	19 286	-5.8
Concentrated solar thermal	15 000	-3.8
Cooking biogas	4 250	-3.6
Solar cooling (industry)	180	-3.3
Second generation bioethanol (passenger road vehicles)	16 601	-3.1
Cooking biomass (solid)	10 250	-1.3
First generation bioethanol (passenger road vehicles)	16 601	-1.1
Solar PV (utility)	107 594	-1.1
Wind onshore (efficient, CF: 35%)	82 814	-1.0
Biomass boilers	58 000	0.7
Large hydropower	59 118	3.0
Onshore wind	63 880	4.7
Solar PV (residential/commercial)	46 810	8.7
PHEV	2 389	11.8
Offshore wind (CF: 27%)	10 357	13.5
Solar CSP without storage	10 485	20.2
Space cooling: solar	3 562	30.0
Self-suppliers, offgrid PV	1 189	38.1
Battery electric two-wheeler	10	45.1

Note: 1 TJ = 1 000 GJ; 1 MWh = 3.6 GJ

ANNEX D:

Overview of production cost of end-use renewable energy and conventional technologies in 2030, business perspective

	Renewable		Fossil	
		USD/GJ		USD/GJ
Industry	Self-suppliers, CHP electricity part (solid biomass, residues)	11.7	Natural gas (steam boiler)	8.2
Industry	Self-suppliers, CHP heat (solid biomass, residues)	11.8	Coal (furnace)	5.9
Industry	Solar thermal	7.2	Petroleum products (steam boiler)	15.3
Industry	Solar thermal	16.4		
Industry	Solar cooling	21.1		
Industry	Geothermal heat	11.1		
Industry	Biomass boilers	6.8		
Buildings	Water heating: solar (thermosiphon)	4.4	Water heating: petroleum products (boiler)	15.4
Buildings	Space cooling: solar	30.0	Space cooling: air conditioner	30.0
Buildings	Cooking biogas from anaerobic digestion	6.7	Cooking traditional biomass	16.4
Buildings	Cooking biomass (solid)	11.8		
		USD/p or t-km		USD/p or t-km
Transport	First generation bioethanol (passenger road vehicles)	0.51	Petroleum products (passenger road vehicles)	0.51
Transport	Second generation bioethanol (passenger road vehicles)	0.51	Petroleum products (passenger road – diesel)	0.54
Transport	Biodiesel (passenger road vehicles)	0.55	Petroleum products two-wheeler (passenger road vehicle)	0.25
Transport	Biokerosene	0.34	Petroleum products (passenger aviation)	0.29
Transport	PHEV	0.52		
Transport	Battery electric two-wheeler	0.25		

Note: 1 MWh = 3.6 GJ

ANNEX E:

Capital and operation and maintenance costs

	Capital costs 2030 (USD/kW)	Operation and maintenance costs 2030 (USD/kW/yr)	Capacity factor 2030 (%, cap)	Efficiency %
POWER				
Renewables				
Large hydropower	2400	30	35	100
Onshore wind	1500	66	27/35	100
Offshore wind	3280	94	40	100
Solar PV (rooftop)	1650	16	20	100
Solar PV (utility)	1500	15	27	100
Solar PV home systems (off-grid)	4000	40	16	100
Solar CSP, no storage	3500	35	27	40
Biomass co-firing	530	53	40	42
Geothermal	3000	135	80	18
Conventional				
Coal	2170	87	60	42
Natural gas	1000	40	70	50
Diesel (gen-set)	2120	53	65	42
INDUSTRY				
Renewables				
Electricity				
Solid biomass – CHP	692	17	50	80
Solar cooling	1060	16	20	100
Heat				
Solar thermal	175	10	13	100
Concentrated solar thermal	490	50	20	100
Biomass boiler	580	15	85	88
Geothermal (heat)	1500	38	55	100
Conventional				
Heat				
Coal (furnace)	200	5	85	90
Petroleum products (boiler)	200	5	85	85
BUILDINGS				
Renewables				
Heat				
Solar thermal (thermosiphon)	100	4	13	100
Solar cooling	1200	12	7	250
Biogas cooking	40	1	10	48
Biomass cooking	15	0.5	10	30
Conventional				
Heat				
Water heating: LPG	175	6	85	85
Space cooling: air conditioner	550	14	15	250
Traditional biomass cooking	10	0.25	10	10

ANNEX F:

Detailed roadmap table

	2010	Reference Case 2030	REmap 2030
Total primary energy supply (PJ/year)			
Coal	436	502	193
Oil	3 166	4 261	4 017
Gas	1 652	4 538	3 566
Nuclear	64	286	286
Hydropower	132	168	240
Traditional biomass	259	51	0
Modern bioenergy (incl. biogas, biofuels)	102	379	681
Solar thermal	4.9	84	162
Solar PV	3.6	468	656
Wind	4.5	151	342
Geothermal	150	210	461
Total	5 974	11 090	10 603
Total final energy consumption (PJ/year)			
Coal	149	75	19
Oil	2 743	4 216	3 975
Gas	529	800	792
Traditional biomass	259	51	0
Modern biomass (solid)	38	241	431
Modern biomass (liquid)	17	75	128
Solar thermal	5	84	124
Geothermal	0	0	14
Electricity	764	1 841	1 840
District Heat	0.0	0	0
Total	4 503	7 383	7 322
Gross electricity generation (TWh/year)			
Coal	36	54	18.8
Natural gas	121	401	267.9
Oil	49	5	4.8
Nuclear	6	26	26
Hydropower	37.3	52.0	72.0
Biomass (incl. biogas)	2.7	3.5	15.0
Solar PV (utility)	0.1	8.1	44.5
Solar PV (rooftop)	0.0	4.8	21.0
CSP	0.0	0.0	3.6
Onshore wind	1.1	38.4	88.0
Offshore wind	0.0	0.0	3.5
Geothermal	6.7	9.4	31.5
Total	259	602	596.8

	2010	Reference Case 2030	REmap 2030
Electricity capacity (GW)			
Coal	5	10	4
Natural gas	21	64	36
Oil	21	2	2
Nuclear	1.6	3	3
Hydropower	12	19.0	25.5
Biomass (incl. biogas)	0.4	1.0	3.8
Solar PV (utility)	0.0	3.5	18.4
Solar PV (rooftop)	0.1	2.1	11.4
CSP	0.0	0.0	1.5
Onshore wind	1.4	11.1	29.4
Offshore wind	0.0	0.0	1.0
Geothermal	1.0	1.2	4.3
Total	53	118	139.1

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