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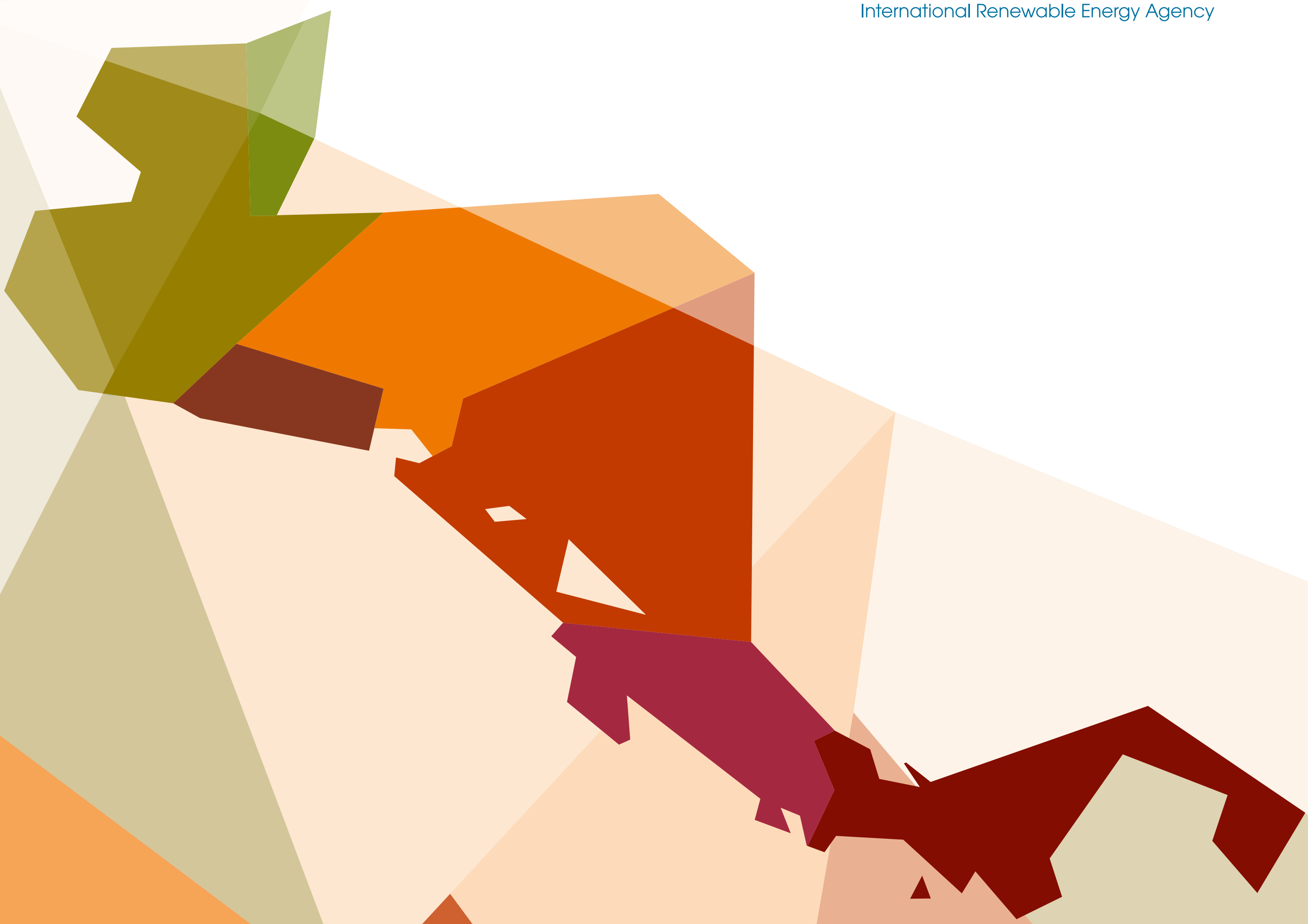

RENEWABLE ENERGY ROADMAP FOR CENTRAL AMERICA:

TOWARDS A REGIONAL ENERGY TRANSITION

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The International Renewable Energy Agency (IRENA) serves as the principal platform for international co-operation, a centre of excellence, a repository of policy, technology, resource and financial knowledge, and a driver of action on the ground to advance the transformation of the global energy system. A global intergovernmental organisation established in 2011, 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. **www.irena.org**

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FOREWORD

IRENA's contribution towards a resilient and more equitable world is presented in its *World Energy Transitions Outlook* and *Post-Covid Recovery: an agenda for resilience, development and equality*. Mindful that the energy transition takes different shapes according to each region and country, IRENA's efforts are now moving towards the implementation of the energy transition at the regional level.

Inspired by the *World Energy Transitions Outlook* technological avenues, IRENA's *Renewable Energy Roadmap for Central America: towards a regional energy transition* dives into the Central America region to contribute to the debate of implementing local energy transition pathways. With an integrated energy transition planning approach, the roadmap has a special focus on evaluating renewable energy technology options in the power and end-use sectors. It serves as an input for government policy makers and stakeholders to update or define their energy planning and Nationally Determined Contribution strategies, as well as inputs for local infrastructure plans and investment packages.

Central America is entering a crucial decade for shaping its future energy system and is strongly engaged in the energy transition. Although the contribution by the Central American countries to the global CO_2 emissions in 2018 was just of 0.2%, the region still expects to experience climate change adverse effects such as shifts in precipitation patterns and average temperature rise. Providing universal access to electricity and clean cooking technologies are key challenges that the region is facing. Its growing population and economic progress will drive an increase in energy demand in the coming decades. Energy security and fossil import dependence mitigation will be crucial in the context of energy prices volatility and global CO_2 pricing discussions. The region has a unique opportunity to develop a sustainable energy system based on renewable energy resources that can help socioeconomic recovery from the recession caused by the COVID-19 pandemic, address climate change mitigation and adaptation strategies, while accomplishing energy security, universalisation and affordability goals.

The *Renewable Energy Roadmap for Central America* provides a comprehensive pathway for the development of a sustainable and cleaner regional energy system. It explores the role of end-use sectors electrification, the feasible expansion of renewable generation, energy efficiency solutions as well the importance of expanding the existing regional power sector integration. Specific sector technological pathways and investment opportunities and tailor actions are important outcomes that will enrich the regional debate and help accelerate the energy transformation.

The engagement with the Central American countries and the close co-operation with them and our local partners SICA, OLADE, ECLAC and IDB, has been key for the outcomes of this study. Our shared future will only be bright if we move forward together, taking everyone along towards a more resilient, equal, and just world.

Francesco La Camera
Director-General, IRENA

ABBREVIATIONS

°C	degrees Celsius
BES	Base Energy Scenario
CO_2	carbon dioxide
DES	Decarbonising Energy Scenario
ECLAC	Economic Commission for Latin America and the Caribbean
EES2030	Estrategia Energética Sustentable 2030 de los países del SICA (Sustainable Energy Strategy 2030 of SICA countries)
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GDP	gross domestic product
GW	gigawatt
GWh	gigawatt hour
ICE	Internal combustion engine
IDB	Inter-American Development Bank
IRENA	International Renewable Energy Agency
$ktCO_2e$	kilotonnes of CO_2-equivalent
kW	kilowatt
kWh	kilowatt hour
LCOE	levelised cost of electricity
LPG	liquefied petroleum gas
LULUCF	land use, land-use change and forestry
m^3	cubic metre
$MtCO_2e$	million tonnes of CO_2-equivalent
MOVE Latam	Movilidad Eléctrica de Latinoamérica y el Caribe (Electromobility of Latin America and the Caribbean)
MW	megawatt
MWh	megawatt hour
Mt	million tonnes
NDC	Nationally Determined Contribution
OLADE	Organización Latinoamericana de Energía (Latin America Energy Organization)
PES	Planned Energy Scenario
PJ	petajoule
PV	photovoltaic
RE	renewable energy
REmap	Renewable Energy Roadmap
SDG	Sustainable Development Goal
SICA	Sistema de la Integración Centroamericana (Central American Integration System)
SIEPAC	Sistema de Interconexión Eléctrica de los Países de América Central (Central American Electrical Interconnection System)
TES	Transforming Energy Scenario
TWh	terawatt hour
USD	United States dollar

COUNTRY CODES

SHORT NAME	OFFICIAL NAME	COUNTRY CODE
Belize	Belize	BZ
Costa Rica	Republic of Costa Rica	CR
El Salvador	Republic of El Salvador	SV
Guatemala	Republic of Guatemala	GT
Honduras	Republic of Honduras	HN
Nicaragua	Republic of Nicaragua	NI
Panama	Republic of Panama	PA

KEY FINDINGS

Integrated **regional planning** for the energy transition is key, linking energy policy with climate policy and country commitments.

The **energy transition** in Central America must focus on transforming the transport sector together with the power sector.

A **decarbonisation** strategy can bring benefits to the region at the same total energy system cost (including investment, operation and maintenance, end use technology costs, and fuel costs) as the current planning strategy.

Regional **power system integration** should be fostered and improved to further exploit a total renewable energy potential of around **180 gigawatts** (GW).

National **transmission and distribution grids** will need expansion and reinforcement to meet growing electricity consumption and enable more efficient and reliable system operation.

Financing feasibility studies of bankable renewable generation projects and expanding the interconnection capacity are vital, as well as surveys to further characterise the demand from end-use sectors in the countries.

Electrification of the transport sector is crucial, as well as the use of biofuels and the implementation of modal changes to decrease transport-related emissions.

Improved cookstoves and electric cookstoves need to increase **8.6 times** by 2050 compared to 2018 levels to help achieve the goal of providing access to clean cooking technologies and fuels for all households in the region.

The direct use of modern **bioenergy, solar thermal and geothermal** can help reduce fossil fuel use in all end-use sectors, representing around **11%** of total final energy consumption by 2050.

Energy efficiency measures and technology standards, with corresponding cumulative investments of around **USD 8.7 billion** for the 2018-2050 period, should be further fostered in the region to bring energy intensity down **43%** by 2050, compared to 2018 levels.

Green hydrogen provides an alternative solution for decarbonising heavy cargo road transport in the region, as well as an opportunity for a cleaner energy supply in international shipping.

SUMMARY

A decarbonisation strategy can bring benefits to the Central America region at the same energy system cost as the current planning strategy. Transforming the energy system is an opportunity to fill existing socio-economic gaps and meet increasing needs for energy services in a more efficient, competitive and sustainable way.

The total energy system costs of the Decarbonising Energy Scenario (DES) – including investment in new installed power capacity and grids, operations and maintenance, fuel costs, and end-use technology costs – are comparable to energy system costs in the Planned Energy Scenario (PES). These costs reach an estimated USD 1 930 billion in the DES versus USD 1 950 billion in the PES, for the period 2018-2050.

Attracting the investment needed to decarbonise the region's energy system can foster national economies and support both COVID-19 recovery and climate resilience.

The installation, operation and maintenance of more and new technologies to fulfil decarbonisation targets would require trained personnel, leading to the creation of local employment (IRENA, 2020).

Using local renewable resources for both power generation and end-use energy services would reduce fossil fuel consumption in the power sector 90% and in the end-use sectors 65% by 2050 in the DES compared to 2050 PES. This would reduce fossil fuel imports and enhance energy security. The use of cleaner fuels in the transport and residential sectors also decreases local and household pollution. Carbon dioxide (CO_2) emissions from the power and end-use sectors would decline 72% in the 2050 DES compared to the 2050 PES.

Diversifying the energy mix through competitive renewable energy and greater regional integration would contribute to reduced volatility in energy costs, as these become less affected by fluctuations in the price of fossil fuels. Together with energy efficiency, this would reduce the relative cost of energy for consumers, improve energy affordability and bring other macroeconomic benefits. Greater diversity in the primary energy supply and in demand management solutions (both distributed and utility-scale, integrated and provided by different localities) also contributes to enhanced resiliency to climate change.

Integrated regional planning for the energy transition is key, linking energy policy with climate policy and country commitments.

The diverse benefits of decarbonisation are unlikely to be gained without increasing co-ordination at the regional level. This implies joint country efforts on many fronts, such as developing infrastructure for the electrification of transport in the region, expanding and reinforcing grids to tap renewable energy potential, and maximising the use of resources among countries. It requires making use of all types of instruments: regional governance, planning, market improvements, policies and regulation.

The energy transition in Central America must focus on transforming the transport sector together with the power sector.

The key drivers of regional decarbonisation are electrification of the transport fleet (around 75% of the vehicles by 2050 in the DES), sustainable mobility and the increasing penetration of renewables in the power sector (around 90% of total installed capacity by 2050 in the DES). Together, these can contribute most of the reduction in the transport sector CO_2 emissions by 2050 in the DES compared with the PES 2050 (around 70%, equivalent to 43 million tonnes of CO_2).

Scaling up the annual deployment of renewables in the region three-fold (by around 1.4 gigawatts (GW) per year) compared to planned deployment is required in order to increase the renewable energy capacity share from 67% in 2018 to nearly 75% by 2030 and more than 90% by 2050.

Under the DES, the share of renewables-based technologies in Central America's power sector would increase from 67% of the total installed capacity in 2018 to 91% by 2050; of this increase, around 45% would be variable renewable energy, *i.e.* solar and wind.

To achieve this high renewable share, annual investment of USD 3.5 billion in new installed capacity (74%) and grids (26%)[1] will be needed, corresponding to 1.6% of the region's gross domestic product (GDP) in 2018. In the DES, hydropower would increase by 350 megawatts (MW) per year, rising from 7 GW today to 18 GW in 2050, reaching around 35% of total generation. Solar photovoltaic (PV) and wind, mainly solar PV, would increase by 870 MW per year, rising from 2 GW today to 30 GW in 2050 to reach around 25% of total generation. Bioenergy and waste would reach around 20%, geothermal 15% and natural gas the remaining 5% of generation in 2050.

This installation of 59 GW of renewable energy could help decrease total power system costs by 7% per unit of electricity delivered between 2018 and 2050.[2]

The decline in power system costs reflects the significant reduction in renewable generation costs observed in the last decade (IRENA, 2021a) as well as the expected optimal regional system operation strategy. In all scenarios, national transmission and distribution grids will need to be expanded and reinforced to meet growing electricity consumption. This will enable more efficient and reliable system operation by unlocking a wider range of technologies for use, including distributed energy resources such as rooftop solar, distributed storage solutions and sector coupling.

Regional power system integration could then be fostered and improved to further exploit a total renewable energy potential of around 180 GW. In the DES, increasing the interconnection capacity to 2 GW can help scale up the currently stranded lower-cost for renewable power generation.

Financing feasibility studies for developing a pipeline of bankable renewable generation projects as well as developing projects to expand the interconnection capacity among countries would contribute to fuller exploitation of the region's available renewable resources. Grid energy storage solutions could also be considered to bolster system flexibility and provide valuable system services.

A closer integration of market operations is required to maximise these benefits, which would enable more effective collective use of assets. In addition, joint co-ordination in regional energy planning for the medium and long terms, including in end-use sectors and the selection of projects, will be required to develop the system in the most cost-efficient and secure way, which is not possible if each national system is separately planned.

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1 Grids include the investment in transmission and distribution, SIEPAC expansion and storage.

2 Calculated as total power system costs (investment in new installed capacity, transmission and distribution, international grid expansion, storage, operations and maintenance, and fuel costs) divided by total generation.

In the DES, the share of electricity use in the region's total final energy consumption would increase from 13% in 2018 to 50% in 2050. This would help reduce the fossil fuel share from 50% in 2018 to 34% in 2050, with required cumulative end-use technology costs of around USD 500 billion for the period 2018-2050.

To reach this electrification target in the DES, efforts will be needed in all end-use sectors, with the greatest transformation in transport. This sector will require around 97% of the cumulative end-use technology costs in electrification[3] estimated from 2018 to 2050. The increase in electricity demand will be accompanied by a need to reinforce the transmission and distribution grid as well as increase electricity generation.

Electrification in the transport sector would be crucial, covering 77% of the passenger fleet and 53% of the cargo fleet by 2050, as part of mitigation policies to decrease sector-related emissions. The CO_2 emission reduction in the DES 2050 would be around 70% compared to that in the PES 2050.

The transport sector is the region's main emitter of energy-related CO_2, contributing around 55% of the estimated 55 million tonnes of CO_2 released in 2018. Under current national mitigation plans and programmes, fossil fuel consumption in the sector would still be 1.8 times higher in 2050, compared to 2018 levels.

A further reduction could be achieved through the application of the measures proposed in the DES, with total end-use technology costs of around USD 485 billion for the period 2018-2050, including for the electric vehicle fleet and related infrastructure. Programmes to promote electric vehicles and develop the related infrastructure would be necessary to foster the market. The development of charging infrastructure, standards and business models for electric vehicles could be done jointly at the national and regional levels.

In the DES, improved cookstoves and electric cookstoves would increase 8.6 times by 2050 compared to 2018, to help achieve the goal of providing access to clean cooking technologies and fuels for all.

Currently, 37% of households in the region do not have access to clean cooking technologies and fuels. In the DES, this share would fall to 1% thanks to the introduction of improved cookstoves and electric stoves, which would require technology costs of around USD 12.5 billion during the period 2018-2050. Additional health and socio-economic benefits would include reducing the pollution from cooking activities, benefiting women and children in particular.

[3] Electrification costs include the introduction of electric cookstoves and space heaters in the residential and commercial sectors and the introduction of electric vehicles and their charging infrastructure. Therefore, the total costs related to the transport sector are considerably higher than those related to the buildings sector. Due to the low characterisation of the industry sector, electrification measures could not be defined in the analysis.

The direct use of modern renewables4 can help reduce fossil fuel use in all end-use sectors, representing around 11% of total final energy consumption in 2050 in the DES.
The introduction of modern renewables – *i.e.* modern bioenergy, solar thermal and geothermal in industry; solar water heaters for water heating and modern biomass for cooking in buildings; and biofuel blending in the transport sector – would contribute to a 65% reduction in fossil fuel demand in the 2050 DES compared to the 2050 PES. The share of modern bioenergy in the end-use sectors would increase from the current 3% of total final energy consumption to 7% by 2050 in the DES, serving as a transitional solution as electrification is gradually deployed in the main sectoral activities.

Cumulative energy efficiency technology costs5 would increase from USD 2.2 billion in the PES to USD 8.7 billion in the DES to bring energy intensity down 43% by 2050 compared to 2018 levels, measured as total final energy consumption per unit of GDP.
The energy efficiency technology costs would trigger fuel and electricity cost savings of USD 82 billion over the 2018-2050 period, which would compensate for the upfront costs needed. Defining and updating regional standards for the use of efficient technologies and units – *i.e.* technical codes for air conditioning, refrigeration, lighting and motors – could foster further regional integration.

Green hydrogen is an alternative solution for decarbonising heavy cargo road transport in the region, as well as an opportunity for a cleaner energy supply in international shipping.
Green hydrogen is a clean fuel that could be used to decarbonise hard-to-abate sectors such as transport and industry. The introduction of 22 300 heavy-duty hydrogen trucks was considered in the DES by 2050, helping to reduce fossil fuel demand mainly in cases where electro-mobility options are complex. Additionally, due to the region's strategic location and the presence of the Panama Canal, the possibility of providing hydrogen to fuel cargo ships as well as exports could be further studied to better understand its implications for the supply chain and infrastructure needs, considering potential stakeholders across Latin America.

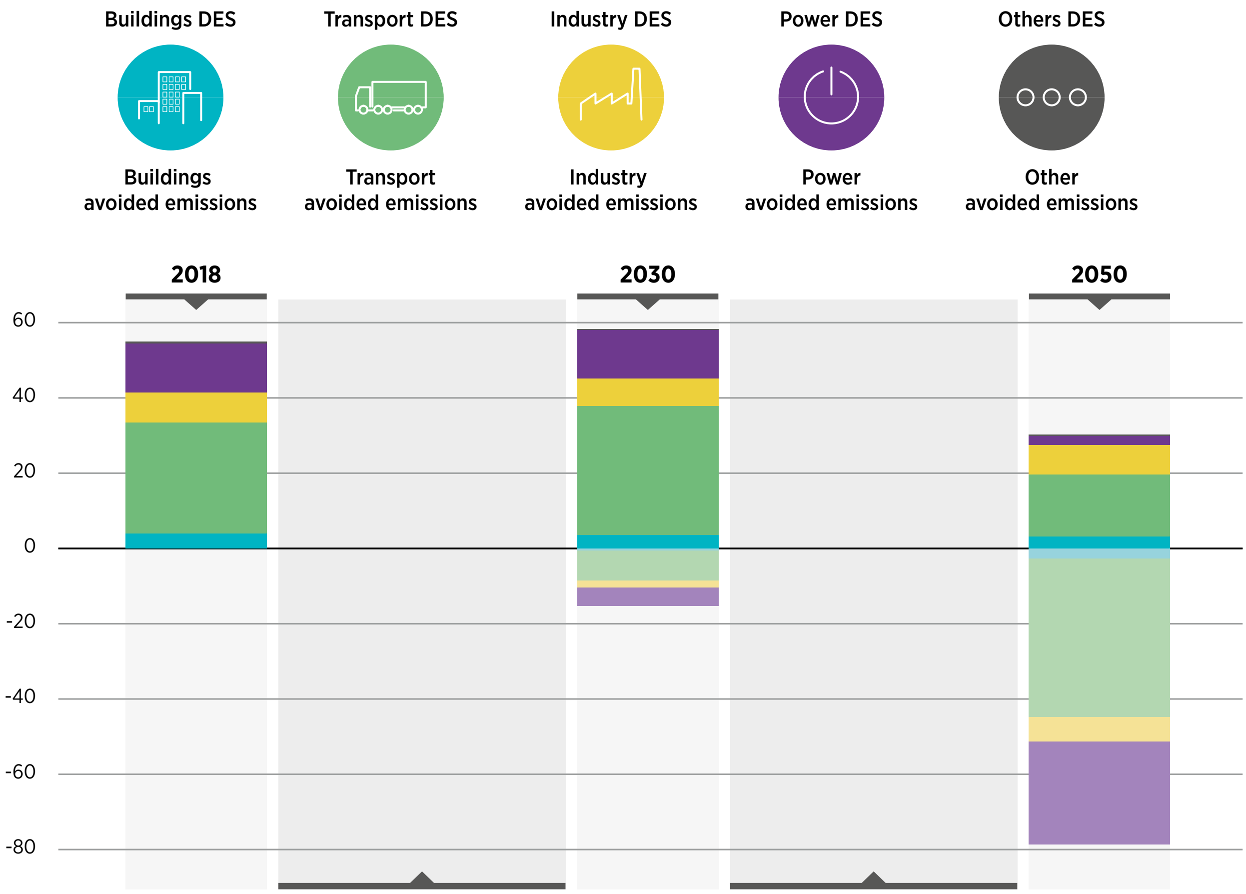
Key actions are needed now to implement the DES and to stabilise the increase in CO_2 emissions in Central America by 2030. By 2050, the actions indicated can help to avoid around 80 million tonnes of CO_2, bringing energy-related emissions down from around 55 million tonnes of CO_2 today to around 30 million tonnes of CO_2 in 2050, despite a growing population and energy demand needs.

Figure 1 illustrates the actions and measures that will need to happen this decade and in the following decades to accelerate the decarbonisation of the Central America region. The transport and power sectors are the key contributors to the total emission reduction by 2050.

4 Direct use of modern renewables includes the following energy carriers: modern bioenergy (bagasse, biodiesel, bioethanol, biogas, biomass and charcoal), geothermal and solar thermal.

5 Cumulative energy efficiency costs refer to the incremental cost of efficient equipment in buildings, mainly air conditioners and refrigerators, compared to the standard ones and to efficiency measures of the industry sector.

Figure 1: Reduction of CO_2 emissions through REmap measures in the DES by 2030 and 2050



Main actions for this decade (until 2030) in the DES

- Install 9 GW of cumulative renewable power by 2030, with 72% of this being solar PV, onshore wind and geothermal
- Continue to deploy hydropower, with 2.3 GW of new additions by 2030
- Establish integrated, regional energy transition planning for the power and end-use sectors (especially transport), considering digitalisation and grid expansion, an enabling framework for variable renewable energy and sector coupling (planning and regulation)
- Promote high electrification of cars, motorcycles, and buses, with the corresponding development of charging infrastructure, to reach an 17% electrified fleet by 2030
- Use biofuels in transport and industry, with blends of 5-10% by 2030
- Deploy distributed power generation in buildings, with 1.8 GW of rooftop solar PV installed by 2030
- Use modern biomass for cooking, while shifting towards electrification (mainly in households), to deploy a minimum of 4 million electric cooking stoves by 2030
- Begin to deploy solar thermal and geothermal energy for water heating in buildings and industry, to account for 2.4% of these sectors' total final energy consumption by 2030
- Implement energy efficiency indexes for air conditioning and refrigeration in buildings
- Implement energy efficiency and conservation measures in industry to decrease energy intensity
- Develop a regional plan to assess the market potential of a green hydrogen hub in Central America
- Develop a regional plan to explore bioenergy production opportunities, including for international markets

Main actions for subsequent decades (2030-2050) in the DES

- Install 39 GW of cumulative renewable power by 2050, with 62% of this being solar PV, onshore wind and geothermal
- Further deploy hydropower, to achieve a 2.6 fold increase from 2018, adding 9 GW from 2030 to 2050
- Implement a regional integrated energy transition plan by 2050
- Further expand SIEPAC in an optimal manner, installing 2 GW by 2050
- Achieve near-complete electrification of cars, motorcycles, and buses, plus a high share of electro-mobility in the road cargo fleet (75% of the total fleet electric by 2050)
- Use biojet fuel in aviation
- Implement modal change measures in passenger transport (shifting from cars to bikes and electric buses)
- Introduce green hydrogen in the transport energy mix for heavy-duty trucks
- Expand distributed generation to cover 10% of the total electricity demand in buildings by 2050 (6.6 GW of installed capacity by 2050)
- Achieve massive electrification in cooking and phase out the use of fuel wood, deploying 10.6 million electric cookstoves by 2050
- Further deploy solar thermal and geothermal energy in buildings and industry, to account for 6.5% of these sectors' total final energy consumption by 2050
- Increase energy efficiency indexes for air conditioning and refrigeration in buildings
- Increase energy efficiency and the use of cleaner fuels (biogas, biomass, electricity) for thermal processes in industry

Note: Positive values correspond to absolute CO_2 energy-related emissions in the respective years. Negative values depict avoided emiss the DES compared to the PES. Results are categorised by sector.

INTRODUCTION

1

INTRODUCTION

The *World Energy Transitions Outlook*, released by the International Renewable Energy Agency (IRENA) in 2021, shows that a drastic reduction in greenhouse gas emissions is needed in order to meet the Paris Agreement goal of keeping the rise in global temperature well below 2 degrees Celsius (°C). Key to this emission reduction over the coming decades will be increased investments in the energy transition, including greater deployment of renewable energy and changes in the energy infrastructure.

IRENA's renewable energy roadmaps programme, REmap, provides strategies for the energy transition at the country and regional levels, with perspectives for 2030 and 2050. The aim of developing regional studies is to understand how a region can promote an energy transition pathway, respecting countries' unique energy resources, socio-economic status, as well as institutional and regulatory endowments, while at the same time contributing to the global emission reduction objective and leveraging opportunities to meet regional energy and investment goals.

Central America is among the regions considered in the ongoing work of IRENA's REmap programme.

1.1 FOCUS OF THE REPORT

This report evaluates the integration of renewable and low-carbon technologies into the end-use and power sectors of seven Central American countries (Figure 2), including a flexibility analysis of the regional power system. This analysis serves as technical guidance that can support the decision-making process of policy makers, energy planners, government institutions and the private sector to define low-carbon development in the region. The findings can cast light on the design, elaboration and implementation of energy plans, Nationally Determined Contributions (NDCs), national mitigation plans and investment plans that are ongoing or in the pipeline. Low-carbon development is also a cornerstone of the post-COVID-19 recovery strategies of governments in the region.

The study contributes to ongoing discussions on the energy transition in the region, and related initiatives. These include, among others: the 2030 Sustainable Energy Strategy for countries in the Central American Integration

Figure 2: Central American countries considered in the REmap-FlexTool analysis

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

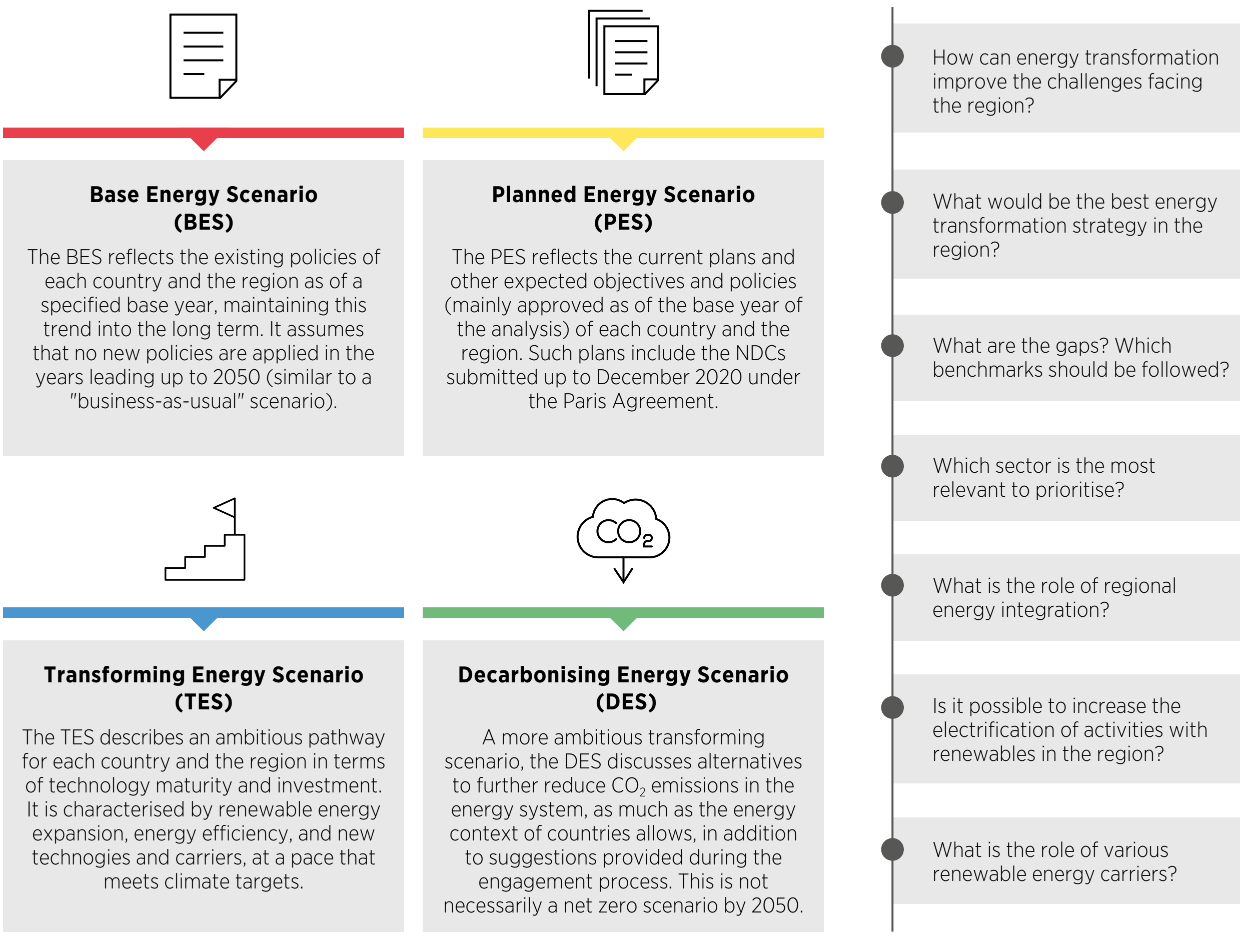
System (SICA)[6] (SICA, 2020); SICA programmes related to the rational use of fuel wood, the deployment of geothermal energy and energy efficiency (*i.e.* regional technical codes for electric devices) (COMIECO, 2020); the MOVE platform (MOVE Latam, 2021); the geothermal programme of Germany's Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) (GIZ, 2020); an electro-mobility programme supported by the United Nations Environment Programme; Euroclima+; as well as programmes to foster the use of biofuels, national decarbonisation plans and the NDC revision process (see the Annex for more information on these initiatives).

The engagement process for this analysis included several multilateral and bilateral meetings with international and regional entities as well as country-based representatives and energy specialists, throughout different stages of the project. The outcomes included: providing a vision and strategies for an energy transformation pathway; proposing technologies applicable to the energy supply and end-use sectors, while respecting the context, status and characteristics of each country and the region, considering activity-level parameters and investment needs; identifying data and information gaps and providing recommendations; and supporting the development of energy transition strategies through workshops and outreach and the provision of inputs to the energy sector NDC processes.

1.2 METHODOLOGY

The analysis of each country included four energy scenarios covering the period 2018-2050, as described in Figure 3. To analyse the end-use sectors, a bottom-up approach was implemented using a tool developed by the REmap team. The power sector was modelled in MESSAGE, and a flexibility assessment was performed using IRENA's FlexTool product (Box 1).

Figure 3: Description of the scenarios in the REmap study

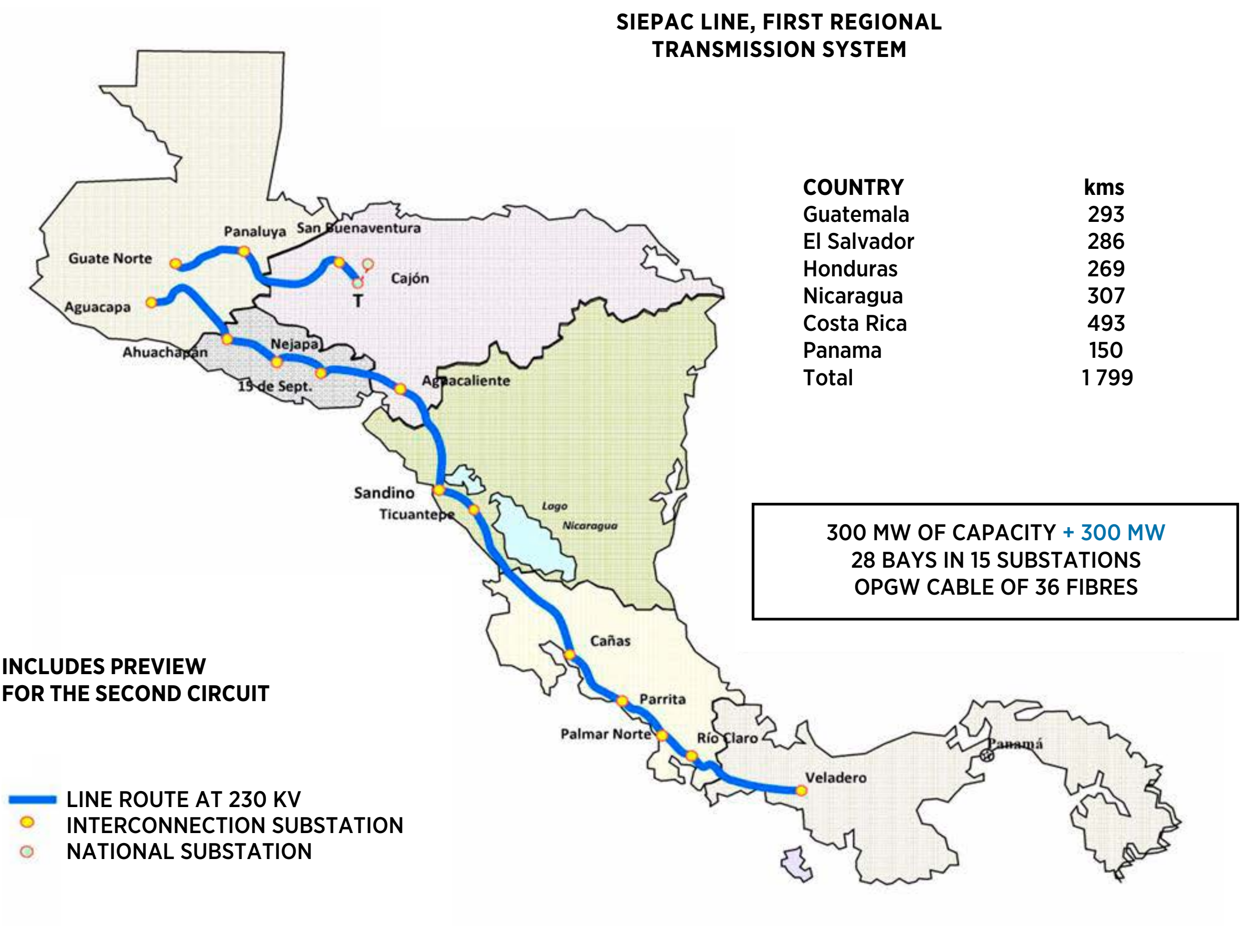


6 The objectives presented in the 2030 Sustainable Energy Strategy for countries in the Central American Integration System (SICA) were defined for the seven Central American countries and Dominican Republic.

Central America's power sector is integrated through an electrical interconnection system known as SIEPAC, which entails a single 230-kilovolt circuit transmission line with a capacity of 300 megawatts (MW) covering six countries (Figure 4). IRENA's power sector simulation was guided by two main questions: 1) What is the role of the interconnection system and regional integration in unlocking the potential benefits of a joint energy transition strategy, with all countries on board as a single market? and 2) How resilient would the new system be to dry periods and to the volatility of fuel prices?

To the extent possible, the study focused on modelling the region's operation as an independent power system rather than as one that is reliant on its northern or southern neighbours, given that these countries were outside the scope of the study and that such analysis would best be analysed in a fully integrated study. The power system modelling was performed to deliver these and related insights.

Figure 4: Overview of the regional electrical interconnection system (SIEPAC)



Source: (Global Infrastructure Connectivity Alliance, 2017)
Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

The power sector simulations span four pillars, as described in Figure 5. These are: 1) showing what the planned capacity and present-day interconnection would deliver in the Base Energy Scenario (BES) and in the Planned Energy Scenario (PES) to 2050; 2) showing what can be achieved in the Transforming Energy Scenario (TES) and the Decarbonising Energy Scenario (DES) through the deployment of renewable energy projects to displace fossil fuel units, while constrained by present-day interconnection levels; 3) showing what can be achieved with higher levels of interconnection in all four scenarios; and 4) showing how the developed scenarios respond operationally to changes in the availability of renewables and in fuel prices.

Figure 5: Rationale for power sector simulations

Existing plans	Higher renewable deployment	Joint regional renewable expansion	Testing resilience – joint regional renewable expansion
• Existing 300 MW SIEPAC • Existing pipeline of renewable energy projects in each country • Fossil fuel expansion based on national plans • Limited exchange between market players – countries	• Existing 300 MW SIEPAC • Expanding pipeline of renewable energy projects in each country, displacing fossil fuel expansion as well as additional electricity consumption, due to electrification of end-uses • Limited exchange between market players – countries	• SIEPAC capacity up to 2 000 MW by 2050 • Additional expansion of renewable capacity based on an optimal expansion of the interconnection, simulated to cover the increasing electrification of the region • No restriction on imports and exports from market players – countries	• What is the implication of natural gas prices for the robustness of the results? • What is the robustness of the results to a dry period in the region?
Relevant scenarios: **BES/PES**	Relevant scenarios: **TES/DES**	Relevant scenarios: **BES/PES/TES/DES**	Relevant scenarios: **BES/PES/TES/DES**

The analysis of the different power sector cases found that expanding the level of interconnection is a key enabling technology for a high share of renewable energy in the power sector and the reduced deployment of fossil fuel projects. Thus, maintaining the existing 300 MW interconnection system out to 2050 and all planned fossil fuel projects was considered only for the BES and PES cases. For the more ambitious TES and DES cases, this interconnection was expanded to 2 gigawatts (GW), with fewer fossil fuel projects commissioned by 2050 in order to facilitate the effective integration of renewables and enable cost-efficient system operation.

The flexibility of the electrical system, assessed using IRENA's FlexTool, considered the role of hydropower, storage solutions, smart charging of electric vehicles and the introduction of hydrogen to the energy mix. For the latter, a supplementary analysis was done considering hydrogen's application in road cargo transport and international shipping through the Panama Canal.

The energy assessment of the region was complemented with an analysis of investment needs and the costs associated with various technologies in the end-use sectors (Figure 6). *Investment needs* refer to the required investment in installed capacity and grids in the power sector, and *end-use technology costs* refer to the technology acquisition costs in the buildings, transport and industry sectors. The REmap tool used for the energy analysis also allows for calculating the related carbon dioxide (CO_2) emissions of countries and their evolution under the proposed scenarios.

Figure 6: Description of investment and costs in the analysis

Investment	End-use technology costs	Fuel costs	Operation and maintenance costs
Capital required for the new installed capacity and grids in the power sector	Acquistion or purchase costs of technologies in the end-use sectors	Related to carriers used in the power and end use sectors	Related to operation and maintenance in the power sector

This report includes the energy assessment, investment, costs and emissions results for the end-use and power sectors. Both the PES and the DES are highlighted, whereas the TES and the BES are discussed mainly in those cases related to the power sector. Further detail is presented in an online content of the study showing more country information and scenario results.

Box 1. REmap and flexibility analysis and tools

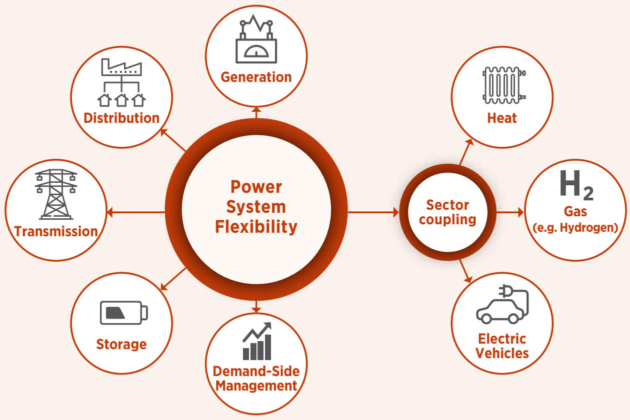
The REmap Activity Tool is a software application used to develop energy scenarios at the country and regional levels. It was developed by IRENA's REmap team and is fully based in Excel in its current version. While the tool is designed primarily for energy analysis, it also allows for the estimation of greenhouse gas emissions – specifically, CO_2 based on values from the Intergovernmental Panel on Climate Change (IPCC) – using emission factors to convert energy flows to emission flows.

The tool approaches energy modelling from the activity levels in different sectors, sub-sectors and energy services. Activity-level information is used to estimate full energy balances and emissions. Because the tool applies a similar rationale for all sectors/sub-sectors to estimate energy consumption, numerous independent analyses are needed (one for each sector/sub-sector).

The IRENA FlexTool, developed with the VTT Technical Research Centre of Finland Ltd., performs power system flexibility assessments based on national capacity investment plans and forecasts. The tool assessments reflect full power system dispatch and offer a detailed view of flexible generation options, demand flexibility and energy storage, along with sector-coupling technologies such as power-to-heat, electric vehicles and hydrogen production through electrolysis (Figure 7) (IRENA, 2018).

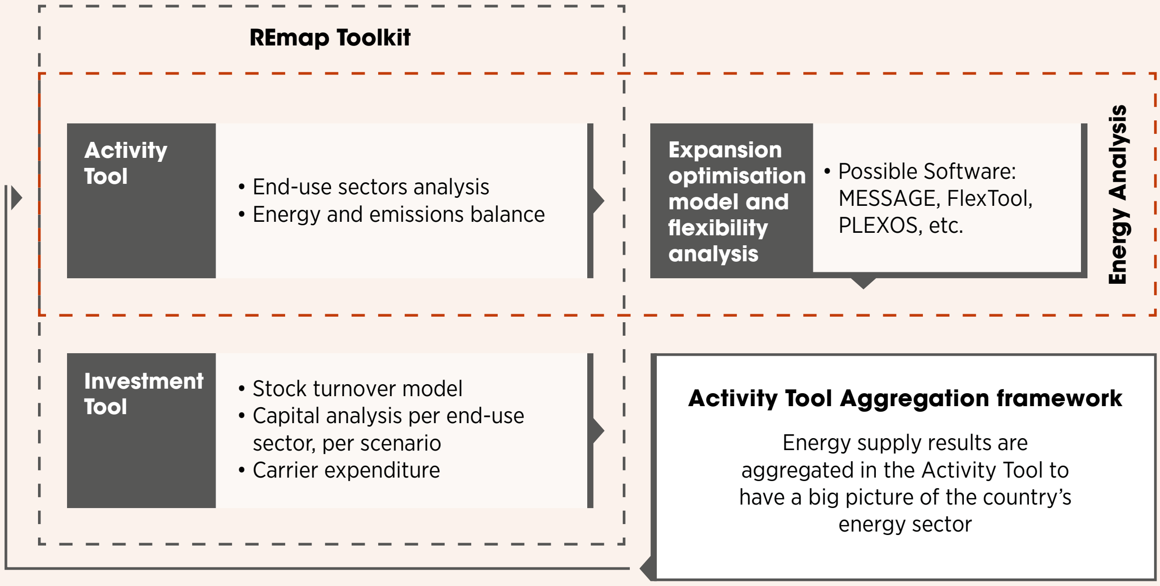
Figure 8 shows the interaction of the different tools to perform energy analyses of the end-use and power sectors, as well as estimations of investment and CO_2 emissions, for the regional assessment.

Figure 7: Power system flexibility enablers in the energy sector



Source: (IRENA, 2018)

Figure 8: REmap tools for analysis of the end-use and power sectors



1.3 ENERGY TRANSITION GOALS AND RECENT PROGRESS

In 2018, Central America was home to around 48 million people, with a regional gross domestic product (GDP) of nearly USD 225 billion. Based on the data provided by countries for this study, by 2050 the region's population will increase to 65 million inhabitants and regional GDP will double, increasing at a compound annual growth rate of 2.8% (Table 1).

Table 1: Regional population and GDP, 2018, 2030 and 2050

STATUS AND PERSPECTIVES	2018	2030	2050
Population [Million]	48	55	65
GDP [Million USD - 2010]	224 753	297 439	541 737
GDP per capita [USD/capita]	4 703	5 419	8 335

Total final energy consumption in the region was around 1 245 petajoules (PJ) in 2018, with the buildings sector being the major consumer, followed by the transport sector (Figure 9). By country, Guatemala was the highest energy consumer, accounting for 47% of the total, while Belize was the lowest, at only 1% (Figure 10).

Figure 9: Total final energy consumption by sector, 2018

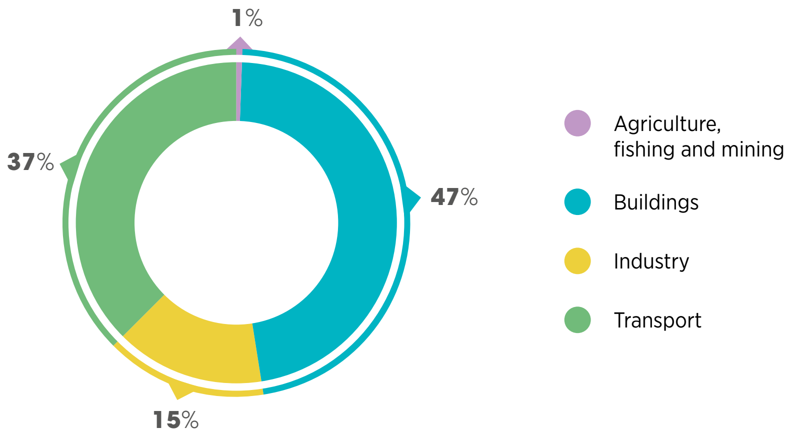
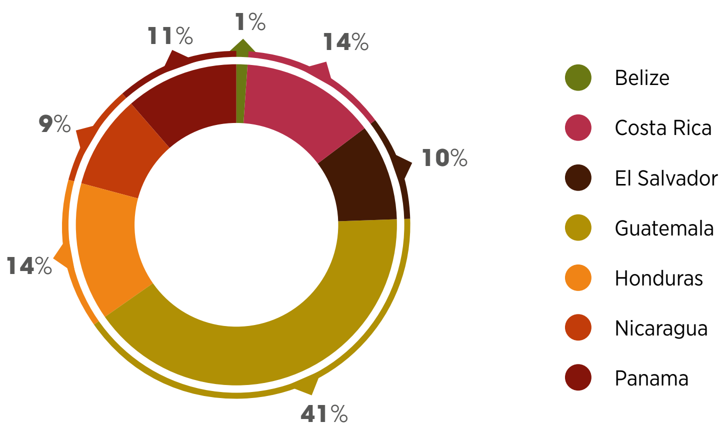


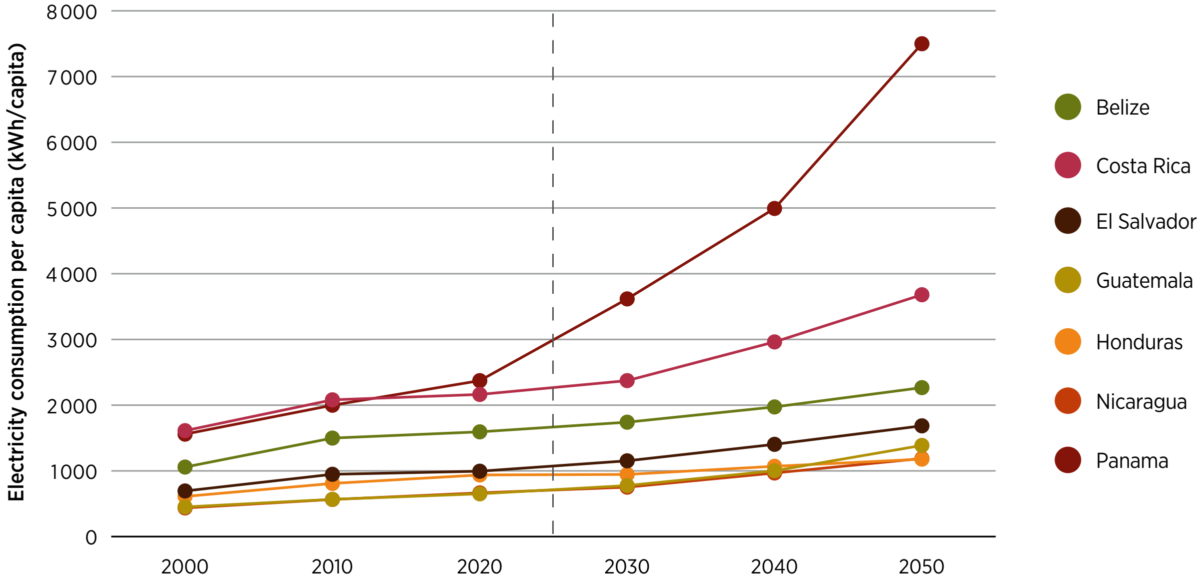
Figure 10: Total final energy consumption by country, 2018



Per capita annual electricity consumption in the region has increased over the last two decades (Figure 11), reaching an average of 1 390 kilowatt hours (kWh) in 2018; this is around one-fifth of the per capita electricity consumption in member countries of the Organisation for Economic Co-operation and Development (OECD). Per capita total final energy consumption in the region was an estimated 26 gigajoules in 2018 and is expected to increase 7% by 2030 and 27% by 2050 under current national energy policies (the PES) (Figure 12).

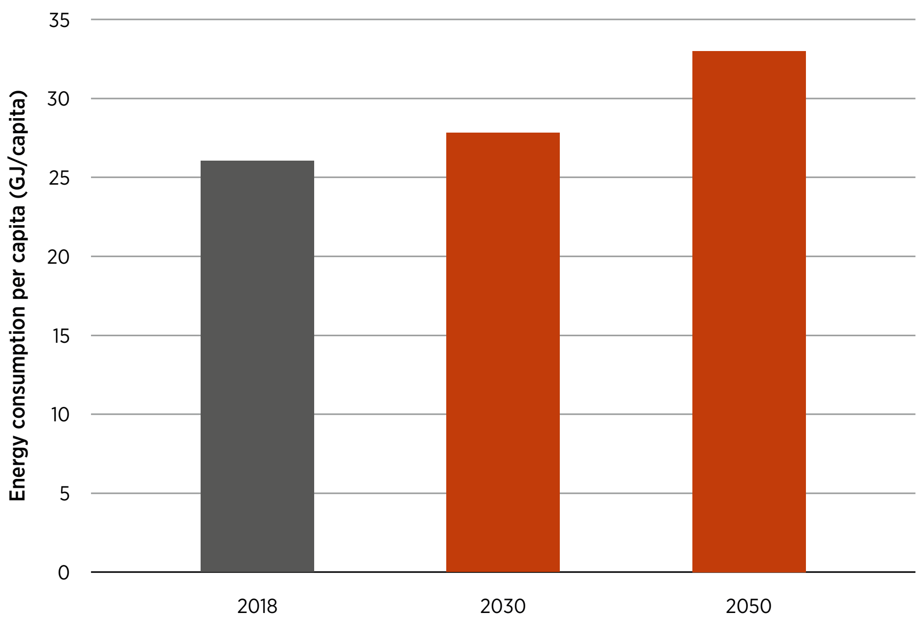
These demographic and energy statistics demonstrate the need for integrated energy planning not only on the supply side (to cover rising energy demand in an optimal way), but also in the end-use sectors, ensuring the rational use of energy while also considering potential environmental and socio-economic impacts.

Figure 11: Per capita electricity consumption by country, 2000 to 2050



Source: (ECLAC, 2021) for values until 2020, PES for 2030 - 2050.

Figure 12: Per capita regional total final energy consumption in 2018 and under the PES in 2030 and 2050



Although countries in the region have reached high shares of electricity access (Table 2), efforts are still needed to reach the target of 100% access by 2030, as set by regional bodies.

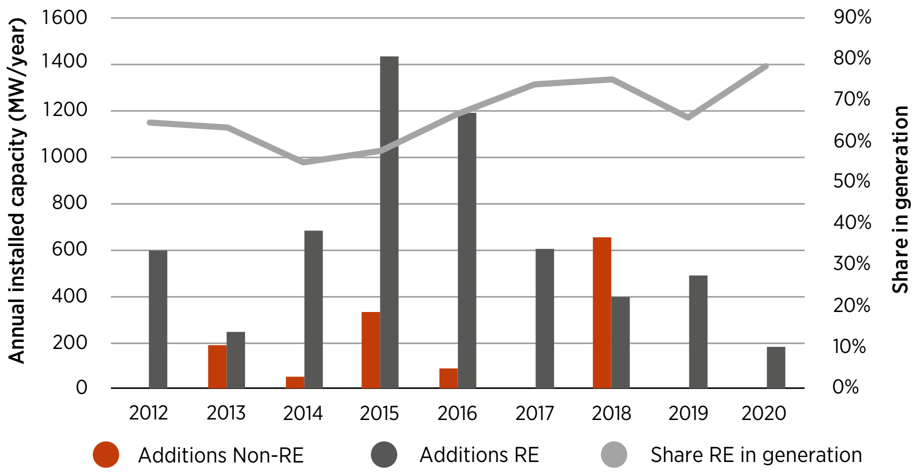
Table 2: Electricity sector indicators by country, 2020

COUNTRY	ACCESS TO ELECTRICITY	INSTALLED CAPACITY	ELECTRICITY GENERATION	ELECTRICITY PEAK DEMAND
Belize	95%	159 MW	364 GWh	103 MW
Costa Rica	99%	3 537 MW	11 534 GWh	1 738 MW
El Salvador	98%	2 312 MW	5 811 GWh	1 010 MW
Guatemala	92%	4 109 MW	11 122 GWh	1 787 MW
Honduras	85%	2 817 MW	9 001 GWh	1 618 MW
Nicaragua	97%	1 600 MW	3 333 GWh	689 MW
Panama	94%	4 132 MW	10 721 GWh	1 969 MW

Note: GWh = gigawatt hours.
Source: (ECLAC, 2021).

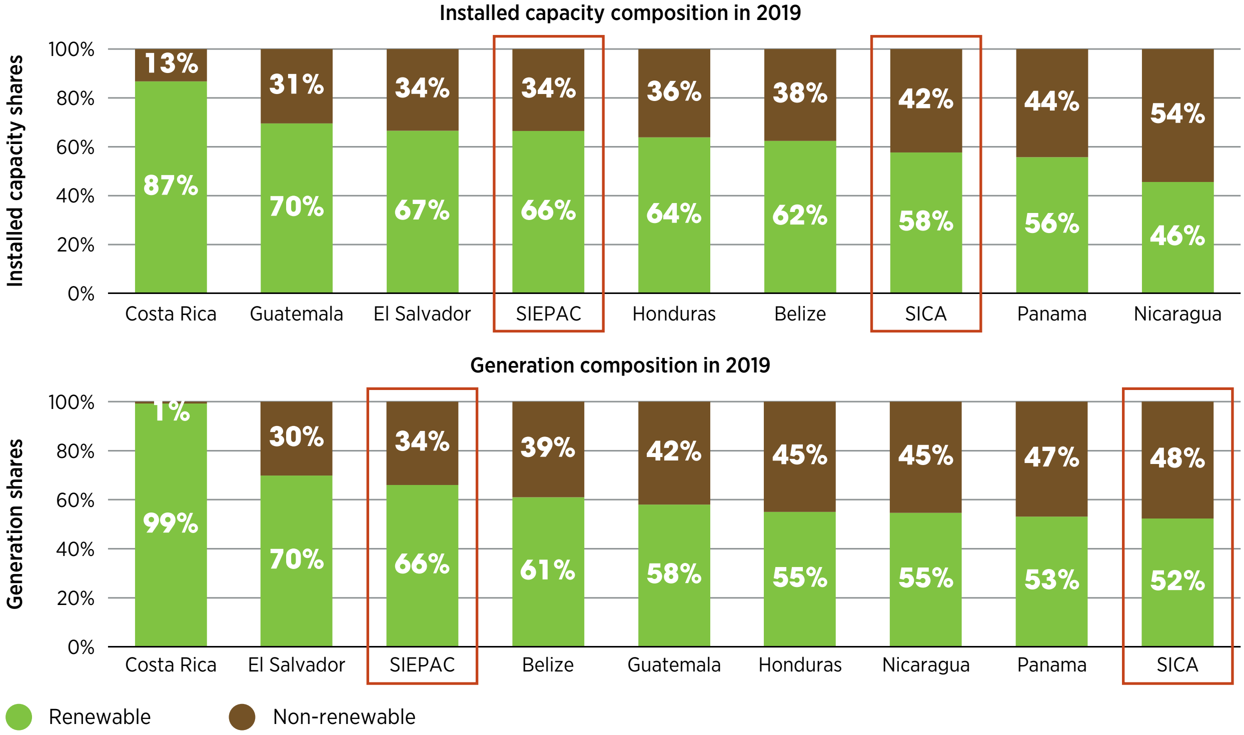
As countries have added renewable energy capacity, the share of renewables in the centralised electricity generation system has remained above 55% for the past decade (Figure 13). In 2019, renewable energy accounted for more than 50% of total generation in the region, with much higher shares in individual countries such as Costa Rica (nearly 87% renewable generation) (Figure 14).

Figure 13: Annual capacity installations and renewable share in generation in Central America, 2011-2020



Note: The region saw major additions in hydro (295 MW), onshore wind (355 MW), biomass (260 MW) and solar PV (520 MW) in 2015; and in hydro (727 MW) and biomass (316 MW) in 2016.
Note: RE = renewable energy
Source: (ECLAC, 2021)

Figure 14: Shares of installed capacity and electricity generation by country, 2019

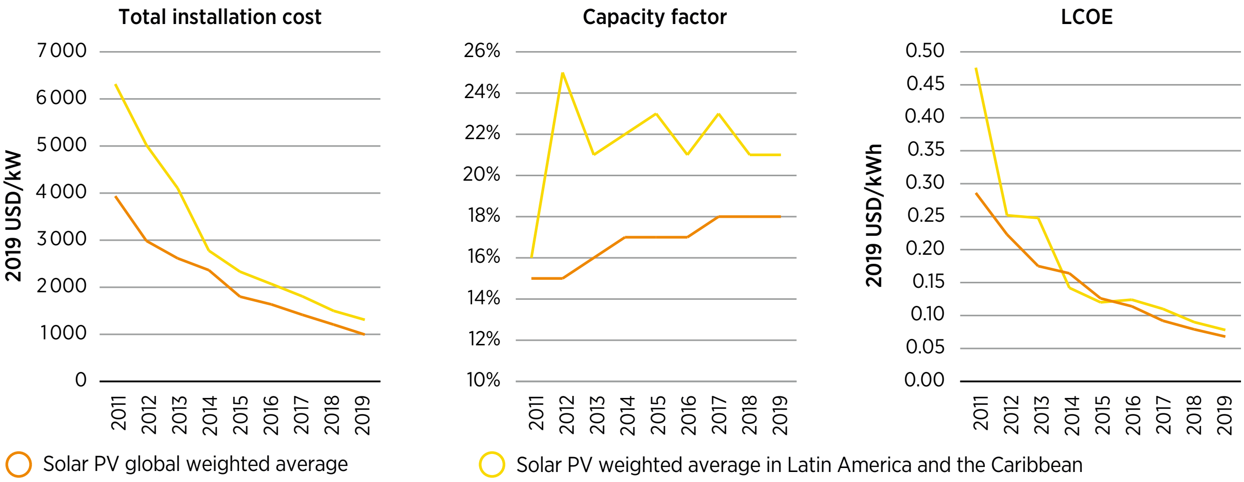


Source: (ECLAC, 2021)

The integration of additional renewable energy capacity in the power sectors of countries is feasible, considering the competitive generation costs and declining cost trends for the main renewable technologies installed in the region: hydro, onshore wind and solar PV. The weighted-average levelised cost of electricity (LCOE) for large hydropower plants in Central America and the Caribbean reached around USD 0.10/kWh in the period 2016-2020. For onshore wind power, installation costs fell 23% in the last decade to USD 2 060/kW in 2020, and the LCOE fell 38% to USD 0.059/kWh IRENA. (2021a), "Renewable Power Generation Costs in 2020."

Solar PV has been deployed even more widely across the region – with additions of around 150 MW annually between 2015 and 2020 (ECLAC, 2021) – and has experienced major cost reductions. For all Latin American and Caribbean countries, total solar PV installation costs fell 80% in the last decade to USD 1 300/kW in 2019, while the LCOE fell 84% to USD 0.078/kWh (Figure 15).

Figure 15: Solar PV total installation cost, levelised cost of electricity and capacity factor for Latin America and the Caribbean, 2010-2019

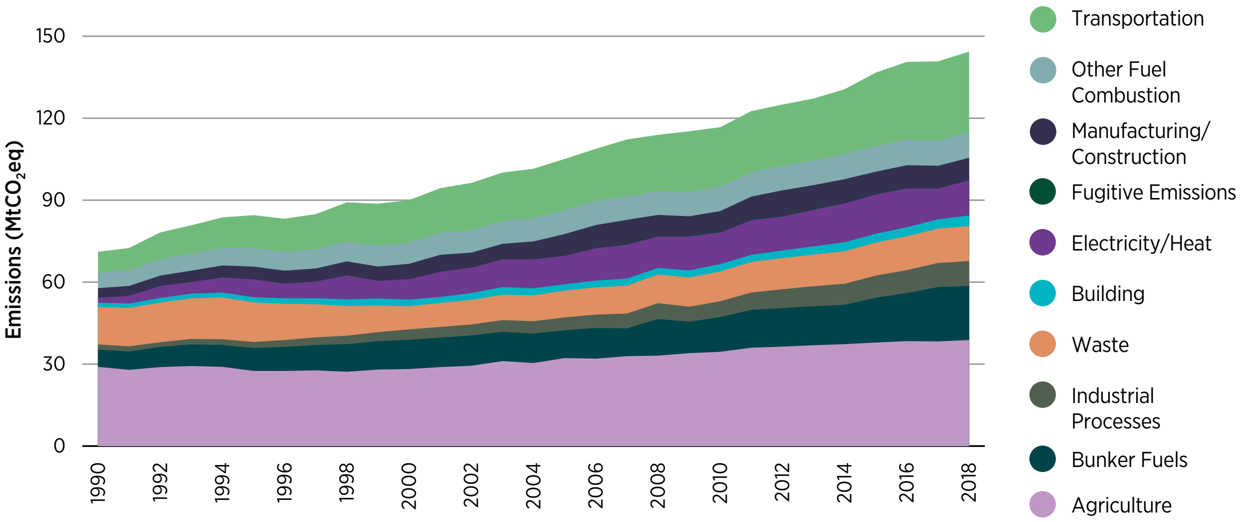


Source: IRENA Renewable cost database.

In a recent example of competitive procurement in the region, Panama held a short-term renewable energy auction in mid-August 2021 that resulted in a price range for large hydropower offers of between USD 0.0584/kWh and USD 0.075/kWh, and for solar PV of between USD 0.0595/kWh and USD 0.083/kWh. The lowest offer at the auction in onshore wind was at USD 0.09/kWh (Energía Estratégica, 2021).

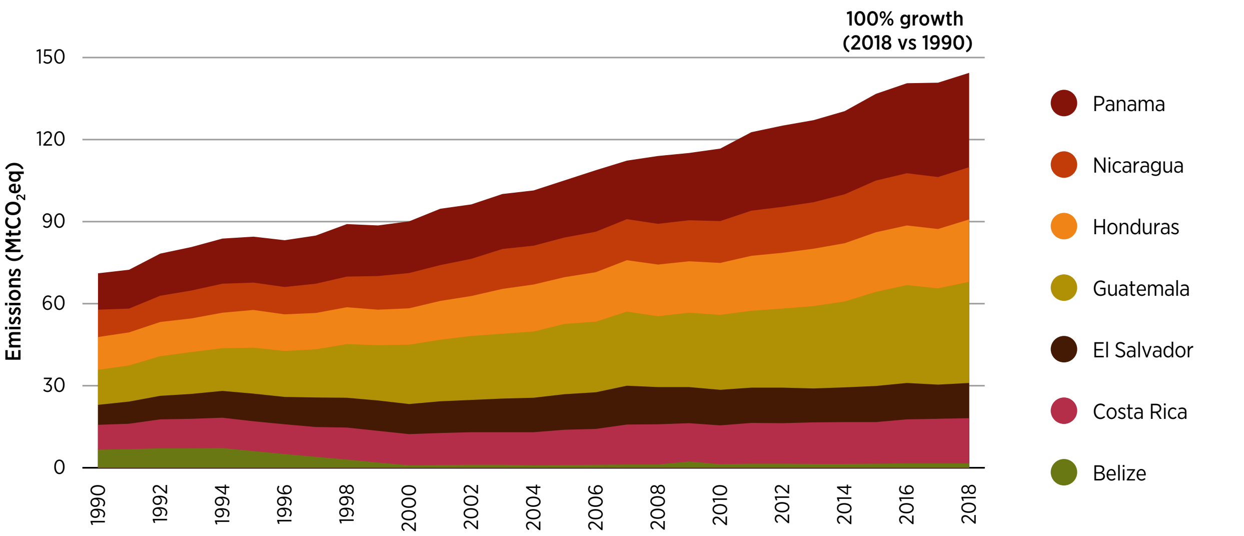
In 2018, Central America contributed just 0.3% of global greenhouse gas emissions (Climate Watch, 2021). However, the region's emissions have gradually increased since 1990 (Climate Watch, 2021). Agriculture contributed the highest share of emissions in the 1990s, and the sector's emissions increased slightly until 2018. In recent decades, emissions from the energy sector have increased more rapidly to become the highest contributing sector. The largest sources of these emissions were the transport sector, bunker fuels, and electricity and heat production, highlighting the need for greater focus on these sub-sectors (Figure 16). Historical emissions by country are shown in Figure 17.

Figure 16: Historical emissions (excluding land-use change and forestry) in Central America by sector, 1990-2018



Source: (Climate Watch, 2021)

Figure 17: Historical emissions (excluding land-use change and forestry) in Central America by country, 1990-2018



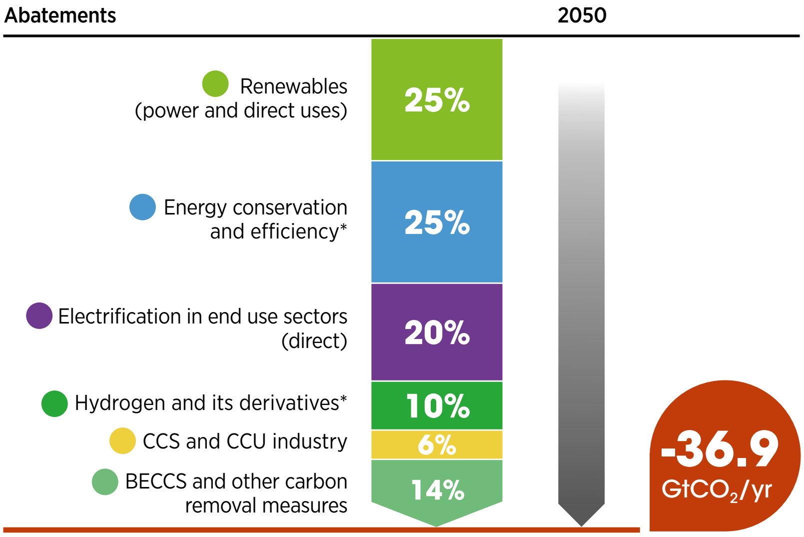
Source: (Climate Watch, 2021)

Several countries in Central America are developing their new energy plans and energy transition agendas under the framework of the United Nations Sustainable Development Goals (SDGs), with the aim of achieving clean and affordable energy for their populations (SDG 7) while also considering the impacts of the energy sector on socio-economic opportunities such as promoting local jobs and economic growth (SDG 8) and enhancing the role of women (SDG 5). The countries are also assessing the contribution of the energy sector to greenhouse gas inventories as well as defining policies to decrease emissions (SDG 13) as part of decarbonisation plans and the process of submitting Nationally Determined Contributions (NDCs) towards reducing emissions under the Paris Agreement.

In the context of the COVID-19 pandemic, energy transition initiatives constitute a fundamental driver for the social and economic recovery of the region, which has also been affected by recent environmental events (hurricanes Eta and Iota, November 2020) (PAHO, 2020). This suggests the need to develop infrastructure and national plans that are resilient to climate change and are strengthened by greater regional integration of resource development and management. A joint effort to reduce regional emissions would be beneficial to all countries and could represent an opportunity to create a regional clean energy industry and enhance overall co-operation among countries.

To reduce energy-related emissions in the region, particularly in the emission-intensive transport and power sectors, countries need to promote the use of renewables and foster energy efficiency and electrification, among other steps. Figure 18 shows, at a global level, how each of these action lines would contribute to reducing greenhouse gas emissions in line with the Paris Agreement goal of keeping global temperature rise below 1.5°C (IRENA, 2021b).

Figure 18: Global carbon emissions abatement under IRENA's WETO 1.5°C Scenario



Source: (IRENA, 2021b)

Countries in Central America have been taking steps in that direction, submitting NDCs that include targets for increased renewable energy integration in the power sector, as well as decarbonisation plans for end-use sectors that aim to achieve emission reductions by 2030 or 2050. Table 3 summarises the countries' progress towards implementing the Paris Agreement and provides an overview of the elements covered in related NDC documents submitted to the United Nations Framework Convention on Climate Change (UNFCCC) as of November 2021.

Besides national plans and the NDCs submitted by most of the countries considered in the analysis, regional initiatives are being pursued on similar topics, such as the deployment of new and cleaner energy resources, electro-mobility, energy efficiency and expansion of the electric grid, among others. These programmes are already contributing to tackling several challenges in the region, such as reducing fossil fuel imports and decreasing local and household pollution.

Table 3: Contents of NDCs of Central American countries, as of November 2021

COUNTRY	MITIGATION TYPE	COVERAGE	SECTORAL SCOPE	MITIGATION TARGET	MITIGATION DETAILS
Belize	Relative emission reduction	Economy-wide	Energy, Transport, Waste, LUCF, Agriculture	Targets are estimated to avoid a cumulative emissions total of 5 647 $ktCO_2e$ between 2021 and 2030	• Reduce GHG emissions and increase GHG removals related to land use change totalling 2 053 kilotonnes of CO_2-equivalent cumulative ($ktCO_2e$-cumulative) over the period from 2021 to 2030. • Enhance the capacity of the country's mangrove and seagrass ecosystems to act as a carbon sink by 2030, through increased protection of mangroves and by removing a cumulative total of 381 053 $ktCO_2e$ between 2021 and 2030 through mangrove restoration. • Reduce methane emissions from livestock by 10% by 2030 and avoid emissions of at least 4.5 $ktCO_2e$ related to agriculturally driven land use change by 2025 • Avoid emissions from the power sector equivalent to 19 053 $ktCO_2e$/year through system and consumption efficiency measures amounting to at least 100 GWh/year by 2030 • Avoid 44 053 $ktCO_2e$ in the national electricity supply by 2030 through the introduction of expanded capacity from renewable energy sources • Avoid 117 053 $ktCO_2e$/year from the transport sector by 2030 through a 15% reduction in conventional transportation fuel use by 2030 and achieve 15% efficiency per passenger- and tonne-kilometre through appropriate policies and investments • Improve waste management processes to avoid emissions of up to 18 053 $ktCO_2e$/year by 2030, in line with the national waste management strategy
Costa Rica	Absolute emission reduction	Economy-wide	Energy, agriculture, transport, waste, LULUCF, industry	9.11 $MtCO_2e$ by 2030; 106.5 $MtCO_2e$ between 2021 and 2030	• Committed to a net emission limit of 9.1 million tonnes of CO_2-equivalent ($MtCO_2e$) by 2030, which includes all gases and all sectors covered by the National Greenhouse Gas Inventory report. This goal is consistent with the country's long-term Plan National Decarbonisation Strategy, presented in 2019, which calls for net zero emissions by 2050, as well as the 1.5°C trajectory. • Committed to a net emissions budget of 106.5 $MtCO_2e$ from 2021 to 2030, which includes all gases and all sectors covered by the National Greenhouse Gas Inventory.

Table 3: Contents of NDCs of Central American countries, as of November 2021 (continued)

COUNTRY	MITIGATION TYPE	COVERAGE	SECTORAL SCOPE	MITIGATION TARGET	MITIGATION DETAILS
El Salvador	Relative emission reduction	Economy-wide	Energy, agriculture, transport, LULUCF	46% reduction (unconditional), 61% reduction (conditional)	• In October 2016, established a goal of a 46% reduction in greenhouse *gas* emissions relative to "business as usual" (growth without specific mitigation actions). The country could achieve a further 15% reduction if financial support is obtained to develop an additional 92 MW of geothermal generation.
Guatemala	Absolute emission reduction	Economy-wide	Energy, agriculture, transport, waste, LULUCF, industry	11.2% reduction (unconditional), 22.6% reduction (conditional)	• Unconditional: Reduce *greenhouse gas* emissions 11.2% from 2005 levels by 2030. This implies that projected business-as-usual emissions of 53.85 $MtCO_2e$ in 2030 would be reduced to 47.81 $MtCO_2e$. • Conditional: Reduce emissions even more aggressively, up to 22.6% from 2005 levels by 2030. This implies that projected business-as-usual emissions of 53.85 $MtCO_2e$ in 2030 would be reduced to 41.66 $MtCO_2e$.
Honduras	Relative emission reduction	Economy-wide	Energy, agriculture, transport, waste, industry	16% reduction except for LULUCF	• Committed to reduce emissions 16% by 2030 relative to a business-as-usual scenario, excluding LULUCF. • Committed to promoting the "conservation and functional restoration of the rural landscape", with a goal of restoring 1.3 million hectares of forest by 2030. • Committed to reducing household fuelwood consumption 39% by 2030, helping to slow deforestation.
Nicaragua	Policies and actions	N/A	Energy, LULUCF	65% renewable electricity	• Increase the share of renewable electricity generation to 65% by 2030.
Panama	Relative emission reduction	Economy-wide	Energy, LULUCF	In energy sector, 11.5% emissions reduction by 2030 and 24% by 2050	• Achieve a minimum 24% reduction in total *energy*-sector emissions by 2050 and a minimum 11.5% reduction by 2030, compared to the trend scenario. • Committed to restoring 50 000 hectares of forest, resulting in the absorption of around 2.6 $MtCO_2e$ by 2050.

THE ROADMAP FOR CENTRAL AMERICA

2

THE ROADMAP FOR CENTRAL AMERICA

2.1 RENEWABLE ENERGY ROADMAP

In the REmap analysis for Central America, a series of scenarios were developed that provide innovative and alternative decarbonising solutions while gradually increasing country ambitions. The scenarios take into account the current situation of the countries in terms of their economic evolution, energy intensity, national and regional power sector contexts, and ongoing initiatives, plans and pledges to tackle sectoral emissions.

The scenarios outline a set of measures and assess their impacts on energy and emissions while also determining the investment and costs required. The measures are grouped in five categories, following selected action lines of IRENA's *World Energy Transitions Outlook* (IRENA, 2021b) that are applicable to the region. The categories are renewables in the power sector, renewables direct use in end-use sectors, electrification in the end-use sectors, energy conservation and efficiency, and hydrogen. Within these five categories, Table 4 summarises the key indicators of the DES – the decarbonising pathway for the region's energy sector – and compares them to current energy sector plans (the PES), with perspectives to 2030 and 2050.

Table 4: Key scenario pathway for decarbonisation of the energy sector

	INDICATOR	HISTORICAL	PES		DES	
		2018	2030	2050	2030	2050
Renewables in the power sector	Renewable energy share in power generation (%)	70%	66%	59%	82%	97%
	Annual solar PV additions (MW/yr)	-	145	280	375	780
	Annual hydro additions (MW/yr)	-	135	130	190	355
Renewables direct use in end use sectors	Share of modern renewables in TFEC (%)	5%	4%	4%	9%	15%
	Solar thermal collectors in residential households (thousand units)	9.2	41	320	534	2 803
	Modern bioenergy in TFEC (PJ)	36	54	73	71	85
Electrification in the end use sectors	Share of electricity in TFEC (%)	13%	16%	23%	22%	49%
	Passenger electric vehicles on the road (million units)	0.0	0.3	2.9	2.3	18.8
Energy conservation and efficiency	Energy intensity in terms of energy demand per GDP (TJ/million USD)	5.5	5.1	4.0	4.2	2.3
Hydrogen	Number of hydrogen heavy duty trucks (units)	0	N/A	N/A	1 190	4 830

Note: TFEC = total final energy consumption; TJ = terajoule.

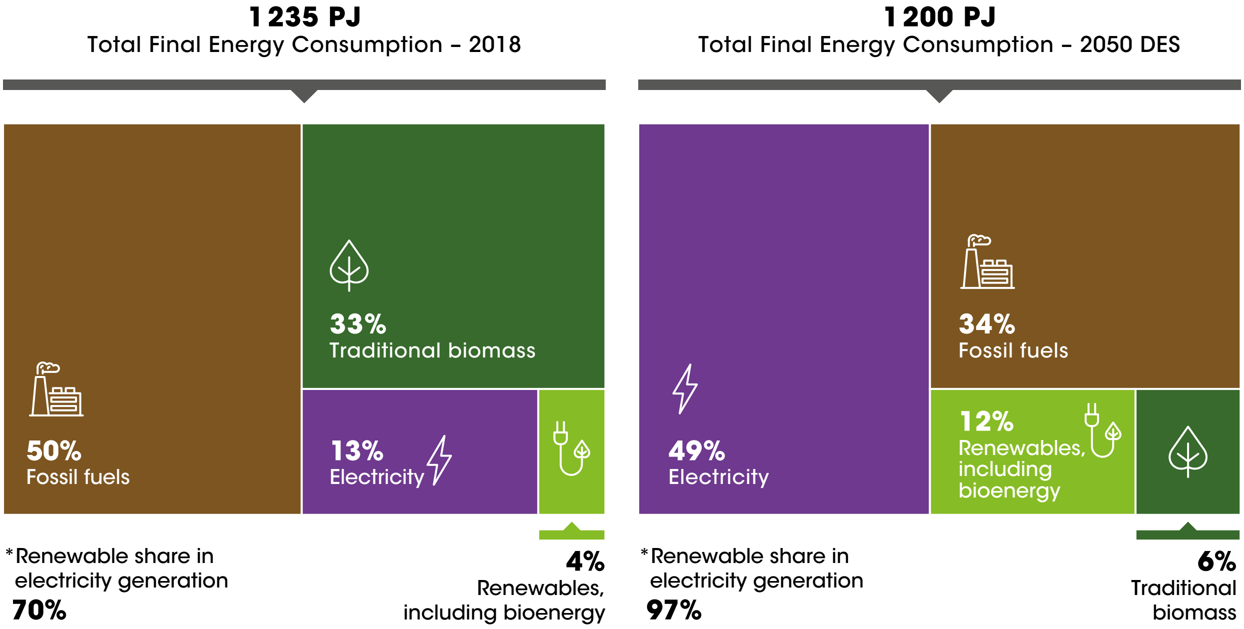
In the DES, the share of electricity generation from renewable energy sources would grow from around 70% in 2018 to 97% in 2050, driven mainly by capacity additions in solar and hydropower.[7] As the share of renewable generation grows, so too does the share of electrification in the end-use sectors. In the DES 2050, nearly 50% of demand in the end-use sectors would be covered by electricity (Figure 19). Electrification of the transport fleet would be essential to meet this share. The renewable energy share in the total primary energy supply increases more rapidly in the DES than in the PES, reaching 62% in the 2050 DES (Figure 20).

Renewables direct use in the end-use sectors would contribute to further reducing the use of fossil fuels and their associated CO_2 emissions. Relevant technologies include the introduction of solar water heaters in buildings to cover water heating needs, and the use of bioenergy in industry to supply heat for low-temperature thermal processes, among others. The use of bioenergy could be further explored with the introduction of biofuels and biomass, among others.

The implementation of energy efficiency measures and the introduction of more efficient technologies would also have an important impact, reducing the energy intensity by half in 2050 under the DES and thus reducing the amount of energy resources needed to cover regional energy needs. Innovative technologies such as the introduction of hydrogen trucks would also be explored to further reduce the emissions of hard-to-abate sectors such as cargo transport, including international shipping (Box 5).

To achieve the shares outlined in Table 4, higher upfront investment in the power sector would be needed, and consumers would face higher costs for end-use technologies.[8] However, these costs could be compensated with the savings obtained through the use of more efficient technologies and cheaper fuels, as explained in the sections below.

Figure 19: Total final energy consumption in 2018 and under the DES in 2050

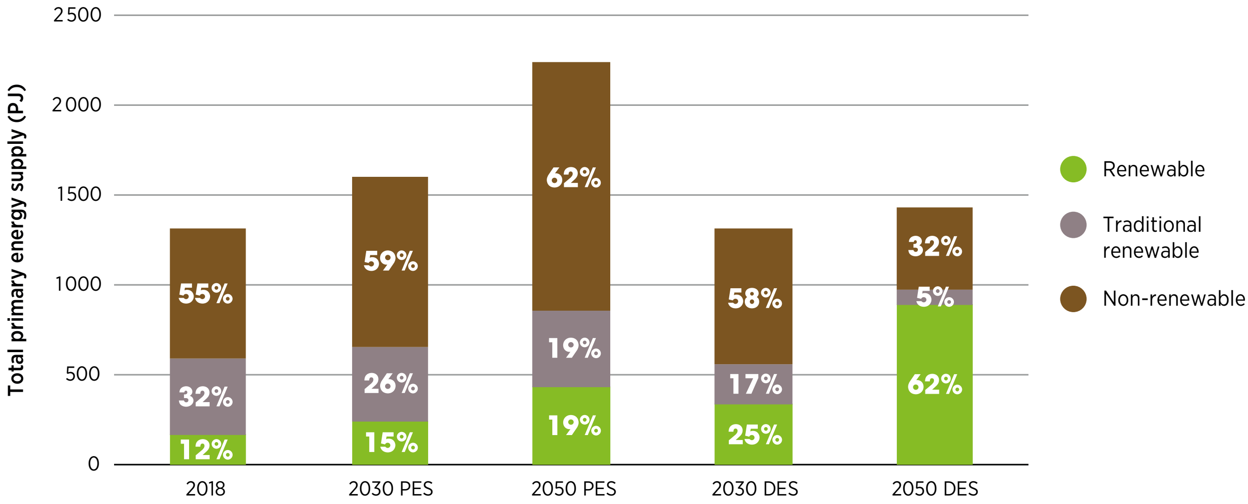


Note: Traditional biomass refers to the traditional use of biomass for cooking and heating purposes in buildings. Bioenergy represented 100% of the renewables share in 2018 and 61% in 2050 DES, being the remaining 39% modern renewables i.e. solar thermal and hydrogen.

[7] Capacity additions for 2030 and 2050 represent annual average values for the 2018-2030 and 2018-2050 periods, respectively.

[8] End-use technology costs refer to the different technologies used in buildings, transport and industry (*e.g.* electric vehicles and related infrastructure, cookstoves and air conditioners).

Figure 20: Renewable, traditional renewable and non-renewable shares of total primary energy supply in 2018 and under the PES and DES in 2030 and 2050



Note: Total primary energy supply increases 70% by 2050 under current policies (PES). However, a reduction of 45% in the 2050 DES compared to the 2050 PES could be achieved by accelerating renewables, electrification and energy efficiency measures. Traditional renewable refers to the traditional use of fuelwood in buildings.

2.2 INVESTMENT OPPORTUNITY

The average annual investment[9] in renewable energy technologies for electricity generation and in grids and flexibility[10] to 2050 would increase compared to the historical public investment during 2015-2020 (Table 5) (IRENA, 2021c). This higher annual investment would be dedicated to hydropower followed by solar, geothermal, biomass, onshore wind and concentrated solar power (CSP). From the data available, the greatest increase in investment is expected to be in hydro, followed by biomass. In the DES, the future annual investment in solar PV and geothermal would be roughly double the historical level, while the annual investment in wind technologies would be 3.8 times higher.

Table 5: Annual average historical and projected investment for the PES and DES

		ANNUAL AVERAGE INVESTMENTS (MILLION USD/YEAR)			SCALE FACTORS	
		HISTORICAL (2015 - 2020)	PES (2021 - 2050)	DES (2021 - 2050)	PES VS HISTORICAL	DES VS HISTORICAL
Power generation capacity	Hydro	98	320	1015	3.3	10.4
	Solar PV (utility and rooftop)	215	172	499	0.8	2.3
	Solar CSP	N.A.	N.A.	95	-	-
	Biomass	74	N.A.	268	-	3.6
	Wind onshore	78	184	102	2.4	1.3
	Geothermal	168	336	419	2.0	2.5

9 Historical values for hydro, biomass, wind and geothermal from (BNEF, 2021a). Solar PV represents public investment according to IRENA (2021c).

10 Investment in the electricity network includes investment in transmission and distribution and the expansion of SIEPAC.

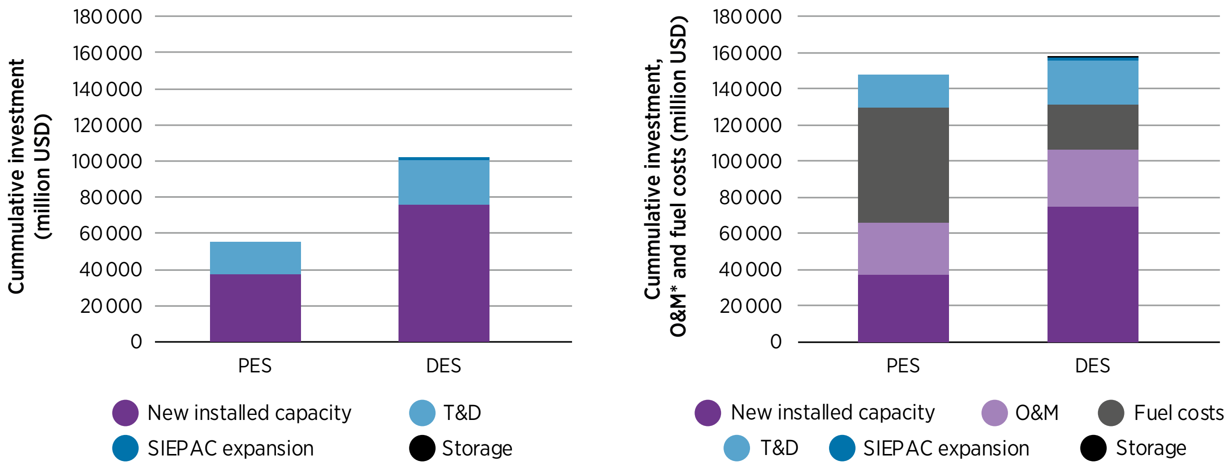
Table 5: Annual average historical and projected investment for the PES and DES (continued)

		ANNUAL AVERAGE INVESTMENTS (MILLION USD/YEAR)			SCALE FACTORS	
		HISTORICAL (2015 - 2020)	PES (2021 - 2050)	DES (2021 - 2050)	PES VS HISTORICAL	DES VS HISTORICAL
Grids and flexibility	Electricity network	N.A.	610	907	-	-
	Flexibility measures (*e.g.* storage)	N.A.	N.A.	9	-	-

Note: CSP = concentrated solar power.

The cumulative investment in the power sector over the 2021-2050 period in the DES would be almost double that in the PES, due mainly to the need to meet the higher electricity demand created by electrification of the fleet. However, if the costs of operations and maintenance as well as fuel are considered together with the investment, then the total power system costs in the DES are just 8% higher than those in the PES (Figure 21). Fuel costs in particular are considerably lower due to the additional use of local renewable energy resources such as hydro, solar and wind technologies, which have no associated fuel costs, as well as the use of biomass and wastes such as municipal solid waste and residues from regional industries, including bagasse from sugar cane (these costs were beyond the scope of the analysis).

Figure 21: Power sector cumulative investment (left) and cumulative investment, operations and maintenance, and fuel costs (right) for the 2018-2050 period under the PES and DES



*Operations and Maintenance

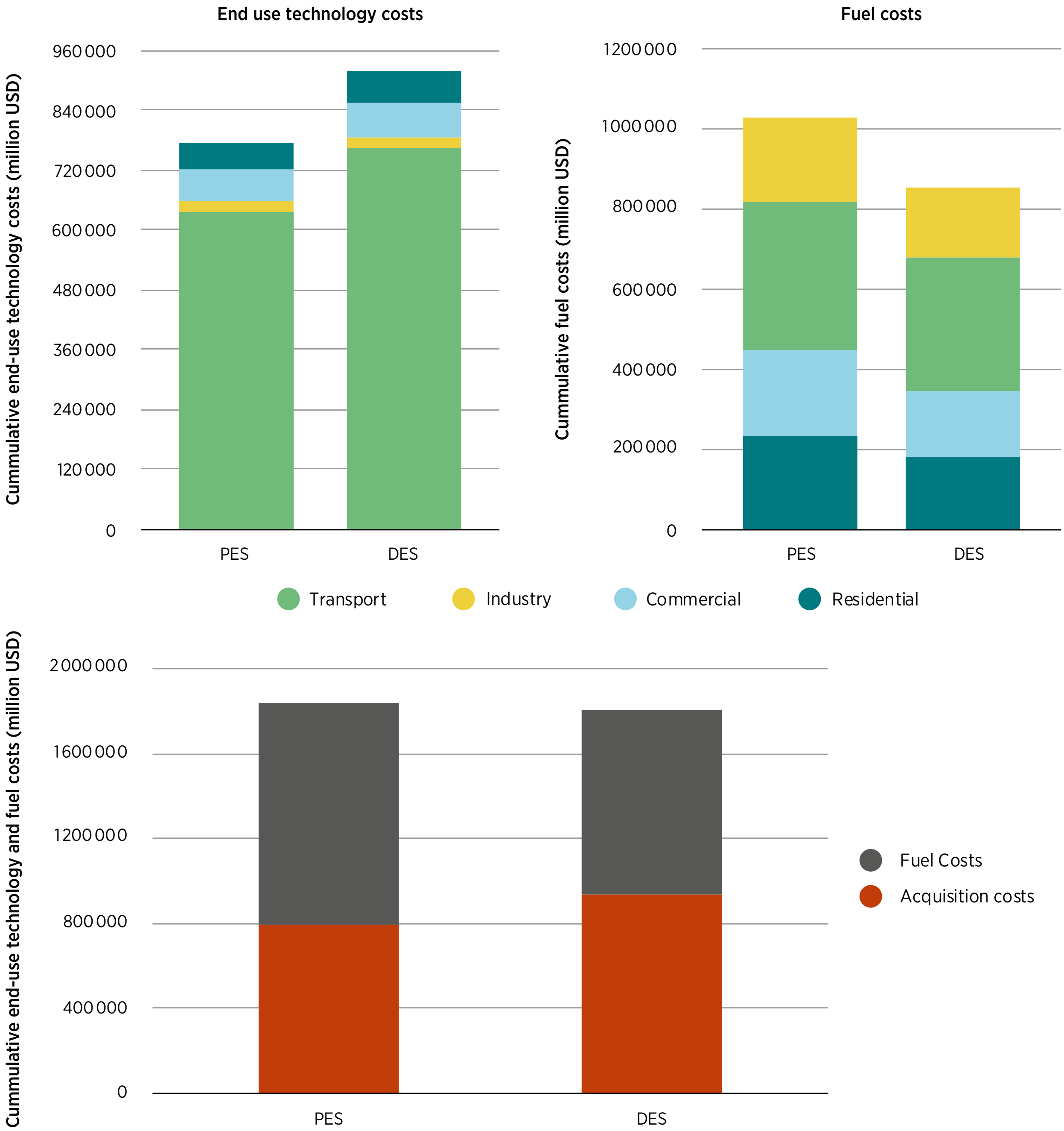
2.3 END-USE SECTOR TECHNOLOGY COSTS

In both the PES and the DES, the bulk of the end-use technology costs (period 2018-2050), are in the transport sector, accounting for 81% and 82% of these total costs, respectively.

As shown in Figure 22, the cumulative end-use sector fuel costs[11] for 2018-2050 decrease 18% in the DES compared to the PES, due to the implementation of energy efficiency measures, the use of more efficient technologies and cheaper fuels. Therefore, if the end-use technology costs and fuel costs are considered together for the 2018-2050 period, the total end use sector costs in the DES could be 1.5% lower than in the PES.

[11] Part of the fuel costs corresponds to electricity costs, which would be dedicated to recover the investment carried out in increasing the power sector installed capacity to meet the consumers electricity demand.

Figure 22: Cumulative end-use technology costs, fuel costs, and end-use technology and fuel costs for the 2018-2050 period under the PES and DES



Note: EUS = end-use sector; O&M = operations and maintenance

In addition, the end-use technology costs required for renewable and more efficient technologies during the 2018-2050 period, in particular in the later years of the analysis, will also result in fuel savings post-2050, benefits that are not considered in the current analysis. Moreover, the end-use technology costs needed in the DES focus on exploiting local energy resources and new technologies, which would require maintenance and service provision on-site, thereby creating local jobs and boosting the region's economy.

The results of this analysis of investment and end-use technology costs could provide valuable inputs to defining the investment and financial needs for SICA's Investment Plan Initial Platform (SICA, 2020).

Box 2. Transition cost benefit analysis

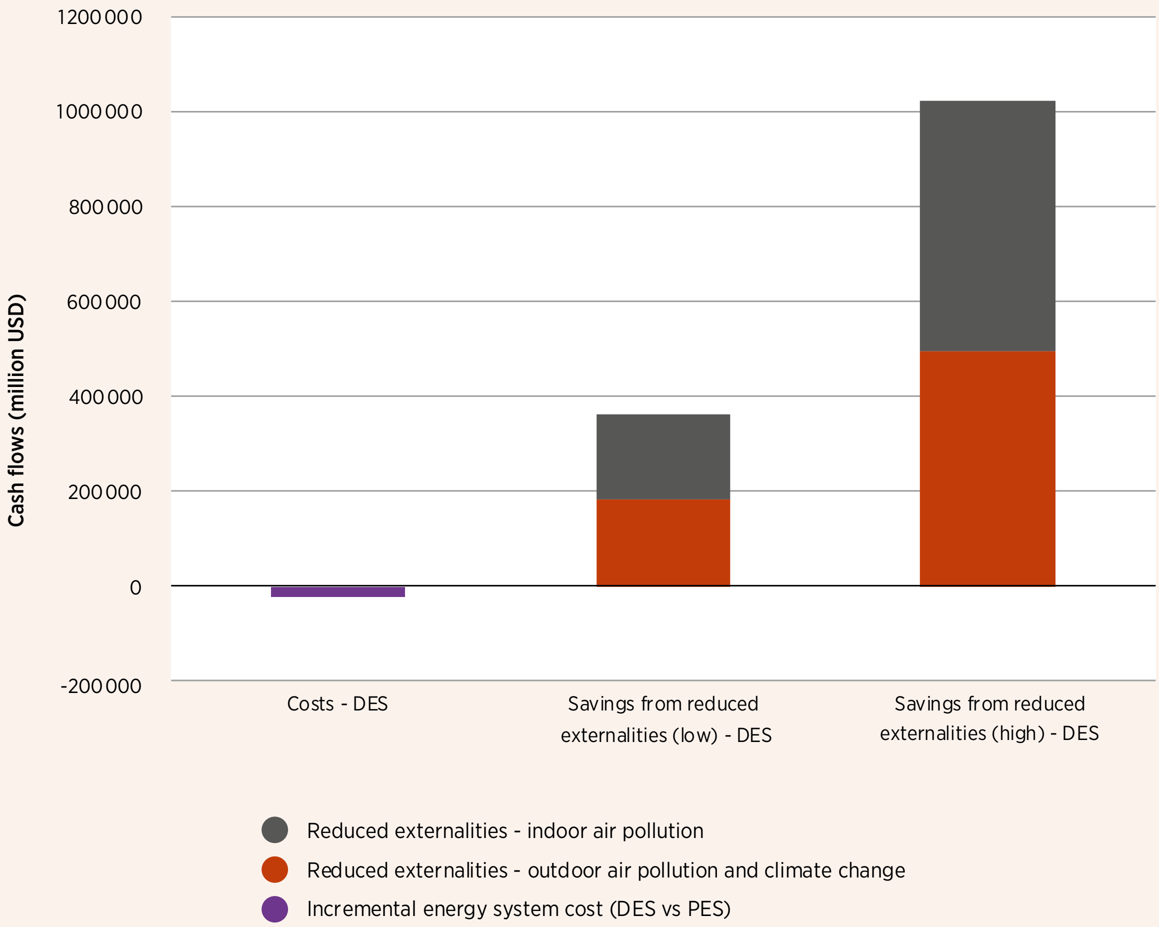
Estimates of the externalities related to outdoor and indoor pollution and climate change were calculated for the Central American region. The overall balance of investing in the DES scenario in comparison with the PES estimate is positive, with benefits exceeding costs.

If the investment in power sector, end-use sector technologies costs and fuel costs are considered together, the overall energy system cost for the scenarios PES and DES would be comparable. This means that the same amount of money would flow in PES and DES, however it would be distributed differently. Investment in the DES scenario could yield a cumulative payback through reduced externalities from human health and the environment of between USD 360 billion and 1 trillion by 2050 (Figure 23).

The savings from reduced externalities fall into two broad categories: outdoor air pollution and climate change, and indoor pollution:

- Outdoor air pollution and climate change represent half of the total. Climate change externalities are quantified using the social cost of carbon approach for the CO_2 emissions.
- Indoor pollution results from using traditional biomass in residential households and represent the remaining half of the externalities. This highlights the importance that providing access to clean cooking technologies and fuels to all the population has in the region.

Figure 23: Cumulative difference between energy system costs and savings from reduced externalities of the DES compared to the PES for the 2018 - 2050 period

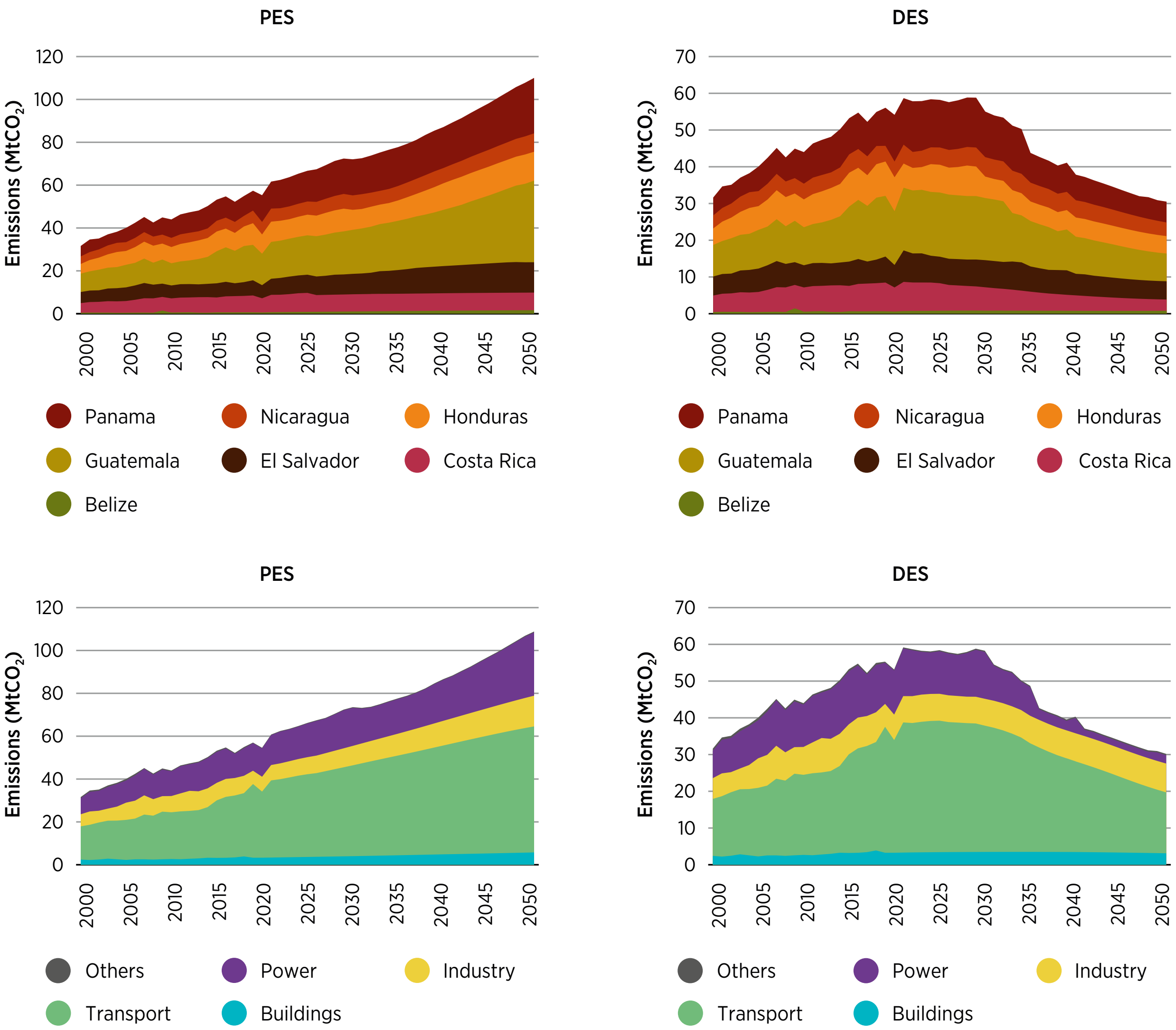


2.4 EMISSIONS

If the established energy targets in the DES are met and the investment and end-use technology costs are undertaken, emissions in 2050 would be reduced around 70% in the DES compared to the PES (Figure 24). In 2018, transport accounted for the highest share of regional emissions, at 54%, followed by the power sector (23%) and industry (15%). The transport sector will remain the highest CO_2 emitter in both the PES and the DES, contributing around 55% of emissions in each scenario in 2050. However, emissions from the sector in the DES 2050 will be 72% lower than in the 2050 PES due to the significant efforts towards fleet electrification.

Under the PES, emissions are expected to continue increasing to 2050 in all countries. Under the DES, all countries would contribute to the emission reductions, bringing emissions down around 70% in DES 2050 compared to 2050 PES (below 2018 levels). Transport and industry sectors would be the main contributors to the remaining emissions in DES 2050. These are derived from the use of the remaining internal combustion engine vehicles, mainly large trucks, and the use of fossil fuel technologies in the industrial sector. A deep-dive analysis in these sectors could be developed to characterise them and propose solutions for a further decarbonisation. Box 8 presents several alternatives to consider in hard-to-abate sectors like industry.

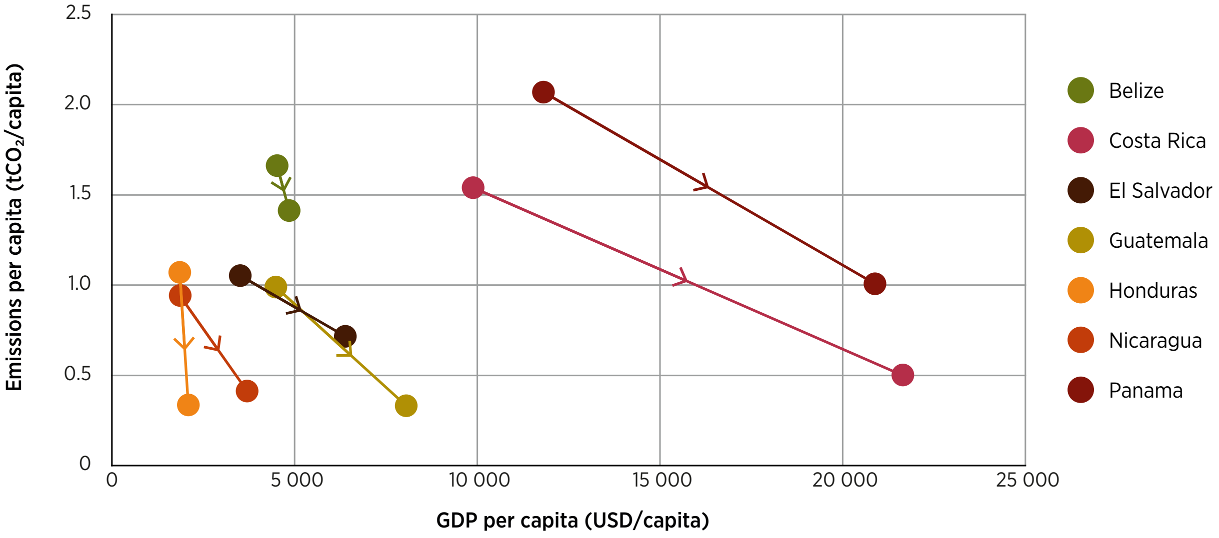
Figure 24: Historical emissions and emissions under the PES (left) and DES (right), by country and sector, 2000-2050



Source: Emissions for 2000-2018 extracted from Climate Watch(Climate Watch, 2021).

Figure 25 shows the evolution of per capita energy-related emissions from 2018 to 2050 in the DES. All countries contribute to the decrease in per capita emissions during the study period.

Figure 25: End-use and power sector emissions per capita with respect to GDP per capita, by country, in 2018 and under the DES in 2050



Box 3. Reducing remaining emissions in industry (IRENA, 2021b)

Central America does not have a high presence of carbon- and energy-intensive industries, such as iron and steel, cement, aluminium and chemicals. However, the region still hosts a diverse set of industries, mainly in the food and beverage, pulp and paper, and construction materials sectors (SICA, 2020). These industries will continue to represent a sizeable share (26%) of the remaining emissions in 2050 under the DES. Given the limited information available on these industries, as well as their diverse nature and relatively small scale, a detailed analysis of mitigation options was not performed for this study. However, based on the features of some of these industries, it is possible to offer general guidance on measures to help further mitigate industrial sector emissions.

Typically, there is large potential to improve energy efficiency in the industrial sector. One way to mitigate emissions in the sector is to maintain a strong focus on energy efficiency by making processes increasingly efficient and by setting or mandating minimum standards for energy efficiency and/or for the carbon intensity of fuels, processes and products. Incentives (*e.g.* through prices or taxes) for energy efficiency are often adopted with good results. In general, opportunities arise in the improvement of process efficiency, the adoption of demand-side management solutions, the introduction of highly efficient motors and the development of material recycling and strengthened waste management.

Industry can also benefit from corporate sourcing and self-generation of renewable electricity. In many countries, the conditions are not in place that allow industry to rely on self-generation or sourcing outside of the regulated market. Policy and regulation thus should allow for more flexibility if the electricity supply is from renewables and recognise the benefits of moving away from fossil-based generation. Allowing and promoting distributed energy resources on-site would enable industrial consumers to also produce energy (making them into prosumers) and to participate in ancillary services. Large consumers should take an active role in energy management services.

The supply of low-carbon heat is another area where industry can contribute emission reductions. One option is to develop sustainable bioenergy supply chains to meet the growing need for bioenergy in industry to supply low, medium- and high-temperature heat. Bioenergy can take the form of solid and liquid fuels and biogas. Low-carbon heat can also be achieved through alternative heating technologies such as solar thermal units, heat pumps and geothermal resources, especially for low- and medium-temperature applications.

These measures have been proposed to some extent as part of the scenarios developed in the present analysis. However, further research and analysis are needed to understand the full extent to which each of these measures can be implemented, considering technical and economical limitations in the region's context.

RENEWABLES IN THE POWER SECTOR

3

RENEWABLES IN THE POWER SECTOR

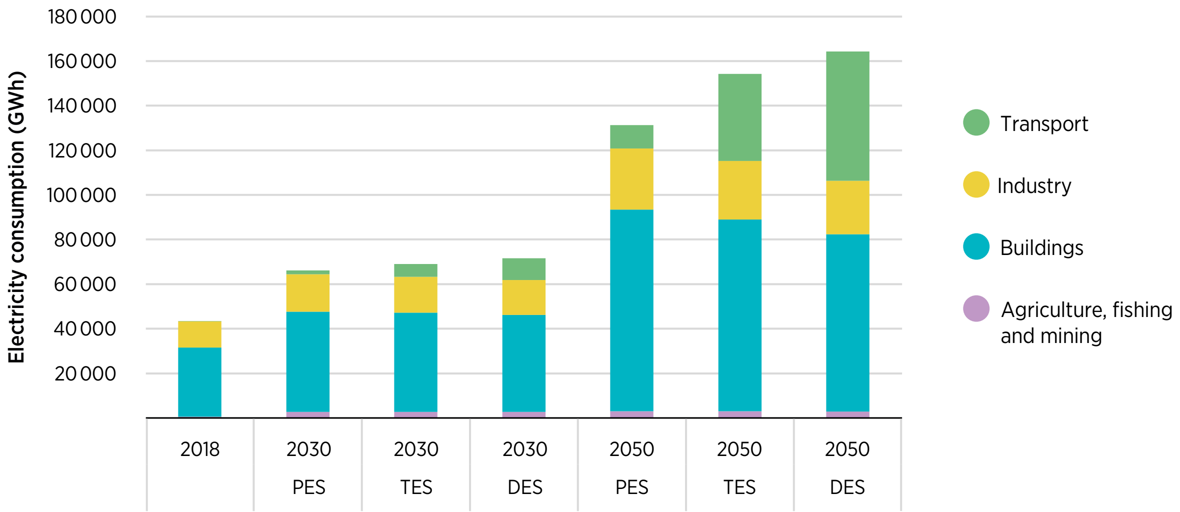
Increasing the use of renewable energy to generate electricity is key for decarbonising the power sector and for using renewables to electrify energy services in the end-use sectors. Two key solutions are available in the region: increasing renewable energy capacity and improving regional power system integration.

3.1 RENEWABLE ENERGY CAPACITY

In the DES, the annual deployment of renewable energy is scaled three-fold compared to planned deployment, to reach renewable capacity shares of nearly 75% by 2030 and more than 90% by 2050 (compared to 67% in 2018).

Renewable energy offers the chance to meet rising electricity demand while driving local economic growth, unlocking some of the lowest-cost electricity sources today and achieving carbon neutrality goals. Total direct electricity consumption[12] in the region is set to increase at least 50% by 2030 and between 300% and 400% by 2050 from 2018 levels (Figure 26, PES). Under planned conditions, annual power sector emissions double from 2018 levels by 2050, but the TES and DES show that this need not be the case. The TES and DES show how emission reductions of 80% can be reached while simultaneously achieving significant cost savings per unit of electricity through the increased use of domestic renewable energy resources.

Figure 26: Direct electricity consumption by end-use sector in 2018 and under the PES, TES and DES in 2030 and 2050



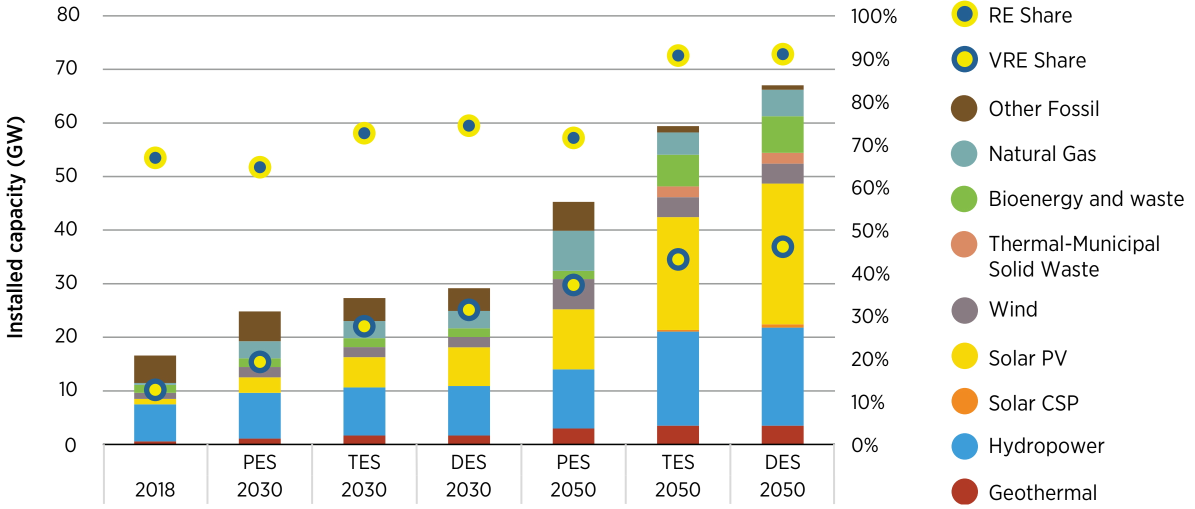
Generation capacity in the region needs to expand greatly in all scenarios to meet demand, regardless of the pathway. In the PES, capacity is expected to increase 66% to 25 GW by 2030 and 300% to 45 GW by 2050. The TES and DES reach total installed capacities of 55 GW and 65 GW respectively by 2050, driven by higher electricity demand and typically fewer full-load hours of renewable generation technologies, meaning that more capacity is needed to deliver the same demand.

[12] Total direct electricity consumption comprises electricity demand in the buildings, transport and industry sectors and does not account for indirect electricity demand, *i.e.* for hydrogen production.

Given the vast potential of renewable energy in the region, renewables will expand in all scenarios; however, in the absence of further policy, fossil fuels (mostly natural gas) will bridge much of the growth in energy demand from today's levels, reaching a total installed fossil fuel capacity of nearly 13 GW by 2050. The DES and TES show how this can drop to below 6 GW by 2050 and improve energy security by relying on domestic and regional resources.

Most notable is the growth in solar PV capacity (to 26 GW) and hydropower capacity (to 13 GW), which form the backbone of the power sector in the DES and TES. Under the PES, the renewable share of capacity remains at today's levels despite considerable growth in electricity demand to 2030 and 2050, indicating that renewables will feature in any future scenario due to their cost-competitiveness. However, as suggested in Figure 27, capacity-based renewable energy targets can be misleading.

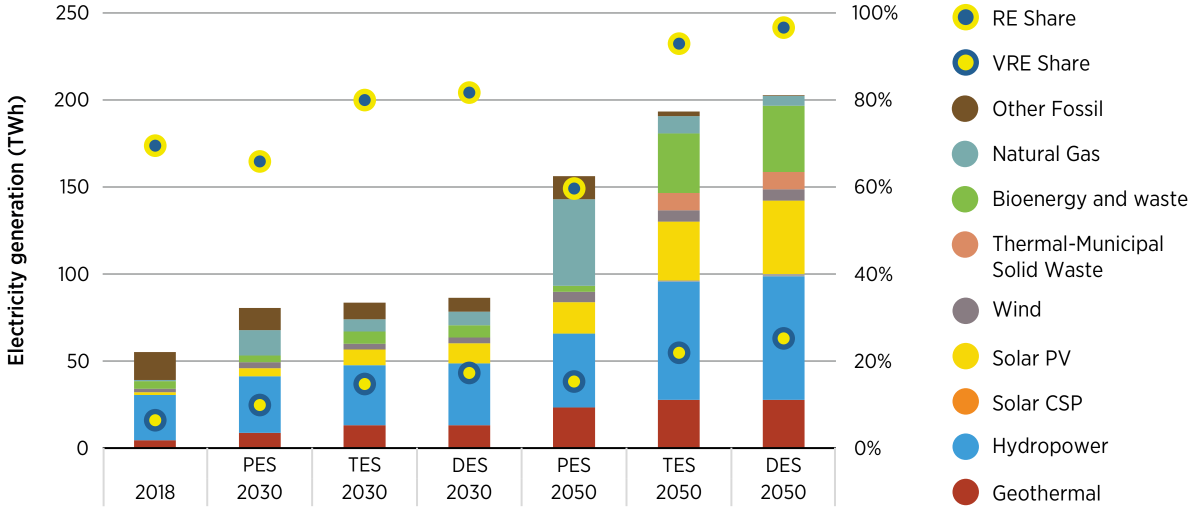
Figure 27: Installed generation capacity by technology and shares in 2018 and under the PES, TES and DES in 2030 and 2050



Note: RE = renewable energy; VRE = variable renewable energy; CSP = concentrated solar power

When generation is considered in the PES, without new policies in place, around half of the growth in electricity demand will be met with imported fossil fuel-based generation, leaving domestic energy sources largely untapped, with significant economic implications. The renewable share of power generation drops considerably under planned conditions even though the renewable share of capacity remains broadly the same (Figure 28).

Figure 28: Electricity generation by technology and shares in 2018 and under the PES, TES and DES in 2030 and 2050



Note: RE = renewable energy; VRE = variable renewable energy; CSP = concentrated solar power

While all three scenarios show the potential of solar PV, deployment so far has been limited. In 2018, the installed capacity of solar PV totalled less than 1 GW across the region, suggesting that capacity will need to grow by several orders of magnitude in all scenarios. In the PES, solar PV capacity reaches 2.9 GW by 2030, but under the TES and DES it reaches higher levels of 5.6 GW and 7.2 GW respectively. This trend is further accelerated by 2050, when the PES reaches 11 GW but the TES and DES reach 21 GW and 26 GW respectively. This corresponds to an average annual build rate in the PES and DES of 320 MW and 800 MW respectively, offering insight into the mobilisation of investment needed in solar PV. The scale of deployment is so great that harnessing both utility-scale and distributed rooftop capacity will be critical.

Hydropower will continue to play a key role in the power system of Central America, growing from a total installed capacity of around 7 GW in 2018 to 9 GW in 2030 in all scenarios. By 2050, however, this capacity will increase to 11 GW in the PES and 18 GW in the DES, which corresponds to average annual build rates of 130 MW and 355 MW respectively. Unlike solar PV, where the solar irradiance does not vary greatly across the region, an ambitious roll-out of hydropower will be concentrated in areas where the resource potential is located. This has significant implications for how the regional power system operates, the funding mechanisms needed and the regulation of the system to ensure fair competition and reliable operation.

Biomass and waste will also be crucial for diversifying the portfolio of power generation technologies in the TES and DES. These relatively untapped resources have a current installed capacity of around 1.5 GW, but this will grow to 7 GW by 2050 in the TES and DES, coming from a range of sources. While notable sugarcane production exists in many countries in the region, there is large untapped potential to expand on and retrofit existing capacity by using highly efficient boilers and harnessing all waste products from harvesting. Significant potential also exists to expand the collection and use of municipal solid waste and landfill gas to produce electricity while simultaneously avoiding landfilling, providing environmental benefits. While these resources are inherently variable, when combined with the variability of solar, hydro and other sources, they reduce the overall variability of the resources underpinning system operation.

The renewable energy share in power capacity and generation in the 2030 and 2050 DES are shown in Figure 29, which shows the progress between the two years.

Figure 29: Power generation installed capacity and generation, by country, under the DES in 2030 and 2050

Table 6 shows the investment needs in generation capacity for the power system and how this would evolve under the three scenarios. Total capital investment roughly doubles in the TES and DES, where it reaches up to USD 75 billion by 2050, compared to the USD 37 billion needed in the PES. Hydro, solar PV (utility and rooftop) and geothermal power are the biggest components of this investment, all of which deliver significant fuel cost savings as well as improvements in energy independence to 2050. These technologies, in addition to biomass, could be prioritised in building a portfolio of bankable projects for auctions so that this potential can be realised. Fossil fuel investments are also greatly reduced in the TES and DES, with both scenarios seeing reduced operation of fossil fuel generators, raising the serious prospects of stranded assets unless action is taken.

Table 6: Cumulative capital investment needs in generation capacity by technology between 2021 and 2050 in the PES, TES and DES

BILLION USD	PES	TES	DES
Geothermal	9.8	12.1	12.2
Hydroplant	9.3	27.6	29.4
Nuclear	-	-	-
Solar CSP	-	1.4	2.8
Solar PV	4.3	9.9	10.1
Solar PV (rooftop)	0.7	0.9	4.4
Thermal-Coal	0.3	-	-
Thermal-Diesel	-	-	-
Thermal-Fuel Oil	0.5	0.2	-
Thermal-Natural Gas	7.0	4.4	5.8
Biomass and Waste	-	6.4	7.8
Wind Turbines	5.3	3.0	3.0
Total	**37.2**	**65.9**	**75.4**

This implies the need to design electricity markets that value many of the non-energy services that these markets provide, such as synchronous inertial response, fast frequency response and ramping margin. Such market design would apply to all modes of generation that could provide these services. It would incentivise smart operation of the system, opening the door to innovations in the sector such as aggregators, distributed generators and demand-side management, which could also provide many of these services by improving their business case.

However, the effective use of these services will require high levels of system observability (a system cannot be managed effectively if only a portion of it is monitored and features actively in operational decisions) to enable smart power system operation to effectively leverage the value of all of its components. This would further unlock the benefits of low-cost renewables by enabling the use of a range of innovations in the areas of enabling technologies, business models, market design and system operation, as detailed in IRENA's innovation landscape report (IRENA, 2019a).

This operational flexibility will be a key enabler of the increased integration of variable renewable energy in the power system, as seen in the TES and DES. This will allow an increasingly weather-dependent electricity supply based on wind and solar to meet the evolving profile of electricity demand. Crucial in providing this flexibility will be expanding both domestic and international transmission and distribution systems in addition to electricity storage and demand flexibility.

The high share of variable renewable energy, mostly solar PV, in TES and DES could pose system operation challenges; thus, a flexibility analysis was performed in these scenarios for 2030 and 2050 using the IRENA FlexTool to assess these potential needs at an international level. No flexibility challenges were found in the 2030 scenarios, independent of the existing interconnection capacity between countries. However, as the penetration of variable renewables increases to 2050, some flexibility challenges might appear if the interconnection capacity remains at 300 MW and power system flexibility is not increased. Expanding domestic transmission and distribution systems will also be essential to facilitate this flexibility.

The analysis showed that expanding SIEPAC's line capacity to 2 GW, as is the case in the TES and DES, is a key enabling technology (as elaborated in the following section). It allows supply and demand to be balanced over a wider area and enables the region to tap into enormous economies of scale for the power sector by sharing resources that otherwise could not be realised. Such expansion reduces the need for duplication of efforts across the region by allowing for increased sharing of capacity rather than each national system needing to provide its own balancing and system services.

The SIEPAC expansion translates to an additional investment in interconnection of USD 1.7 billion, adding around 2.3% to the total capital investments shown in Figure 21. In addition to this investment, electrical storage capacity reaches up to 810 MW and 1.7 GWh in the DES, at an investment of USD 250 million, which corresponds to an additional investment of 0.3%. The proportional share of these investments belies the rich benefits that they unlock, given that they could reduce total power system costs by 7% per unit of power generated by 2050 compared to the PES.

3.2 REGIONAL POWER SYSTEM INTEGRATION

Fostering and improving regional power system integration could enable the region to further exploit an untapped renewable energy potential of around 180 GW.

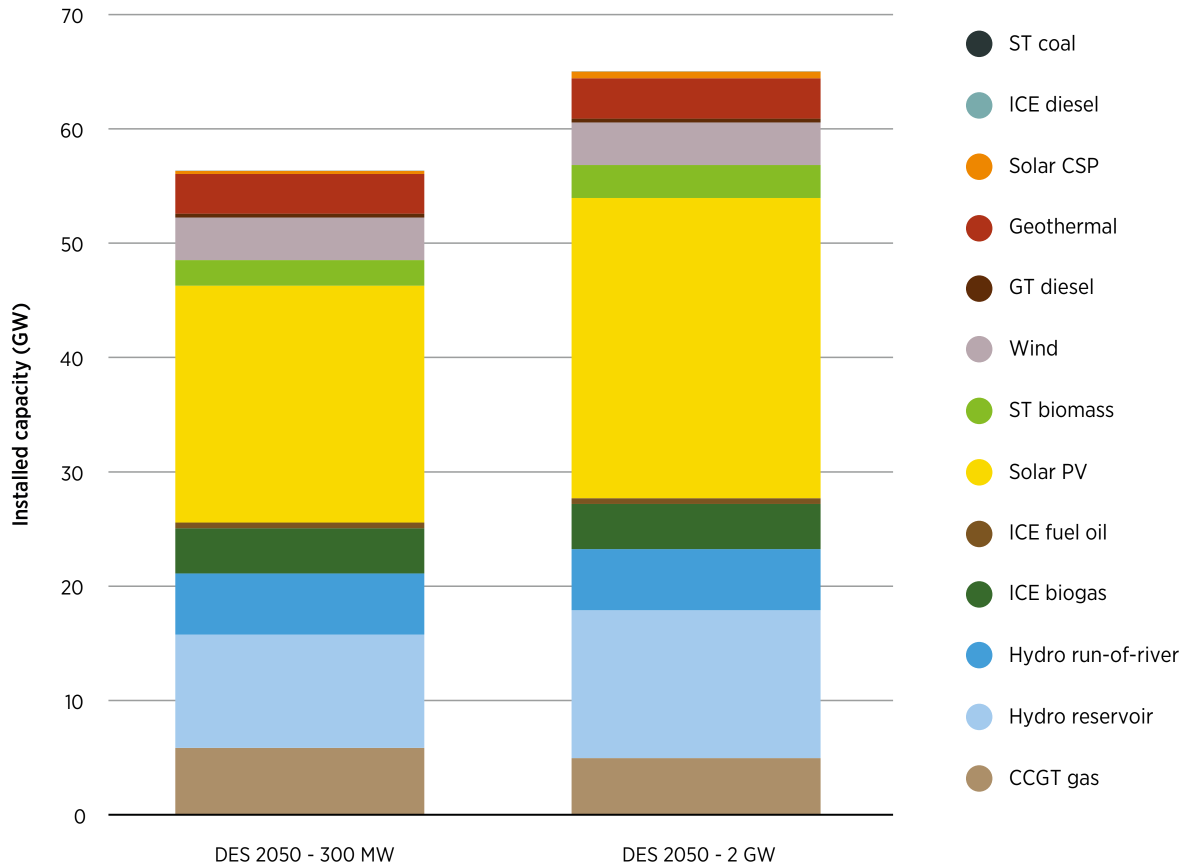
Co-operation among the Central American countries is key to ensure a reliable, low-carbon and cheap supply of electricity by fostering further integration of renewable sources into the system. The countries are currently interconnected via the SIEPAC line, a 230-kilovolt power transmission line with a net transfer capacity of up to 300 MW.[13] This line has been in operation since October 2014 and could be easily expanded to 600 MW if required (IDB, 2017). Thanks to the establishment of the Regional Electricity Market (MER), system operators or market operators from the member countries can also submit offers for importing or exporting energy more efficiently.

[13] Note that this is the maximum possible transfer capacity of the line. In reality, due to internal transmission bottlenecks in certain sub-stations in the region, the transfer capacity between some countries tends to be considerably lower.

Both the SIEPAC line and the MER benefit the region by decreasing total system costs and marginal prices, and fostering the integration of renewables, thereby reducing emissions (IDB, 2017). However, as both electricity demand and renewable energy capacity increase, so too will the power flows between countries, causing congestion of the SIEPAC line. This could lead to curtailment of renewables, rising price differentials between countries, higher CO_2 emissions and even loss of load if no additional measures are considered.

Under the DES, which has the most ambitious penetration of renewables, the optimal transfer capacity of the SIEPAC line by 2050 is around 2 GW. Figure 30 shows the difference in installed capacity and generation in the DES between keeping the SIEPAC capacity at 300 MW and increasing it to 2 GW.

Figure 30: Installed capacity by technology in the two interconnection scenarios under the DES in 2050



Note: CCGT = combined-cycle gas turbine; GT = gas turbine; CSP = concentrated solar power; RES = reservoir; ROR = run of river; ICE = internal combustion engine; ST = steam turbine

In the DES scenario with increased interconnection (2 GW), the installed capacity of renewable energy increases by 9.6 GW (mostly solar PV and hydro), and the installation of 900 MW of natural gas-fired plants is avoided. The renewable energy share increases from 86% to 90%, resulting in a decrease in annual power sector CO_2 emissions from 8.9 million tonnes to 2.6 million tonnes (*i.e.* around 60 grams to 20 grams of CO_2 per kWh generated). Because the emissions result mostly from natural gas generation, the difference in both interconnection scenarios is mainly because of this.

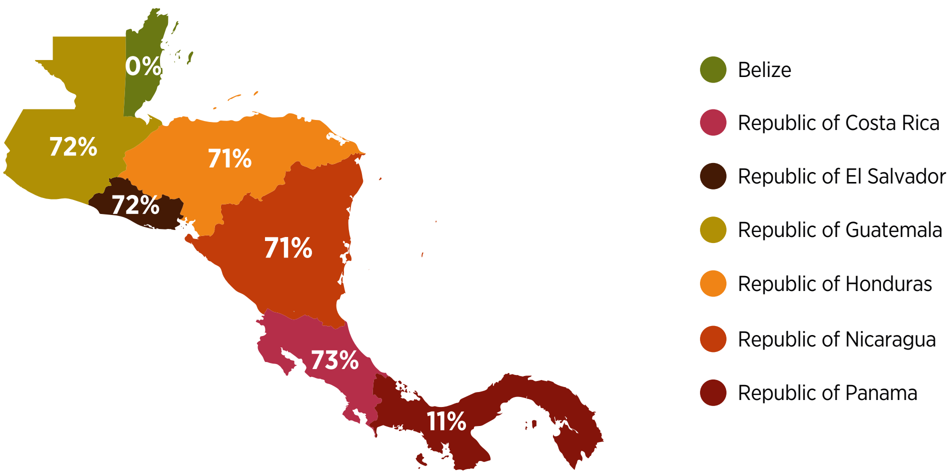
In the absence of increased interconnection, in 2050 around 7 terawatt hours (TWh) of mostly solar PV capacity is curtailed in the DES and 4 TWh is curtailed in the TES, and a very small share of electricity demand in some countries cannot be met. In this case, different flexibility options were considered separately to analyse their impact on the system. Simulations were carried out to consider smart charging of electric vehicles (unidirectional charging, not vehicle-to-grid; see Box 4), electricity storage and increased interconnection capacity.

In all three of these simulations, the loss of load disappears, and the curtailment of variable renewable energy is reduced considerably (*e.g.* electricity storage reduces curtailment in the DES 2050 from 7 TWh to 1.5 TWh). These simulations also present lower CO_2 emissions, higher renewable energy shares, lower marginal prices, and lower total system costs, as a capacity expansion problem was solved to obtain the cost-optimal capacity of these flexibility options. A combined scenario with different flexibility options was also simulated, resulting in the most cost-efficient scenario and showing that a basket of flexibility solutions is key.

In the 2 GW increased interconnection case, curtailment of variable renewable energy is reduced from 6.2% of the total potential to just 2.7%, and all customer load is met. Line congestion, which for some lines exceeds 7 000 hours annually in the 300 MW case, is reduced to the minimum. Additionally, given the importance of hydro generation in the region, a dry year sensitivity analysis was considered in the model. Although hydro capacity factors are already conservative in the main scenarios, a 25% reduction of annual inflows was considered, reaching an average capacity factor of around 32%. This sensitivity analysis showed that even if the year of study is dry, the system has enough installed capacity and flexibility to be operated, with only 0.17% of loss of load (which can be reduced to zero with the installation of solar PV and electricity storage in some regions) and very low renewable curtailment. A dry year, however, would have negative implications in terms of total system costs, marginal price, and CO_2 emissions due to the increase in fossil-fuelled generation to cover the most critical demand periods with low hydro and/or variable renewable energy availability.

The increase in interconnection would also have an impact on the marginal system price, and indirectly on the electricity tariff. While in the 300 MW case the average system price is different for every country in the region, in the increased interconnection case the price is the same[14] and lower as there is no transmission congestion[15] and this avoids market splitting. Figure 31 shows the marginal price reductions in the increased interconnection scenario under the DES in 2050.

Figure 31: Reduction of the marginal system price in the increased interconnection scenario under the DES in 2050



Note: Marginal system price refers to the price of the technology/power plant which would have to increase generation if demand is increased

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

14 Except for Belize, which is not interconnected with the SIEPAC line, and therefore the increased interconnection scenario does not affect the results.

15 Note that the model assumes that there are no internal transmission constraints within the countries

Increasing the net transfer capacity of the SIEPAC line also has considerable cost benefits.[16] Expansion of the line plays a key role in achieving 7% lower costs per unit of electricity generated by 2050 in the DES compared to the PES (where the line is not expanded). Mutual reliance in regional operation and planning thus has significant efficiency benefits and can help lower the costs for all while meeting a higher electricity demand.

In addition to the technical and economic benefits, increased interconnection could improve energy security in the region, with less macroeconomic risk for countries as their use of fossil fuels decreases.

Box 4. Innovation outlook: Smart charging for electric vehicles

IRENA's *Innovation outlook: Smart charging for electric vehicles* (IRENA, 2019b) shows that steady reductions in the costs of renewable power generation are making electricity an attractive low-cost energy source to fuel the transport sector. Scaling up the deployment of electric vehicles also represents an opportunity for power system development, with the potential to add much-needed flexibility in electricity systems and to support the integration of high shares of renewables.

However, achieving the best use of electric vehicles requires a close look at which use cases would align best for both the transport and electricity sectors. Optimally, electric vehicles powered by renewables can spawn widespread benefits for the grid without negatively impacting transport functionality. For that, smart charging and smart charging infrastructure are key, providing an intelligent interface that enables charging cycles that are adaptable to both the conditions of the power system and the needs of vehicle users.

Among other aspects, IRENA's innovation outlook discusses the potential impact of electric vehicle charging on the electricity distribution systems in cities and showcases how smart charging could reduce the investment associated with reinforcing local grids. The report also highlights the ability of smart charging of electric vehicles to facilitate the integration of variable renewable energy sources, including in and around cities. The discussion further explores the possible impact of other disruptive technologies that can potentially transform urban transport, such as autonomous vehicles and mobility-as-a-service.

16 Operational reserves were not modelled in detail; however, it would be useful to analyse the possibility of sharing reserves through a regional ancillary services market, as is done in European balancing markets, bringing additional benefits (ENTSO-E, 2018).

Renewables in the power sector: actions needed for the period 2018-2030 and 2030-2050

ACTIONS DONE BY 2030

- Build a portfolio of bankable renewable energy projects prepared for auctions.
- Encourage roll-out of distributed energy resources.
- Expand transmission and distribution systems within countries to untap the renewable energy potential, allowing low emissions and low-cost generation.
- Increase interconnection capacity between countries in the region by 1.5 GW.
- Create a regional balancing and ancillary services market to share operational requirements among countries.
- Develop strategies for smart charging of electric vehicles.

ACTIONS DONE BY 2050

- Enable smart operation of transmission and distribution systems so that distributed energy resources and appliances can be harnessed.
- Install energy storage to further integrate renewable energy, especially solar PV.
- Enable demand-side flexibility with time-of-use tariffs and aggregators.
- Establish regional integrated market and system operation.
- Enhance regional joint governance on energy planning, market trade and system operation.
- Install electrolysers for domestic production of green hydrogen and power system flexibility.

CONTRIBUTIONS TO THE REGION

- Increased investment and stimulus to the economies – post-COVID-19 recovery process.
- Generation of employment for the installation and operations and maintenance of stock.
- Increased energy security by reducing fossil fuel dependency.
- Avoidance of fossil fuel lock-in and positions the region to take advantage of highly innovative technologies, spurring local innovation.
- Reduction of total system costs, as well as marginal system price.
- Reduction in local pollution.

COMPLIANCE WITH CURRENT REGIONAL STRATEGIES

- EES2030
- Euroclima+

TECHNICAL/ FINANCIAL PARTNERS

- World Bank
- Inter-American Development Bank
- CABEI – Central American Bank for Economic Integration
- CAF – Development Bank of Latin America

ELECTRIFICATION IN THE END-USE SECTORS

4

ELECTRIFICATION IN THE END-USE SECTORS

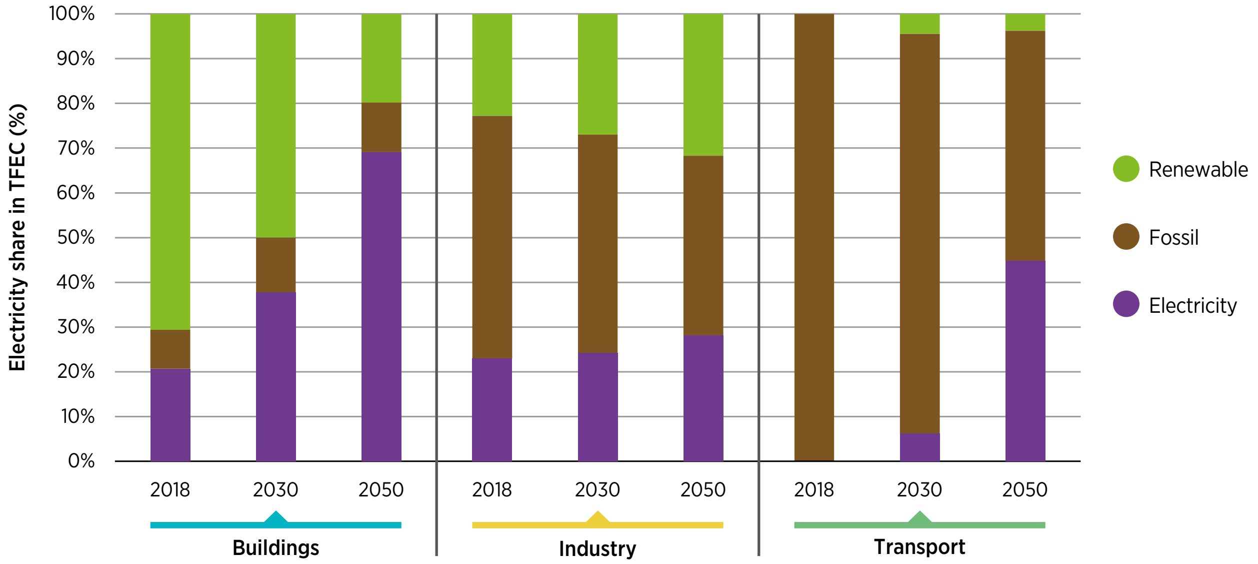
When the electricity generation mix is predominantly renewable, the electrification of certain energy services in the end-use sectors could trigger numerous benefits, as described in the following sections.

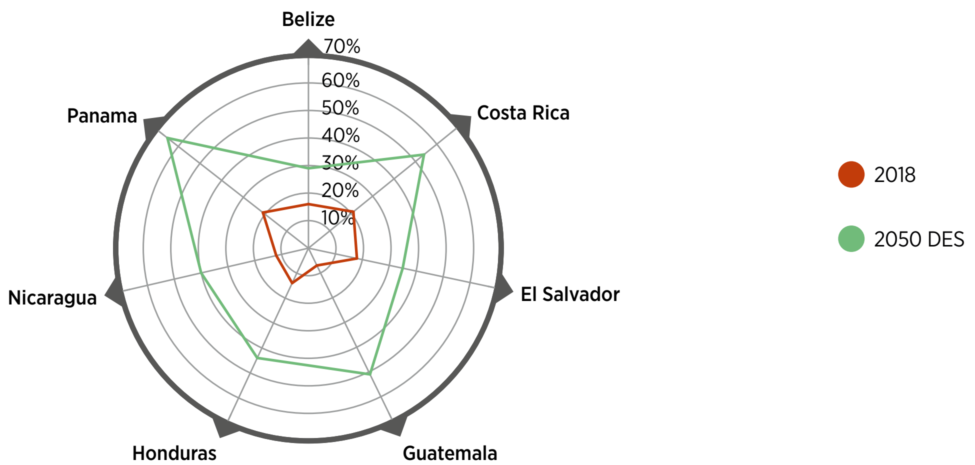
4.1 ELECTRICITY USE IN TOTAL FINAL ENERGY CONSUMPTION

In the DES, the share of electricity in total final energy consumption increases from 13% in 2018 to 50% in 2050, helping to reduce the fossil fuel share from 50% in 2018 to 33% in 2050, with end-use technology costs of around USD 500 billion.

The electrification of energy services in the end-use sectors will result in a greater share of electricity in total final energy consumption, compared to fossil fuels, as shown in Figure 32.

Figure 32: Electricity share in total final energy consumption by sector in 2018 and under DES in 2030 and 2050, and share by country in 2018 and under DES in 2050





Electrification of the transport sector is expected to be moderate in the PES, with the share of electricity in transport energy demand reaching just 4% in 2050 from 0% in 2018. In the DES, in contrast, strong electrification efforts occur and the electricity share in transport energy demand rises to 44% in 2050.

The share of electricity use in the buildings sector increases from 20% in 2018 to 40% in the PES 2050 and 70% in the DES 2050. This is due mainly to the decrease in demand for traditional renewables, specifically fuel wood, triggered by reductions in the use of traditional cookstoves

The electricity share in the industry sector is expected to grow from 23% in 2018 to 26% in the PES 2050 and 28% in the DES 2050. Despite this slight difference in electricity shares in 2050, the contribution of fossil fuels decreases in the DES compared to the PES, while the share of modern renewables increases.

Technology costs[17] of USD 500 billion would be required to cover the electrification of end-use sectors in the DES, for period 2018-2050. Nearly all of this (97%) would be spent in the transport sector, for the purchase of electric vehicles (82%) and related charging infrastructure (18%). Table 7 shows the specific cost needs for each sector.

Table 7: Cumulative end-use technology costs for electrification of end-use sectors the 2018-2050 period under the DES

END-USE SECTOR	SUB-SECTOR	TECHNOLOGY COSTS (MILLION USD)
Transport	Electric vehicles	399 146
	Infrastructure	86 831
Residential buildings	Cooking	11 493
	Heating	1 080
Commercial buildings	Cooking	393
	Heating	102
Total		**499 045**

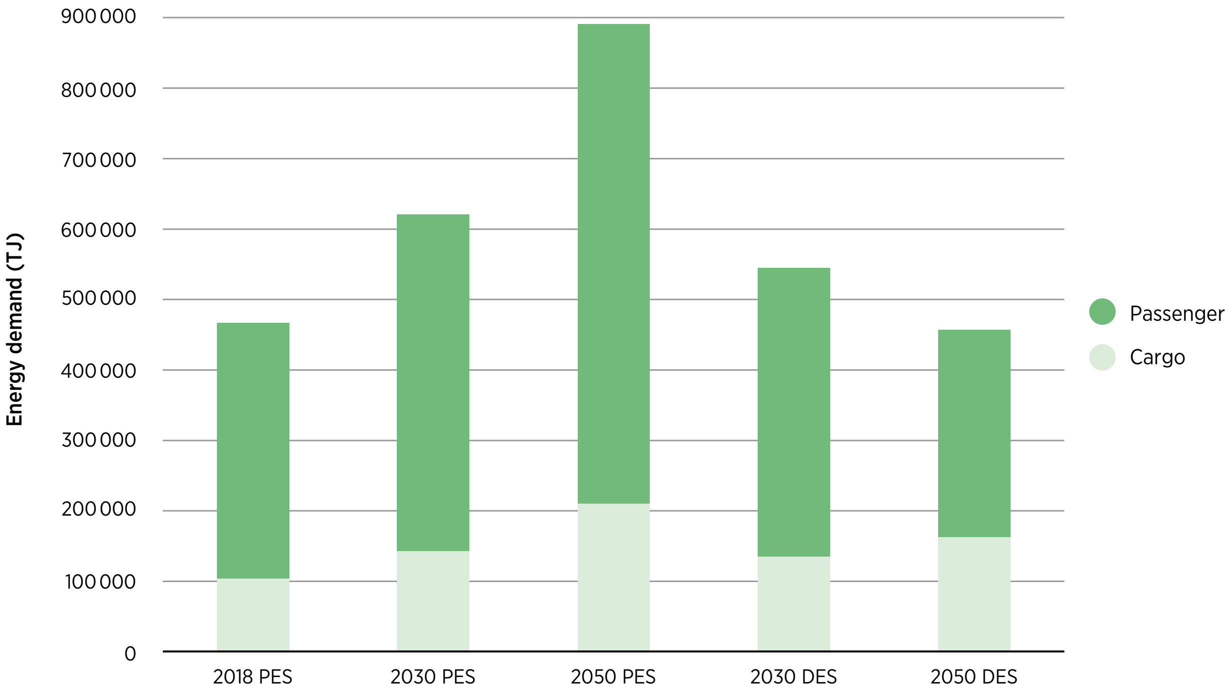
Note: Electric vehicles includes the acquisition costs of electric motorcycles, cars, SUVs, Vans, minibuses, buses and small and large trucks. Transport Infrastructure includes the acquisition cost of private and public electric vehicles chargers. Cooking includes the acquisition costs of electric stoves. Heating includes the acquisition cost of electric heaters.

Energy demand in the transport sector could decrease considerably if the measures proposed in the DES are implemented,[18] as shown in Figure 33. Most of this decrease is achieved thanks to the implementation of measures in passenger transport, mainly electrification of the fleet. Electric vehicles require about 80% less energy per kilometre travelled compared with the internal combustion engine vehicles, being considerably more efficient. Consequently, fleet electrification efforts will be key for reducing energy demand.

17 Costs in transport infrastructure refer to public and private chargers for electric vehicles, and in residential and commercial cooking and heating refer to electric heaters and electric cookstoves. Industry electrification measures could not be defined in the analysis due to the low characterisation of the regional industry sector.

18 The set of measures proposed in the DES for the transport sector are indicated in the section "Sector action required now".

Figure 33: Energy demand by transport sub-sector in 2018 and under the PES and DES in 2030 and 2050



In the residential and commercial buildings sector in 2018, cooking was the most energy-demanding service due to the large share of inefficient traditional cookstoves, followed by space heating (relevant only in Guatemala, where open fire is used for this activity) (Figure 34). For 2050, the greatest energy savings under the DES would be obtained by implementing measures in cooking in residential buildings and in space cooling and cooking in commercial buildings.

Figure 34: Energy demand by energy service in the residential and commercial buildings sector in 2018 and under the PES and DES in 2030 and 2050

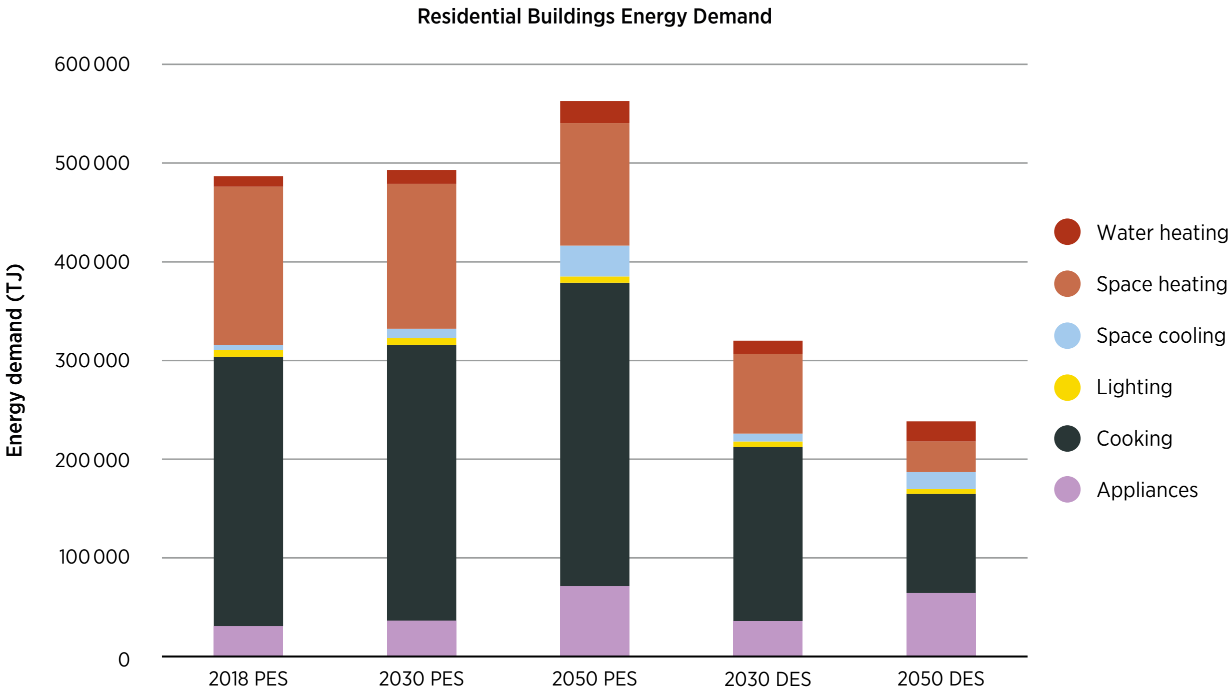
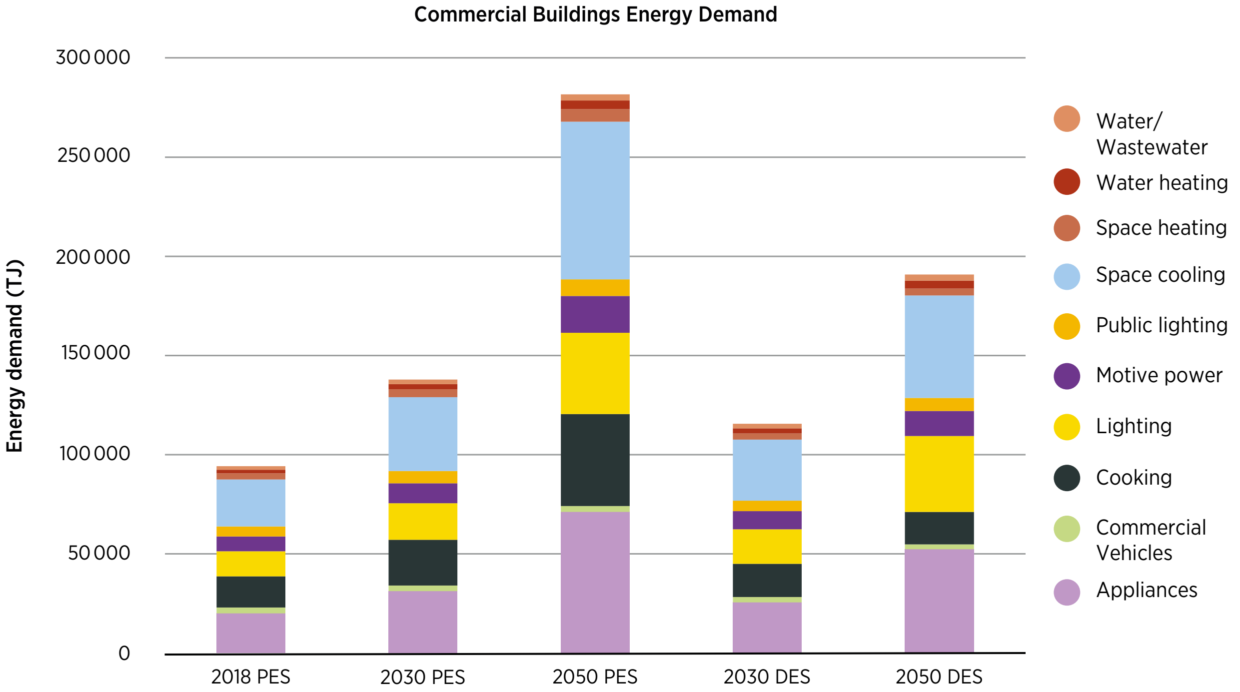


Figure 34: Energy demand by energy service in the residential and commercial buildings sector in 2018 and under the PES and DES in 2030 and 2050 (continued)



The electrification of energy services in the end-use sectors could be key for the post COVID-19 economic recovery, as it provides opportunities for local investment and industrialisation on a regional scale, as well as increasing the employment rate in the countries. Additionally, the increase in electricity use would decrease the need for fossil fuels, which are not readily available in the region, thereby increasing energy security and reducing local pollution. As Central America continues to grow, infrastructure development is needed that takes into consideration energy transition objectives and resiliency to climate change.

4.2 ELECTRICITY USE IN THE TRANSPORT SECTOR

In the DES, 77% of the passenger fleet and 53% of the cargo fleet are electrified by 2050, which requires average annual sales of around 190 000 electric vehicles by 2030 and 1.1 million by 2050. With this, transport sector emissions decrease 72% in 2050 in the DES compared to the PES. Fossil fuel demand of around 8 exajoules is avoided between 2018 and 2050 in the DES compared to the PES, equivalent to 17 times the transport fossil fuel demand in 2018.

Several countries in Central America as well as regional entities and committees have defined plans, strategies, programmes and targets to foster electro-mobility as an opportunity to decrease transport sector emissions (PNUMA, 2021). Transport is a major contributor to countries' CO_2 emissions inventories, accounting for 55% of the roughly 55 million tonnes of CO_2 emitted by the region's energy sector in 2018.

The REmap analysis integrated these measures in the PES and increased them for the TES and DES by 2050. For the DES, it was assumed that all type of vehicles used for passenger and cargo transport can be electrified, reaching shares of 18% in the passenger fleet and 13% in the cargo fleet by 2030.

Electrification of the transport sector occurs primarily in cars (39% of the passenger fleet in 2050 DES) followed by motorcycles (31% in 2050 DES), since these vehicle types have the highest shares in most countries' fleets in the region (Figure 35). Figure 36 shows the vehicle units of the higher shares of electric passenger and cargo vehicles in 2030 and 2050 in the DES.

Figure 35: Share of road transport vehicles by type in 2018 and under the PES and DES in 2030 and 2050

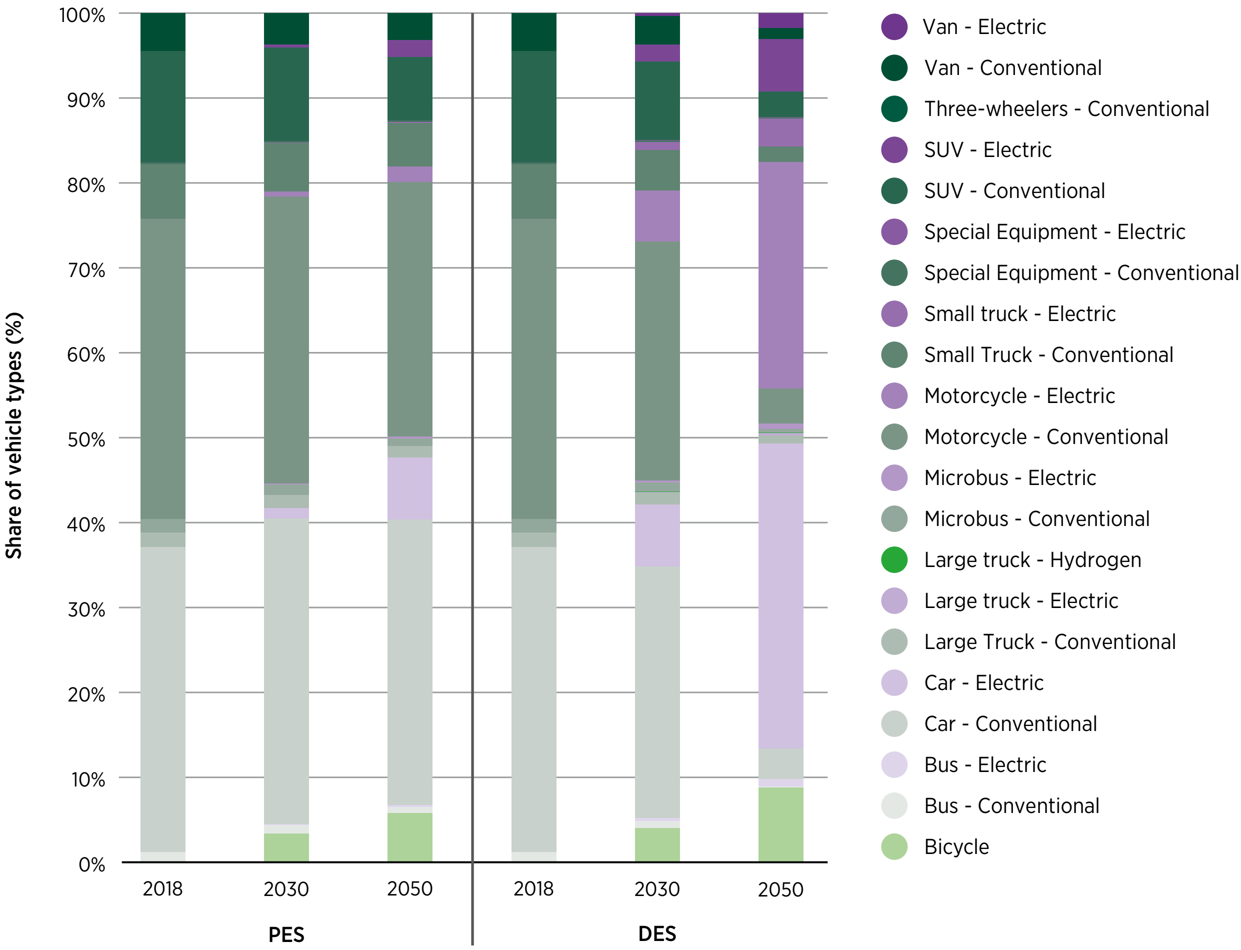


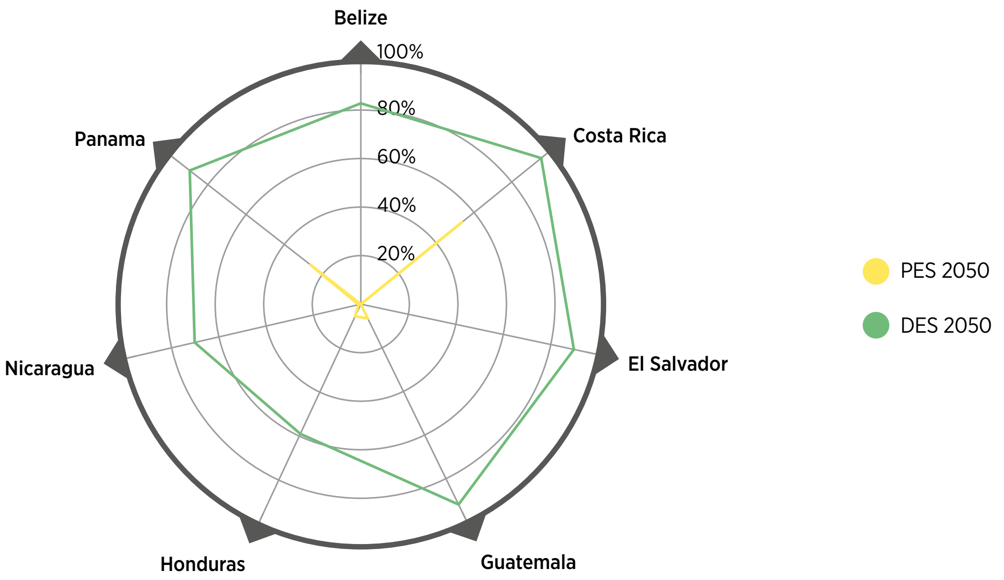
Figure 36: Electric vehicle stock by vehicle type under the DES in 2030 and 2050

	2030	2050
E-Cars	**1.04 million**	**9.4 million**
E-Buses	**45 thousand**	**231 thousand**
E-Motorcycles	**857 thousand**	**7 million**
E-LD Trucks	**131 thousand**	**853 million**
E-HD Trucks	**11 thousand**	**68 thousand**

Note: LD = light-duty; HD = heavy-duty.

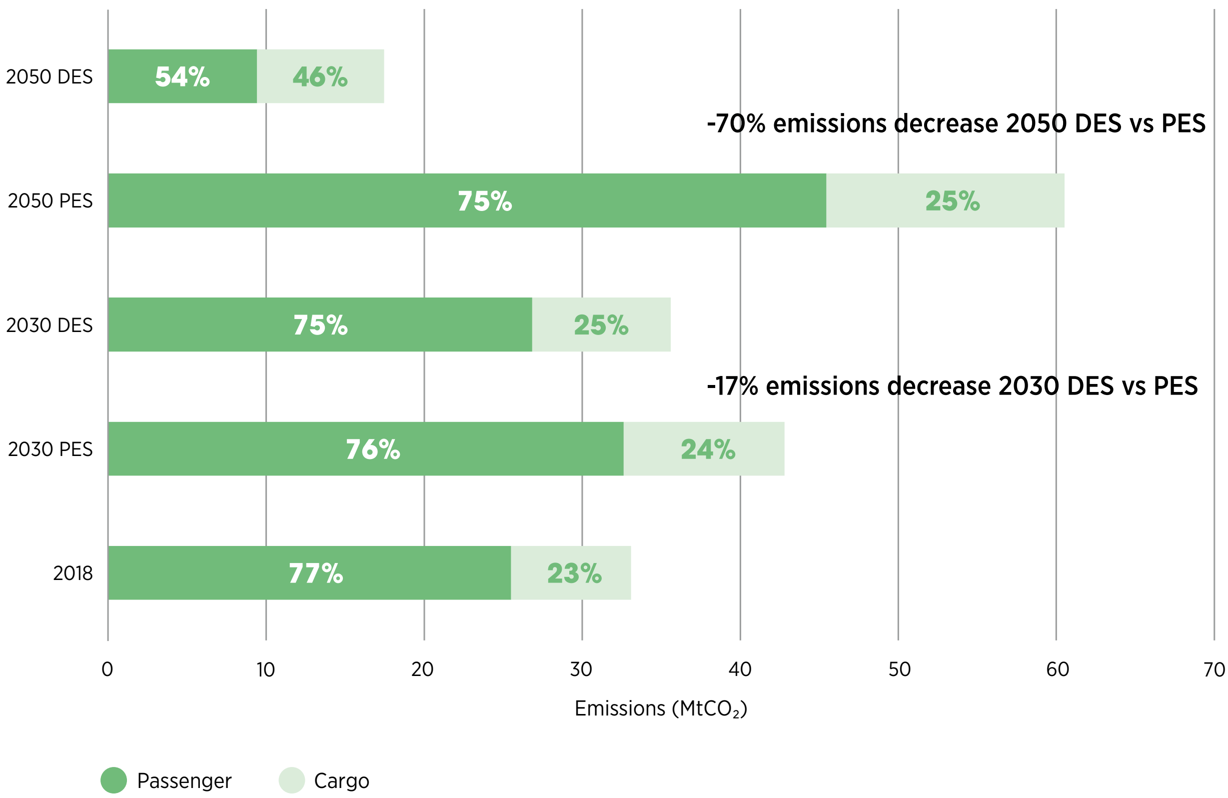
Figure 37 shows the share of electric vehicles in the fleet by country in 2050 under the PES and DES, indicating overall efforts to decarbonise the transport sector. Costa Rica and Panama are considering ambitious targets in their current plans for fleet electrification. According to estimates, less than 1% of the region's overall fleet is currently electrified.

Figure 37: Share of electric vehicles in the fleet by country under the PES and DES in 2050



By sub-sector, passenger transport contributed the highest share of emissions in 2018 due to the large share of cars and motorcycles in the region's fleet (Figure 38). With the introduction of electric vehicles, the emission contribution of passenger transport relative to cargo transport decreases, from 77% in 2018 to 54% by 2050 under the DES.

Figure 38: Emissions by transport sub-sector in 2018 and under the PES and DES in 2030 and 2050



Electrification of the fleet requires building out the appropriate charging infrastructure. Table 8 shows the number of electric chargers by type and size that would be required under the DES, with small private chargers predominant. Developing this infrastructure would require cumulative costs of USD 86.8 million over the 2018-2050 period. Additionally, the power grid would need to be reinforced to provide reliable service to all electric vehicle users, considering flexibility measures such as smart charging. The associated investment for this was covered earlier in the USD 24.6 billion cumulative investment in transmission and distribution during the 2018-2050 period, as shown in Figure 20.

Table 8: Number of electric chargers by type and size in 2030, 2040 and 2050 under the DES

TYPE OF ELECTRIC CHARGER	2030	2040	2050
Small private charger	1 115 154	4 887 439	9 199 899
Large private charger	226 086	747 233	1 343 442
Small public charger	111 515	488 744	919 990
Large public charger	11 304	37 362	67 172

Note: Small private chargers refer to home chargers of typically 3.6 kW to 7 kW for motorcycles, cars and sport utility vehicles (SUVs); small public chargers refer to chargers of typically 22 kW. Large private and public chargers refer to chargers of <50 kW for vans, mini-buses, buses, and small and large trucks.

Box 5. Status of battery technology

Battery storage is a key building block of the transformation towards net zero emission energy systems. Inexpensive, mass-produced batteries will enable cost-effective decarbonisation of the road transport sector, which currently accounts for around one-fifth of global energy-related CO_2 emissions. Batteries can store cheap, carbon-neutral solar and wind generation, contributing to the safe, reliable operation of power systems with very high shares of renewables. Batteries can also support a wider range of services in the power sector, including frequency response, reserve capacity and black-start capability, among others (IRENA, 2017).

Battery technology has experienced impressive progress over the last decade, with costs declining around 90%. The cost of lithium-ion battery packs, typically used in electric vehicles, exceeded USD 1 100/kWh in 2010 but fell to USD 137/kWh by 2020 (BNEF, 2020). If current trends continue, average costs could soon break the USD 100/kWh mark, a figure often cited as the threshold for light-duty road vehicles to reach up-front cost parity with internal combustion vehicles. By 2030, battery pack prices could reach USD 61/kWh (BNEF, 2021b), further improving the cost competitiveness of electric vehicles.

At the same time, the global battery production capacity is growing exponentially. Battery production capacity for electric vehicles reached 180 gigawatt hours per year in 2020, and the pipeline for large battery factories (>1 GWh capacity) now includes 181 plants with a planned capacity of 3 terawatt hours per year by 2030 (Moores, 2021). Such capacity would enable the production of 48 million light-duty vehicles annually, more than half of the global market in recent years.*

Existing battery technology is quickly reaching commercial maturity to enable decarbonisation of some energy services, for example, road transport, short-term power storage and ancillary services. Long-duration power storage (tens to hundreds of hours), aviation and maritime shipping are candidates to benefit from improved battery technology in the future. Each of these applications requires batteries that are optimised for their specific needs (Trahey et al., 2020).

*Assuming that 80% of the production is dedicated to light-duty electric vehicles, and an average battery pack size of 50 kWh.

Source: IRENA, 2021b

Electricity use in the transport sector: actions needed for the period 2018-2030 and 2030-2050

ACTIONS DONE BY 2030

- Organise working committees integrating public and private institutions and possible technical/ finance partners.
- Assess the current situation of the sector to identify barriers and define priorities.
- Develop specific plans and strategies for sustainable mobility (*e.g.* Costa Rica, Panama).
- Implement pilot projects (*e.g.* Costa Rica, Panama).
- Undertake efforts to finance investment in electro-mobility – *e.g.* current initiatives by banks and governments providing clients with special bank loans conditions for electric vehicle acquisition (UNEP, 2021).
- Deploy charging infrastructure and grids for electric vehicles.
- Develop business models and regulation for electric vehicle charging.
- Deploy smart charging solutions and design a tariff framework with local and regional funcionalities.
- Reduce transport volume and congestion through modal shift (switch 2.5% of distance travelled from cars to bikes, and 5% of distance travelled from cars to electric buses).

ACTIONS DONE BY 2050

- Accelerate the shift to electro-mobility by giving electric vehicles priority access in cities.
- Explore introduction of other modal shifts solutions (*e.g.* railways in major citiies)
- Improve transport infrastruture, network systems and stock.

CONTRIBUTIONS TO THE REGION

- Increased investment and stimulus to the economies – post COVID-19 recovery process.
- Generation of employment for the installation, operations, and maintenance of stock and required infrastructure, considering gender equality for job applications.
- Reduction in fossil fuel imports, with the corresponding impact on goverment expenses, plus greater en*ergy* security from using local renewables for electricity generation.
- Reduction in local pollution.

COMPLIANCE OF CURRENT REGIONAL STRATEGIES

- EES2030
- MOVE Latam – Electromobility in Latin America
- Euroclima+

TECHNICAL/ FINANCIAL PARTNERS

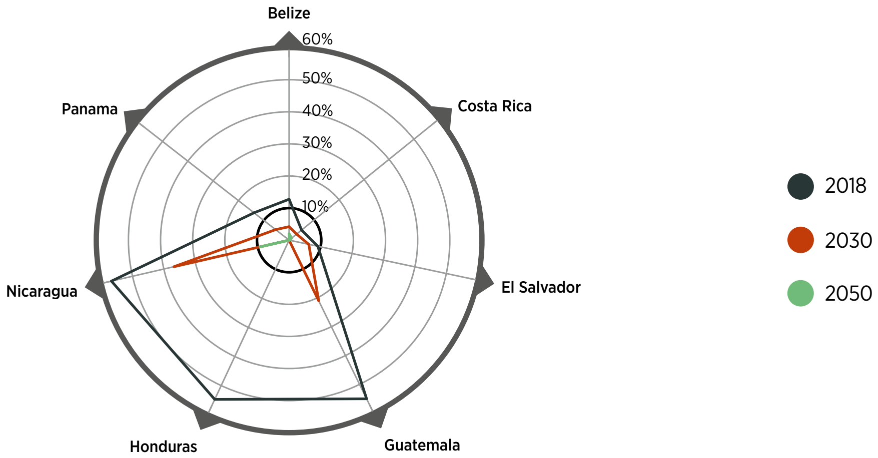
- World Bank
- Inter-American Development Bank
- CABEI – Central American Bank for Economic Integration
- CAF – Development Bank of Latin America

4.3 ELECTRICITY USE IN COOKING

In the DES, improved cookstoves and electric cookstoves increase 8.6 times by 2050 compared to 2018, helping to achieve the goal of providing access to clean cooking technologies and fuels to all.

As of 2018, 37% of households in the region, or around 18 million people, did not have access to clean cooking technologies and fuels, which results in indoor pollution and health problems, particularly for women and children. Concentrations of fine particulate matter (PM 2.5) were highest in Guatemala, El Salvador and Honduras (with annual mean levels of 25-35 μg/m³), followed by Belize, Costa Rica and Nicaragua (15-25 μg/m³) and Panama (10-15 μg/m³) (WHO, 2021). The highest shares of traditional cookstoves in 2018 were in Nicaragua, Guatemala and Honduras followed by Panama (Figure 39).

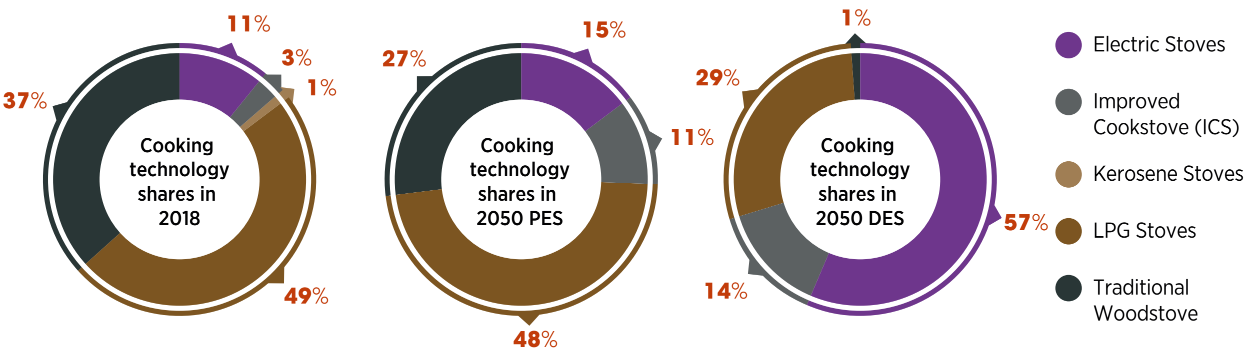
Figure 39: Share of households using traditional cookstoves by country in 2018 and under the DES in 2030 and 2050



The collection of fuel wood falls mainly on women and occupies a large part of their time (ECLAC, 2020). Introducing clean cookstoves and clean cooking fuels could free more time for women to engage in educational or paid economic activities. In addition, women would be less exposed to health problems and other risks from pollutants emitted during cooking or accidents and from dangers during harvesting. Finally, the introduction of clean cookstoves and clean cooking fuels could represent an opportunity for women to be involved in cookstove-related businesses and projects (*i.e.* restaurants, catering, and cookstove production and distribution). This would lead to income generation, empowering women financially and giving them greater household decision-making power (GINN, 2021).

The region is already making efforts to reduce the use of traditional cookstoves, as reflected in the PES. In this scenario, the share of traditional cookstoves reaches 27% in 2050, and of electric stoves reaches 15%. However, in the DES further efforts to promote the use of clean and efficient technologies occur. In this scenario, the shares for electric stoves reach 28% in 2030 and 57% in 2050, while the shares for traditional cookstoves are 13% and 1% respectively (Figure 40).

Figure 40: Share of cooking technologies by type in 2018 and under the PES and DES in 2050



In the DES, 4.2 million households use electric stoves by 2030 and 11 million households by 2050. This implies the addition of 230 000 electric cookstoves annually to 2030 and 330 000 electric cookstoves annually from 2030 to 2050. In this scenario, the average share of electricity consumption dedicated to cooking in the region's households increases from 6.5% in 2018 to 13% in 2030 and 20% in 2050.

With the introduction of electric cooking stoves, the demand for liquefied petroleum gas (LPG) for cooking decreases, as do LPG imports and the government subsidies dedicated to maintaining a low price of LPG for residential use. Ecuador, for example, implemented an Efficient Cooking Programme in 2014 to foster the use of electric cookstoves rather than LPG stoves, with the aim of reducing the costs for LPG subsidies, introducing more efficient cookstoves and reducing the accident risks related to LPG stoves (Empresa Eléctrica Quito, 2021).

The specific cost requirements for cooking in residential buildings are presented in Table 9. To achieve a cleaner cooking technology mix in 2050, additional cumulative costs of USD 6.3 billion would be needed, as shown in Figure 39, along with corresponding policy and finance schemes for execution. International co-operation could play a key role in providing technical and financial assistance.

Table 9: Cumulative cost in cooking technologies in the residential sector for the 2018-2050 period under the PES and DES (million USD)

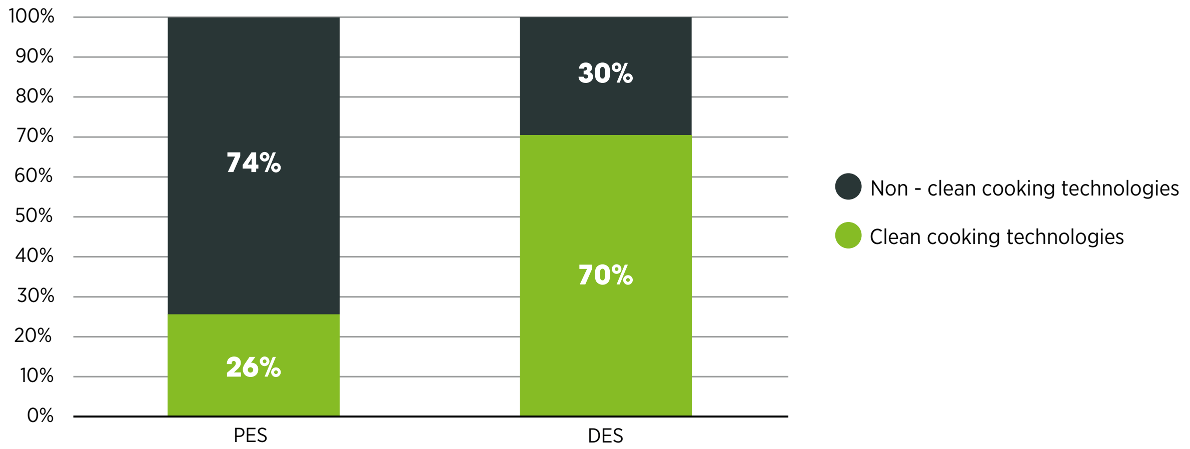
COOKING TECHNOLOGY	PES	DES
Electric stoves	3 292	11 493
Improved cookstoves	887	1 156
LPG stoves	7 212	5 210
Traditional woodstoves	0	0
Total	**11 391**	**17 859**

Note: Cumulative cost refers to the acquisition cost of the different types of stoves.

Around 70% of the households in the region use clean technologies for cooking in the DES by 2050, as shown in Figure 41. The predominant alternative to electric stoves is LPG stoves, which do not generate indoor pollution, but still it is fossil fuel based. In contrast, under the 2050 PES, electric stoves are representative only in Costa Rica, representing 55% of the country's cookstove mix.

Although the context of the countries varies among them, in terms of cooking technologies available, fuels used, prices and regulatory frameworks, a regional effort could be considered taking advantage of the scale and experience of leading countries in this matter.

Figure 41: Share of clean technologies for cooking under the PES and DES in 2050



Note: Clean technologies refer to electric cookstoves (conventional and efficient), and improved cookstoves. Non-clean technologies refer to LPG and traditional fuelwood-based units.

To be able to meet the higher electrification shares in cooking mentioned above, as well as to facilitate access to electric lighting and other appliances, it is fundamental to provide universal access to electricity to all populations in the region. According to the EES2030 strategy (SICA, 2020), this objective would be met by 2030. This will bring not only health benefits to the region's population, but also social benefits such as gaining access to lighting and information.

Electricity use in cooking: actions needed for the period 2018-2030 and 2030-2050

ACTIONS DONE BY 2030

- Characterise the health, economic and social status of the population that still uses traditional stoves.
- Assess the current status of clean cooking technologies and identify the best way to transition to them.
- Develop specific plans and strategies for fostering the clean technologies, from national and regional perspectives (possibly a regional strategy following the example of the RTCA).
- Develop financial incentives for the promotion of clean cooking technologies.
- Revise current subsidies to fossil fuels for cooking energy carriers.

ACTIONS DONE BY 2050

- Implement the plans and strategies developed and assess/update them considering a regional perspective.
- Promote the financial incentives set for fostering clean cooking technologies.
- Monitor the progress made during the period to make sure the set targets are met.

CONTRIBUTIONS TO THE REGION

- Increased investment and stimulus to the economies – post COVID-19 recovery process.
- Generation of employment for the installation, operations, and maintenance of stock, considering gender equality for job applications.
- Reduction in fossil fuel imports, with the corresponding impact on goverment expenses, plus guarantee of energy security.
- Reduction in local pollution.

COMPLIANCE OF CURRENT REGIONAL STRATEGIES

- EES2030
- Euroclima+
- NDCs

TECHNICAL/FINANCIAL PARTNERS

- World Bank
- Inter-American Development Bank
- CABEI – Central American Bank for Economic Integration
- CAF – Development Bank of Latin America
- GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit

RENEWABLES DIRECT USE IN THE END-USE SECTORS

5

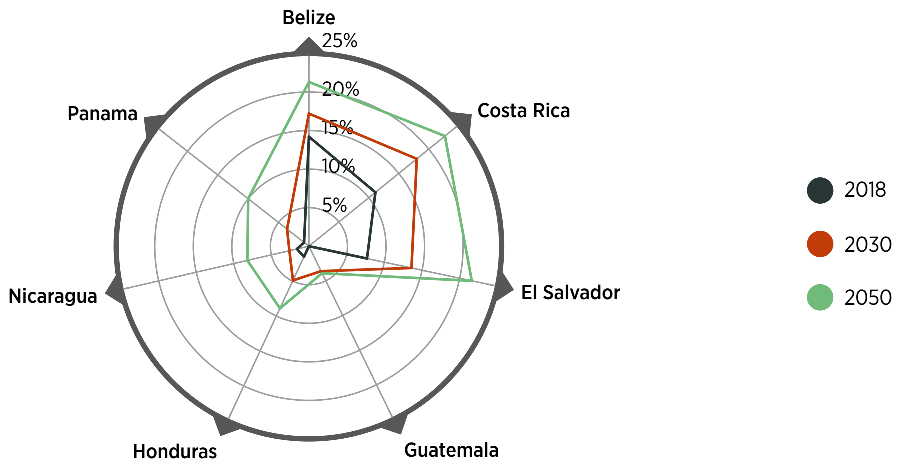
RENEWABLES DIRECT USE IN THE END-USE SECTORS

For certain energy services, electrification may not be the only available – or optimal – solution to reduce the use of fossil fuels. In some cases, the direct use of renewables might represent a more adequate and efficient solution.

The direct use of modern renewables[19] can help reduce fossil fuel use in the end-use sectors today and would reach an 11% share in 2050 in the DES.

Across the region, the share of modern renewables in 2018 as well as in the DES in 2030 and 2050 is highest in Belize, Costa Rica and El Salvador, due to the use of bagasse and modern biomass in the industry sectors of these countries (Figure 42).

Figure 42: Share of modern renewables in total final energy consumption in 2018 and under the DES in 2030 and 2050



Modern bioenergy[20] could represent 7% of the total energy demand by 2050 under the DES. The region has potential to use its bioenergy resources as part of the decarbonisation energy policies, with applications in all end-use sectors, provided that the bioenergy is produced in a sustainable manner to avoid environmental damages and effects related to changes in land use.

Overall, the energy demand mix is expected to evolve, as shown in Figure 43. Traditional biomass[21] is less representative in the 2050 DES, while modern renewables assume a higher share.

The use of modern renewables in 2050 doubles under the PES and triples under the DES compared to 2018 (Figure 44). In both scenarios, the bulk of this use (around 70%) occurs in the industry sector. The direct use of renewables in buildings in the DES 2050 occurs mainly through the introduction of solar water heating systems. In the transport sector, biofuels (mainly biodiesel, bioethanol and biojet) are used more widely in the PES than in the DES, mainly because electrification of the fleet is greater in the DES, and fewer internal combustion engine vehicles are in use.

[19] Direct use of modern renewables includes the following energy carriers: bagasse, biodiesel, bioethanol, biogas, biomass, charcoal, geothermal and solar thermal.

[20] Modern bioenergy includes the following energy carriers: bagasse, biodiesel, bioethanol, biogas, biomass and charcoal.

[21] Traditional biomass refers to the traditional use of biomass for cooking and heating purposes in buildings.

Figure 43: Total final energy consumption in the end-use sectors by energy carrier in 2018 and under the PES and DES in 2030 and 2050

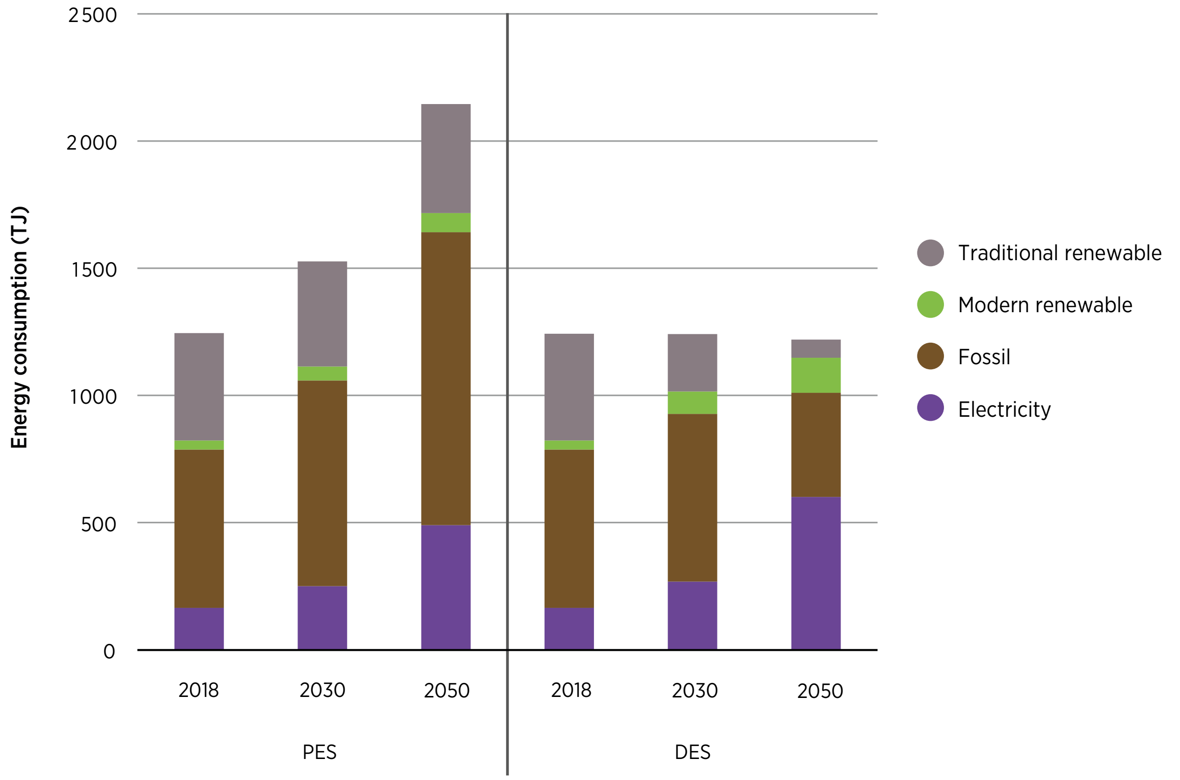
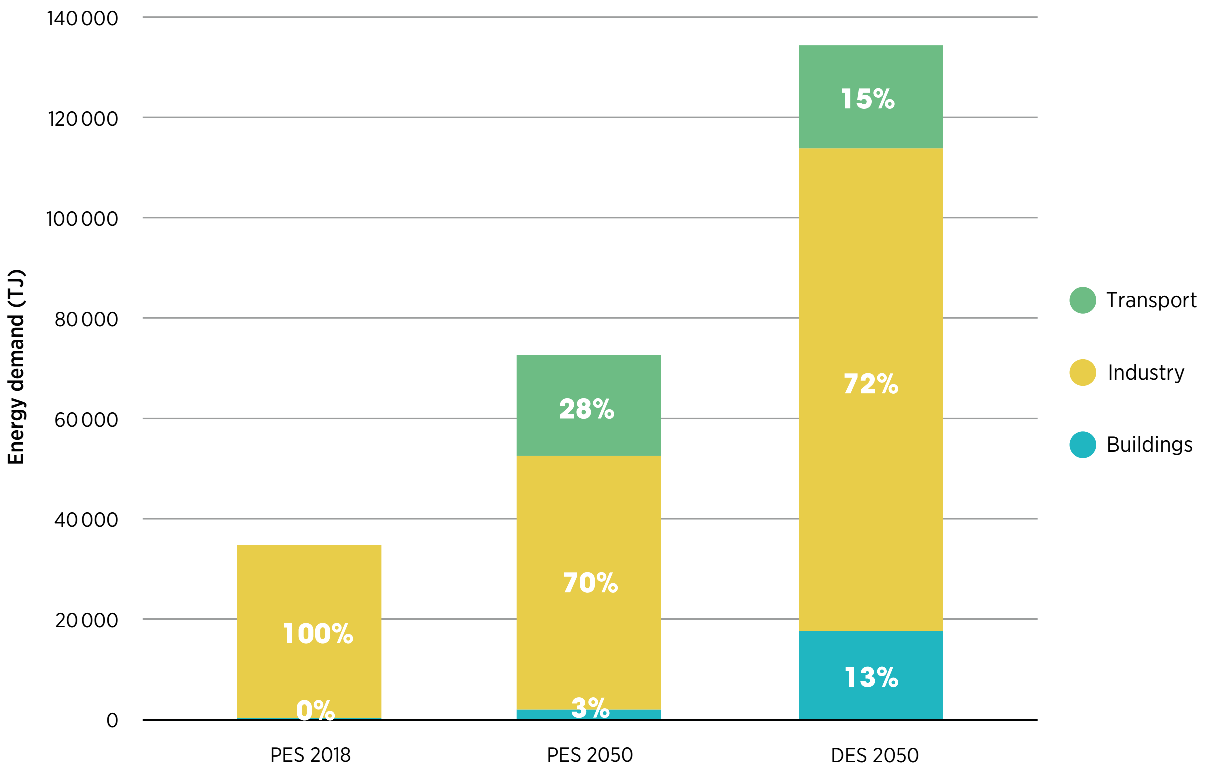


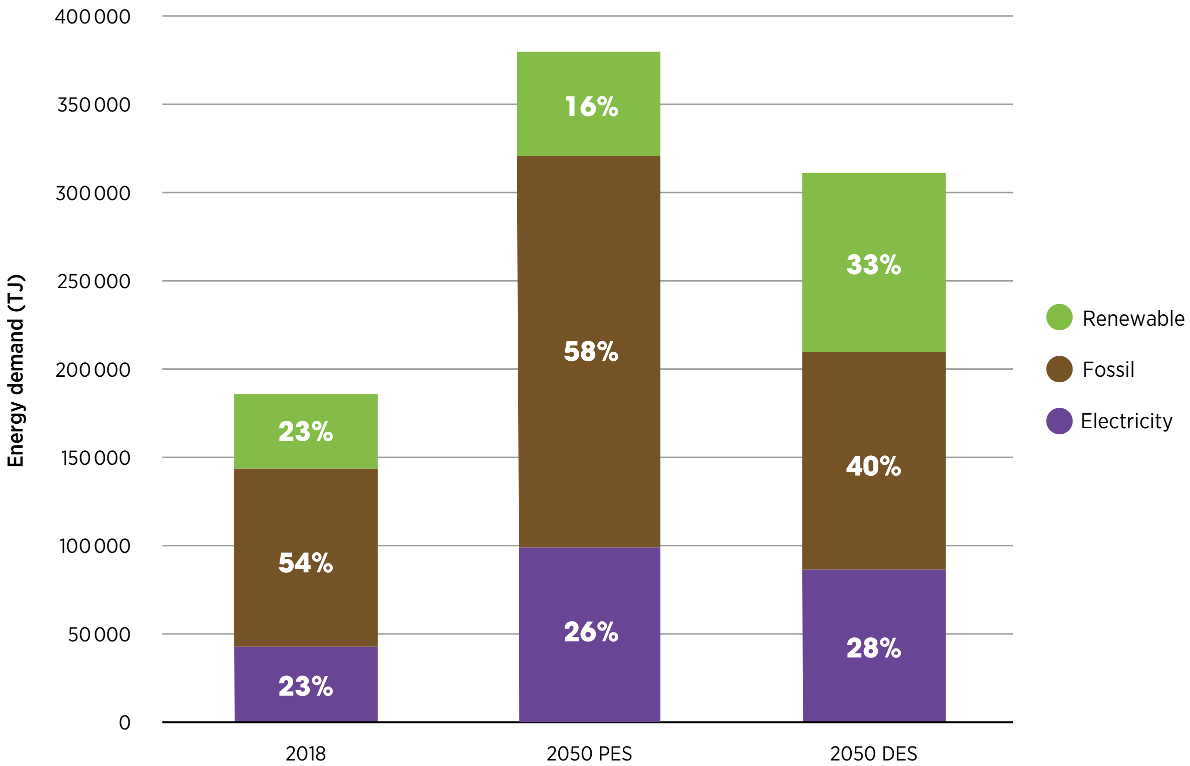
Figure 44: Demand for modern renewables by end-use sector in 2018 and under the PES and DES in 2050



5.1 RENEWABLES DIRECT USE IN INDUSTRY

The direct use of renewables in the industrial sector leads to a reduction in fossil fuel demand, as shown in Figure 45. Food and beverages, textiles and cement are the predominant industries identified in the region, and renewable resources are assumed to be integrated into low-temperature thermal processes. In the DES, renewables cover 33% of the industrial energy demand. Additionally, if the energy efficiency improvements proposed in the DES are implemented, the industrial energy demand in 2050 is 18% lower in the DES compared to the PES.

Figure 45: Industry energy demand by carrier in 2018 and under the PES and DES in 2050



The analysis of industry energy demand in this study was developed using a top-down approach due to the lack of information in this sector. Further research is needed to better characterise the region's industry sector and its related energy consumption, for example through the development of industry energy demand surveys. This would facilitate better analysis of the sector, as well as more specific recommendations and the development of a plan for industry decarbonisation.

5.2 RENEWABLES DIRECT USE IN BUILDINGS

The introduction of solar water heaters in buildings would contribute to a higher share of renewables direct use in the end-use sectors. The number of installed units in the PES and DES and their related costs for the 2018-2050 period are shown in Table 10. The upfront costs for covering the water heating needs are higher in the DES due to the higher costs of solar water heaters compared to current technologies, mainly LPG boilers. However, the technology mix proposed in the DES brings fuel savings in water heating of USD 6.7 billion compared to the PES over the study period, compensating the upfront costs needed. The introduction of solar water systems would also bring increased local employment, energy security and access to water heating services.

Table 10: Residential solar water heater units in 2018, and in 2030 and 2050 under the PES and the DES, and related investment needs

PARAMETERS	2018	PES 2030	PES 2050	DES 2030	DES 2050
Solar water heaters in residential buildings (units)	9 180	41 408	319 519	533 839	2 803 187
Solar water heaters cumulative investment in residential buildings (USD million)	–	50	518	789	4 830

Additionally, the use of modern biomass in buildings could be a feasible option to provide a clean and efficient solution for cooking. In response to the widespread burning of fuel wood in the region, countries are considering a sustainable bioenergy supply, mainly for Indigenous communities or hard-to-reach areas. Under the DES, charcoal accounts for 1% of the total final energy consumption in buildings by 2050.

5.3 RENEWABLES DIRECT USE IN TRANSPORT

Lastly, the blending of bioethanol in petrol, biodiesel in diesel, and biojet in jet fuel could contribute to reducing the fossil fuel demand in the transport and industry sectors. The blending rates assumed in the DES are higher than those in the PES. Blending rates in volume reach 15% for bioethanol and 10% for biodiesel in the DES, which are the maximum possible rates so that no technology change needs to be made in the current internal combustion engine vehicles fleet. If the vehicle fleet was composed of vehicles that allows higher blending rates, the use of biofuels could be higher both in PES and DES. However, due to the stronger electrification of the fleet in the DES, the number of internal combustion engine vehicles in which the blending would be applied is lower, and thus the demand for biofuels in the DES is lower than in the PES, as shown in Table 11.

Table 11: Bioethanol, biodiesel and biojet consumption in 2018 and under the PES and DES in 2030 and 2050

	2018	PES 2030	PES 2050	DES 2030	DES 2050
Bioethanol (million litres)	0	158	190	445	172
Biodiesel (million litres)	0	506	742	422	409
Biojet (million litres)	0	0	0	47	75

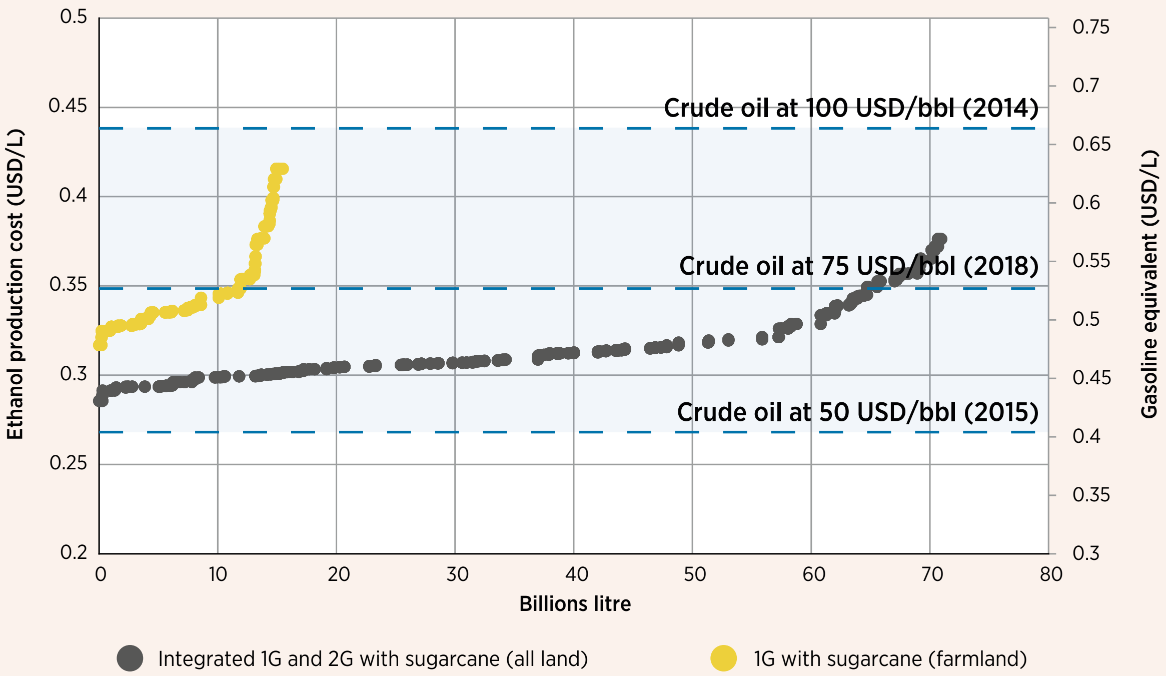
Box 6. Sugarcane bioenergy in Central America – large and competitive potential for energy production and greenhouse gas emission mitigation

Sugar cane is an excellent carrier of solar energy and is a raw material of choice for producing both liquid biofuels and electricity, as has been successfully adopted in some countries.

Taking advantage of the region's good climate and land availability, sugarcane cultivation and processing represents a key economic activity across the seven countries of Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama, where a world-class sugar agroindustry exists, processing around 58 million tonnes of sugar cane in 2019 (FAO, 2021).

However, only about 12% of sugarcane production is used for energy purpose and there is yet potential to be scaled up significantly. IRENA evaluated how much sugarcane bioenergy can be produced at what cost, in diverse technological scenarios including productivity with an agronomic model, land availability, energy cane varieties, and processing technologies (IRENA upcoming). The results show a significant potential to increase the bioenergy supply from sugarcane, which reaches 15 billion litres ethanol (first generation with sugarcane on farmland, yellow in Figure 46) - 71 billion litres for ethanol (advanced technology with energy cane on all available land, grey in Figure 46) and 12.3 – 110 TWh for electricity cogeneration. A large share of the ethanol potential in scenarios would be cost-competitive with gasoline in crude oil price range of USD 50 to USD 100 per barrel.

Figure 46: Supply curve example for ethanol from sugarcane in Central America



Adopting sustainable practices, sugarcane bioenergy can be economically attractive complying with strict sustainability indicators and reducing greenhouse gas emissions by up to 80% compared to gasoline (Seabra *et al.*, 2011). In addition to the conventional blending to gasoline or direct use in ICE, ethanol can also be used in different ways for energy transition, such as in fuel cell electric vehicles, either using hydrogen produced by ethanol reform on board (NISSAN, 2019) or direct ethanol fuel cells (Akhairi and Kamarudin, 2016), as a feedstock for bioethylene to replace to replace fossil-based chemicals (IRENA and ETSAP, 2013) and for biojet fuels through alcohol-to-jet process (IRENA, 2021d).

Renewables direct use in transport: actions needed for the period 2018-2030 and 2030-2050

ACTIONS DONE BY 2030

- Organise working commitees integrating public and private institutions and possible technical/ finance partners.
- Develop an industry characterisation study.
- Develop specific plans and strategies for industry decarbonisation (*e.g.* Costa Rica).
- Identify specific projects by industry sector to facilitate access to finance.
- Develop an incentive programme for the promotion of solar water heaters in the residential and commercial buildings sector (*e.g.* Termosolar Panama).
- Provide financial support to cover the upfront costs of solar water heaters.
- Develop specific plans and strategies for biofuel blending.

ACTIONS DONE BY 2050

- Develop specific industrial projects to foster decarbonisation and meet the objectives set in the plans and strategies.
- Implement the incentive programmes for the promotion of solar water heaters to provide access to water heating services.

CONTRIBUTIONS TO THE REGION

- Increased investment and stimulus to the economies – post COVID-19 recovery process.
- Generation of employment for the installation and operations and maintenance of stock.
- Reduction in fossil fuels imports, with the corresponding impact on goverment expenses, plus guarantee of energy security by using local renewable resources for electricity generation.
- Reduction in local pollution.

COMPLIANCE OF CURRENT REGIONAL STRATEGIES

- EES2030
- Euroclima+

TECHNICAL/ FINANCIAL PARTNERS

- World Bank
- Inter-American Development Bank
- CABEI – Central American Bank for Economic Integration
- CAF – Development Bank of Latin America
- GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit

ENERGY CONSERVATION AND EFFICIENCY

6

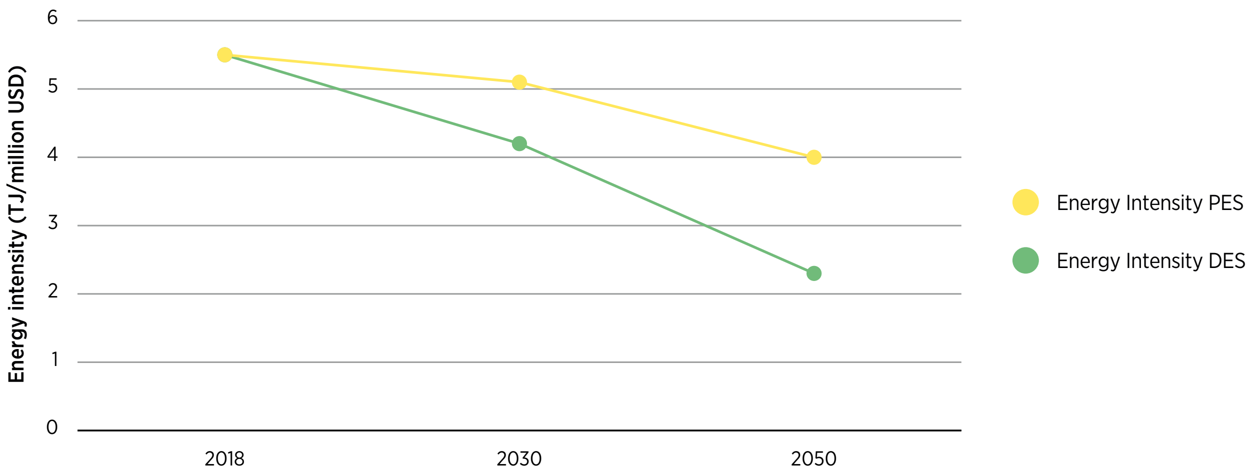
ENERGY CONSERVATION AND EFFICIENCY

The use of energy-efficient technologies in the DES could help the region meet the same level of energy needs as in the PES, but with a lower energy demand. The establishment of energy efficiency standards would play an important role in fostering the use of efficient technologies.

Energy efficiency costs increase from USD 2.2 billion in the PES to USD 8.7 billion in the DES, to reduce energy intensity 43% by 2050 (measured as total final energy consumption per unit of GDP) (Figure 47).

An ongoing initiative in the region aims to implement energy efficiency measures in buildings to reduce energy consumption and thus the expenses associated with electricity bills, generation costs and fuel imports (COMIECO, 2020). Some countries have already established energy efficiency indexes, starting with air conditioners and refrigerators, which together represented around 38% of the average household's electricity consumption in 2018.

Figure 47: Energy Intensity in 2018 and under the PES and DES in 2030 and 2050



To restrict the imports of less efficient products in the remaining countries, regional organisations have worked on developing the Central American Technical Regulations (RTCA in Spanish), covering the main loads such as air conditioners, refrigerators and motors.

The approved and planned regulations of countries were modelled in the PES, TES and DES, specifically covering the energy services of space cooling, refrigeration and lighting in the buildings sector. The reduction in energy intensity is achieved through the introduction of space cooling and refrigeration units with lower power consumption, as well as the replacement of conventional light bulbs (such as incandescent, halogen and fluorescent) with LEDs.

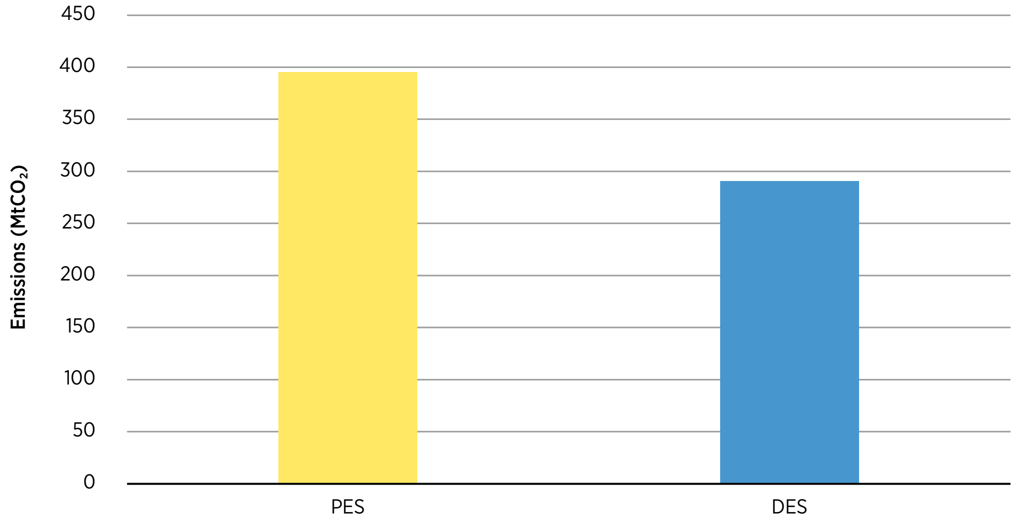
For the transport sector, an improvement in fuel consumption during the study period was modelled assuming further developments in the efficiency of the automotive industry under the PES, TES and DES. Electric vehicles are already more efficient than internal combustion engine vehicles (using less energy per kilometre). However, this is accounted for in the fleet electrification modelling, as the efficiency improvement is embedded in the technology change.

The industry sector data collection and document review process for this study found that only limited information exists regarding industrial energy demand and its distribution in the main activities of the sector, from thermal processes to the use of electricity for motors, cooling and lighting.

A top-down approach was therefore used to carry out the modelling of the industry sector in each country, drawing on economic variables and energy balances. The main energy measures introduced were applied to the estimated energy intensity of the sector, as well the carriers required for final uses, decreasing the magnitude or consumption by 2050 and among scenarios, plus replacing traditional fuels with cleaner ones or electricity, mainly with renewable resources available in the region.

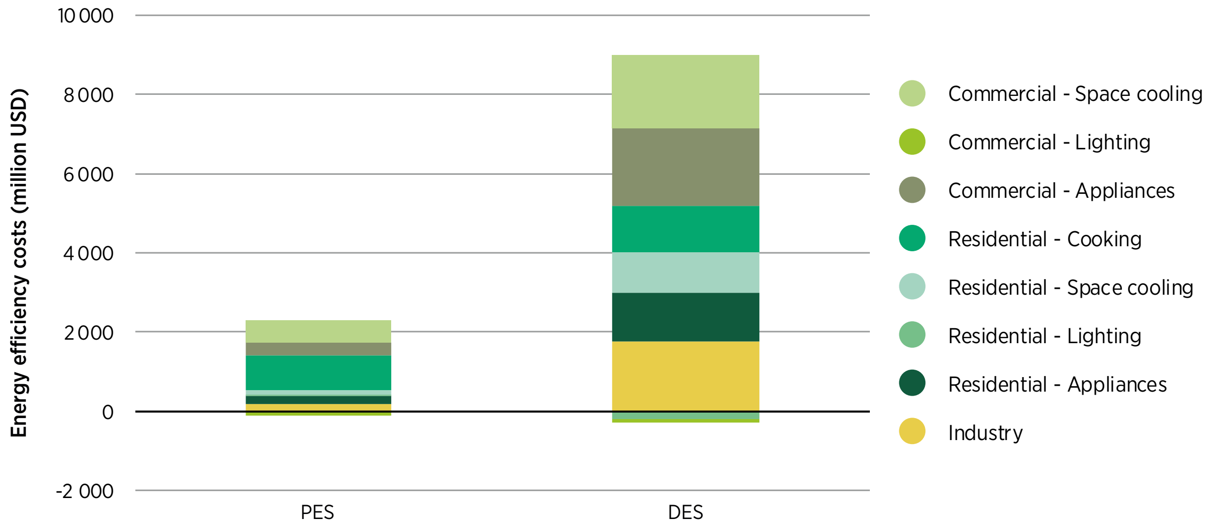
In the DES, implementation of the proposed energy efficiency measures in the industry sector, together with technology switches, reduce the share of fossil fuels from 54% in 2018 to 49% in 2030 and 40% in 2050. This results in an 26% decline in emissions for the 2018-2050 period compared to the PES, as shown in Figure 48.

Figure 48: Cumulative emissions from industry for the period 2018-2050 under the PES and DES



To achieve the reduction in energy intensity shown in Figure 49, cumulative costs of USD 8.7 billion over the 2018-2050 period are needed in the DES, which is 4 times the costs in the PES (Figure 49). In both scenarios, there is a negative expense, or savings, in residential and commercial lighting, due to the longer lifetime of LED bulbs and the accumulated savings over time.

Figure 49: Cumulative energy efficiency costs by sub-sector for the 2018-2050 period under the PES and DES



Importantly, the reduction in energy intensity would result in fuel cost savings of USD 82 billion during the study period in the DES compared to the PES. Considering the energy efficiency expenses and the resulting fuel cost savings, investing in energy efficiency would pay off over the 2018-2050 period, achieving cumulative savings of USD 75 billion.

Energy conservation and efficiency: actions needed for the period 2018-2030 and 2030-2050

ACTIONS DONE BY 2030

- Define targets for the penetration of efficient air conditioners, refrigerators and light bulbs.
- Reduce the en*ergy* intensity of the industry sector around 8% (through improved infrastructure design and materials for en*ergy* recovery, better practices in operations and maintenance, improved production processes, etc.).
- Accelerate the deployment of low-carbon technologies for industrial process heating (biofuels, solar thermal, geothermal and modern bioen*ergy*).
- Organise working commitees for the definition of sectoral en*ergy* plans/programmes, integrating public and private institutions and possible technical/finance partners.
- Continue defining en*ergy* standards for remaining countries and other high-consumption electric devices.
- Define building codes for new construction and retrofitting plans for old units.
- Conduct surveys and studies to characterise the en*ergy* demand of the sectors.
- Develop efforts for financing investment and studies or creating incentives for en*ergy* efficiency (*e.g.* current initiatives by banks and governments providing benefits for en*ergy*-efficient buildings).
- Implement building certifications (*e.g.* LEED).
- Establish regulations for second-hand vehicle imports and emissions standards to control the quality of the market.
- Implement digitalisation, demand-side management and micro smart grids in end-use sectors through pilot projects.
- Implement monitoring, reporting and verification (MRV) systems to track the performance of en*ergy* efficiency measures.

ACTIONS DONE BY 2050

- Reduce en*ergy* intensity 15%.
- Increase the penetration of modern bioen*ergy* and other renewables in final en*ergy* consumption.
- Assess the impact of the implemented en*ergy* efficiency indexes.
- Evaluate the increase in standards.
- Evaluate the implementation of a district cooling system.
- Fullly deploy digitalisation, demand-side management solutions and smart grids.

CONTRIBUTIONS TO THE REGION

- Increased investment by new companies at a local level (industrial hubs), and stimulus to the economies thanks to competitive electricity prices and more sustainablity in processes post COVID-19 recovery plans.
- Generation of employment for the installation, operations and maintenance of new technologies and solutions, considering gender equality for job applications.
- Reduction in fossil fuel imports due to less en*ergy* requirements in process heating or electricity generation.
- Increase in en*ergy* security by using local renewable resources, resulting in reduction in local pollution.

COMPLIANCE OF CURRENT REGIONAL STRATEGIES

- EES2030
- RTCAs (Central American Technical Regulations)

TECHNICAL/ FINANCIAL PARTNERS

- World Bank
- Inter-American Development Bank
- CABEI – Central American Bank for Economic Integration
- CAF – Development Bank of Latin America
- GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit

HYDROGEN AND ITS DERIVATIVES

7

HYDROGEN AND ITS DERIVATIVES

Several hard-to-abate sectors, such as heavy-duty cargo shipping by truck, might require the use of more innovative technologies to achieve decarbonisation. Hydrogen and its derivatives could serve as alternative fuels in these sectors.

Green hydrogen serves as an alternative solution for decarbonising heavy cargo road transport in the region, as well as an opportunity for a cleaner supply in international shipping.

Hydrogen and its derivatives provide an alternative avenue to further decarbonise sectors such as specific industrial processes, long-haul transport, shipping, and aviation, as presented in IRENA's *World Energy Transitions Outlook* (IRENA, 2021b). In the analysis of Central America, considering the low-to-medium energy intensity of the region's industries, hydrogen was only introduced in the road transport sector of countries that are currently considering green hydrogen as an innovative solution for the cargo fleet. It is considered as a solution mainly to reach remote or isolated areas where a robust power distribution grid for electric vehicles is unfeasible and there is a need for high-capacity chargers.

The DES of selected countries, namely Costa Rica and Panama, included hydrogen as an alternative carrier for large trucks, in addition to intensive electrification. This hydrogen use starts with a small share of conventional units, reaching 1.3% of the regional heavy-duty fleet by 2050. The assumption in both countries was that hydrogen heavy-duty trucks could constitute 20% of the fleet by 2050, which follows the vision of the Hydrogen Council (Hydrogen Council, 2017).

These shares in the DES translate to higher stocks of hydrogen trucks, electrolysers and storage by 2050, as shown in Figure 50.

Figure 50: Stock of large trucks using hydrogen, electrolysers required for fuel production, and hydrogen storage under the DES in 2040 and 2050

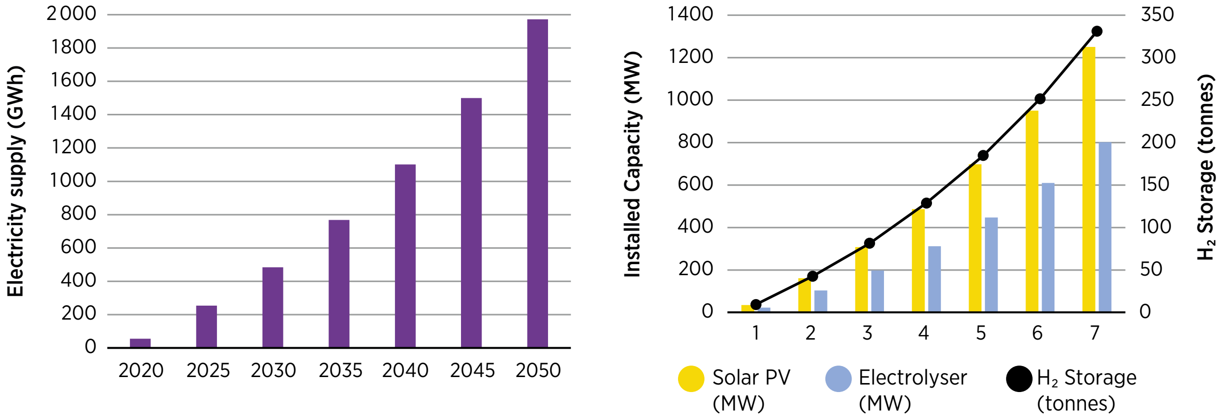
	2040	2050
Large trucks	**11.1 thousand units**	**22.3 thousand units**
Electrolysers	**448 MW**	**802 MW**
H_2 Storage	**185 tonnes**	**331 tonnes**

With respect to the power sector, Figure 51 shows the installed capacity of renewables (solar PV[22] in this case) and the electricity generation required for the hydrogen production process in the period 2020-2050. In total, 698 MW of capacity and 1100 GWh of electricity are required for 2040, and 1250 MW and 1973 GWh[23] for 2050, representing only 1% of the total electricity demand in the region.

[22] The model invests in solar PV due to its higher potential in the region compared to other technologies, lower installation costs and easy deployment. Off-grid projects are considered to guarantee the renewable/green production of hydrogen. Optimal storage is added assuming steel storage tanks at a price of USD 500/kilogram.

[23] Electrolyser specifications: alkaline unit with an efficiency of 49 MWh/tonne, off-grid installation in a dedicated facility, investment cost of USD 480/kW and fixed costs of USD 9.6/kW/year.

Figure 51: Electricity generation and installed capacity required to produce renewable hydrogen by technology under the DES, 2020-2050



As a result of the fuel switch replacing conventional units in the cargo fleet, the share of hydrogen in the total final energy consumption of the transport sector rises from 0.6% in 2040 to 1% in 2050.

Hydrogen and its derivatives: actions needed for the period 2018-2040 and 2040-2050

ACTIONS DONE BY 2040

- Organise working commitees for the definition of plans/ strategies, integrating public and private institutions and possible technical/ finance partners.
- Develop efforts to finance studies and investment in green hydrogen facilities.
- Develop specific plans and strategies for green hydrogen production and distribution.
- Deploy production, distribution and fuelling infrastructure to supply heavy-duty fleets.
- Implement pilot projects.

ACTIONS DONE BY 2050

- Deploy fuelling infrastructure and design a tariff framework with local and regional funcionalities.
- Improve transport infrastructure, network systems and stock.

CONTRIBUTIONS TO THE REGION

- Increased investment and stimulus to the economies – post COVID-19 recovery process.
- Generation of employment for the installation, operations, and maintenance of stock and required infrastructure, considering gender equality for job applications.
- Reduction in fossil fuel imports, using local renewable energy resources for production of hydrogen.
- Reduction in local pollution.

TECHNICAL/ FINANCIAL PARTNERS

- World Bank
- Inter-American Development Bank
- CABEI – Central American Bank for Economic Integration
- CAF – Development Bank of Latin America
- GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit

Box 7. The Panama Canal and a possible hydrogen hub

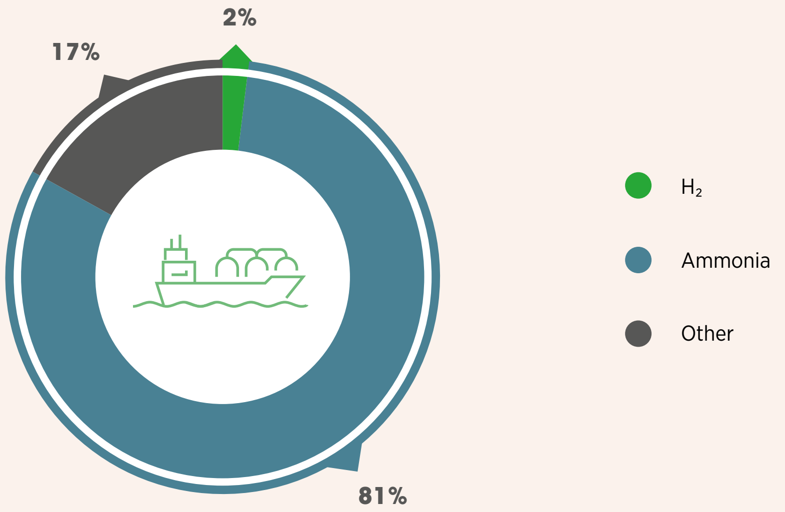
The Central America region, and particularly Panama, has significant influence in the international shipping sector (Ricardo Energy and Environment, 2020). With the implementation of the International Maritime Organization's 2020 regulation on emissions from shipping, ships approaching ports must switch to cleaner fuels (Autoridad del Canal de Panamá, 2019). The Panama Canal signed the agreement, which entered into force in January 2020.

Panama, as presented in its Energy Transition Agenda 2020-2030 (Secretaría de Energía - República de Panamá, 2020), provides a great opportunity for the development of a green hydrogen hub, due to its geographical position, logistics expertise in the region and the Panama Canal facilities.

A what-if analysis was carried out to estimate the potential hydrogen demand in the region, for both cargo transport and shipping through the Panama Canal. For the cargo fleet, it was assumed that the remaining large trucks using diesel in the DES would switch to hydrogen and its derivatives starting in 2030, with this fleet completely supplied by 2050. For shipping, marine fuel sales registered by the Maritime Authority of Panama were used as reference values that would be replaced by hydrogen and its derivatives during the period 2030-2050. The evolution profile of international shipping and shares of hydrogen, ammonia and methanol according to IRENA's *World Energy Transitions Outlook* analysis were considered to complete the analysis (IRENA, 2021b), as well as energy efficiencies and conversion factors.

Figure 52 shows the most feasible carriers based on green hydrogen to supply the shipping energy demand in 2050, with ammonia dominating at around 80%, followed by methanol (the second derivative proposed to replace conventional fuels).

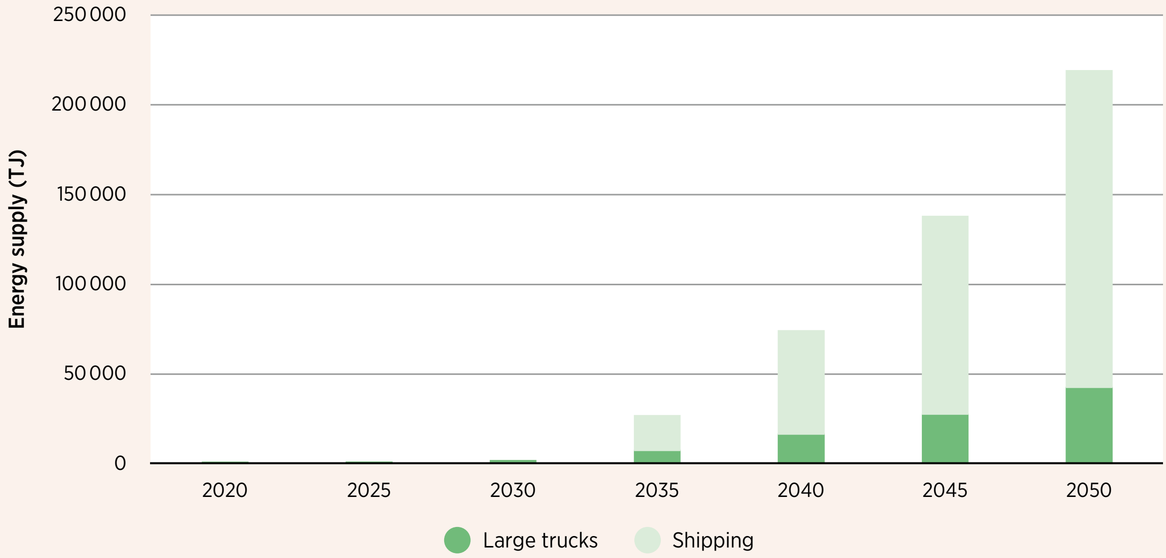
Figure 52: Share of hydrogen and its derivatives used for shipping in 2050



Box 7. The Panama Canal and a possible hydrogen hub (continued)

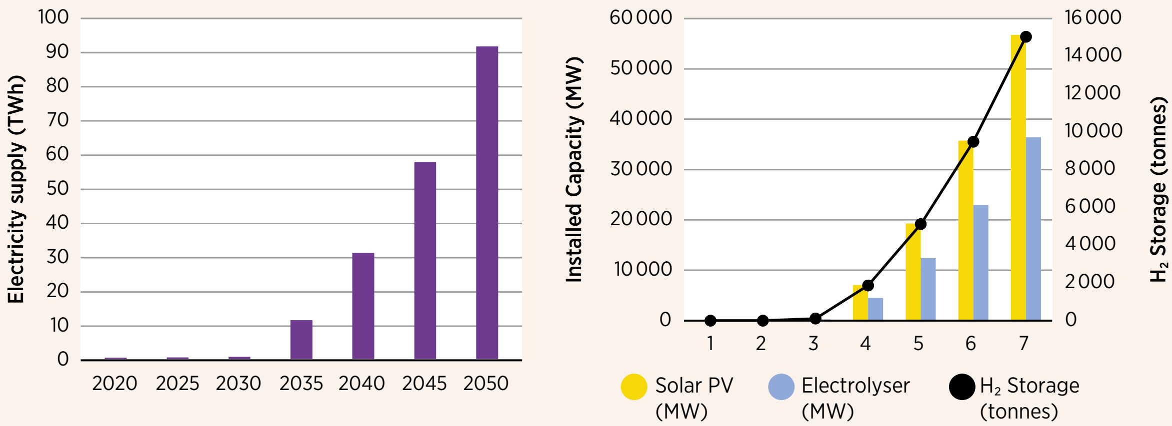
Figure 53 shows the total hydrogen supply needed to cover the energy consumption of large trucks and shipping. in 2050. Around 219 PJ would be required for both transport modes, with shipping representing around 80% of the total. This accounts for around 1800 kilotonnes of hydrogen production in 2050.

Figure 53: Hydrogen energy supply by transport mode, 2020-2050



Producing the total green hydrogen needed in 2050 would require around 89.5 TWh* of electricity generation, which assumes a 47% increase in the regional electricity demand (190 TWh). Using the same amount of solar PV to supply electrolysers, as well as the hydrogen storage ratio that was used in the large truck scenarios, this would require the installation of 36 GW of electrolysers, 15 kilotonnes of hydrogen storage and 56 GW of solar PV (Figure 54). This would triple the suggested solar PV capacity in 2050 compared to the DES and possibly far exceed the solar potential in the region. These results show that a combination of imports of hydrogen and derivates from other regions with local production could be considered to supply the forecasted energy requirements.

Figure 54: Electricity supply and installed capacity of electrolysers that would be required for domestic hydrogen production, 2020-2050



A more detailed analysis would be required to estimate the region's potential for supplying green hydrogen, either through local generation or via regional imports if the renewable energy potential is insufficient. Here too, benefits arise from the logistics of wider Latin American integration. For example, Chile's plans to produce hydrogen could be integrated into a regional study to define the distribution logistics and additional infrastructure needs, considering the advantages of the Panama Canal facilities.

*Assuming an alkaline electrolyser with an efficiency of 49 MWh/tonne.

SECTOR ACTION NEEDED NOW

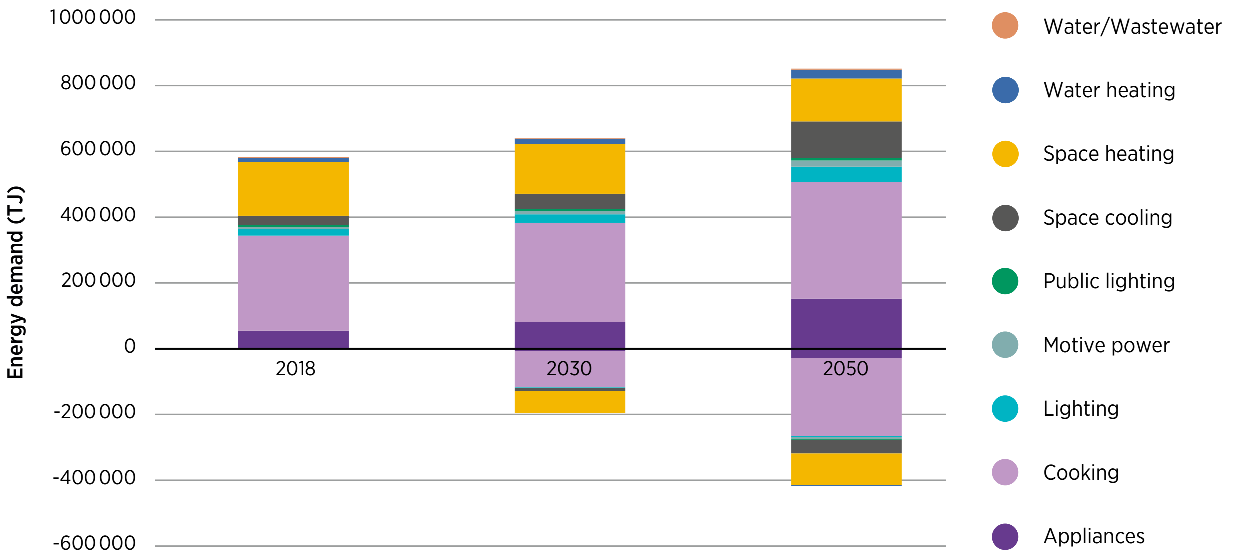
8

SECTOR ACTION NEEDED NOW

In the section, the energy demand in 2018, as well as the energy demand in 2030 and 2050 in the DES (positive axis) and the differences relative to the PES (negative axis), are presented for the three end-use sectors of buildings, transport and industry, as well as for the power sector. This is accompanied by a set of proposed measures that enable the decrease in energy demand for each sector. These measures serve as an overview of the different "actions" that would need to be taken as soon as possible to foster the decarbonisation of the energy sector and enable the sustainable energy transition.

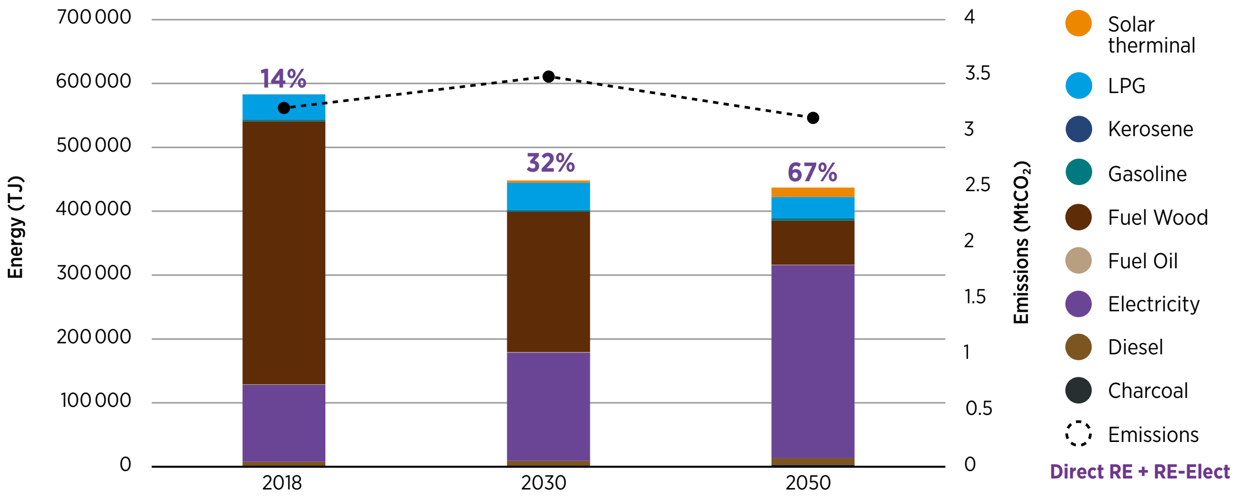
8.1 BUILDINGS

Figure 55: Buildings energy demand in 2018 and under the DES in 2030 and 2050, and energy saved compared to the PES



Note: Positive values correspond to the absolute energy demand under DES. Negative values correspond to savings comparing the energy demand of DES with respect to PES. Categories refer to the share of each energy service in the energy demand of buildings.

Figure 56: Total final energy consumption by carrier, emissions and share of renewable energy in buildings in 2018 and under the DES in 2030 and 2050



Note: Decrease of final energy consumption in buildings due to electrification and energy efficiency measures; RE =renewable energy.

Table 12: Regional actions for the buildings sector

BUILDINGS: INDICATOR OF PROGRESS - STATUS IN 2018 AND TARGETS FOR 2030 AND 2050

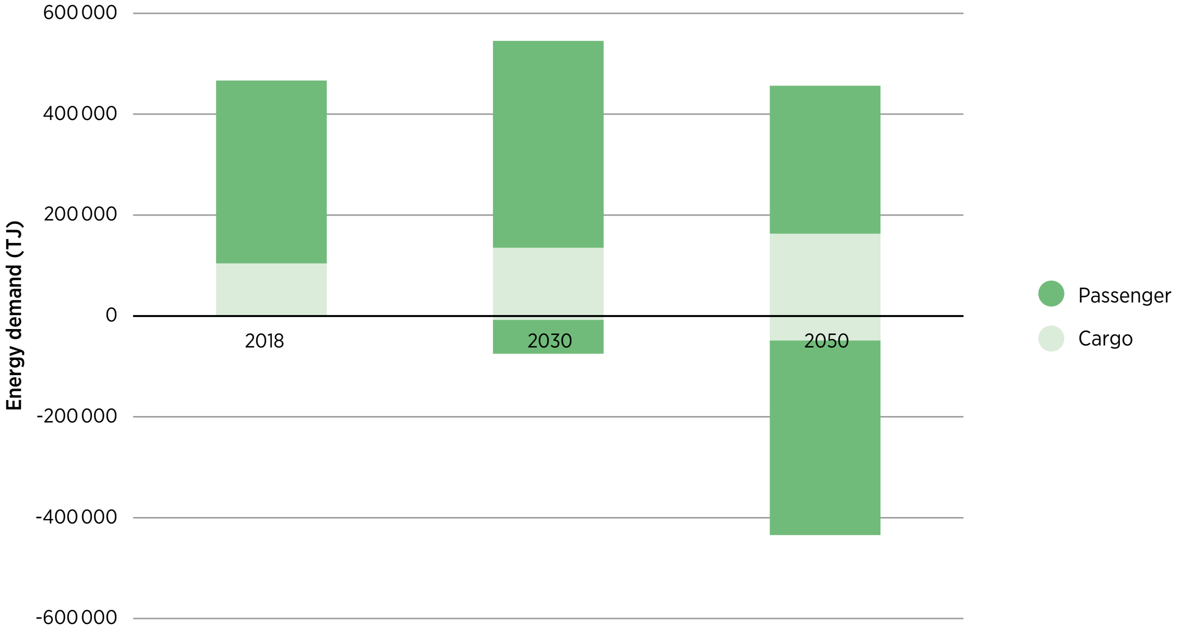
ENERGY TRANSITION COMPONENT	INDICATOR (UNIT)	HISTORICAL 2018	MOST AMBITIOUS SCENARIO (DES) 2030	MOST AMBITIOUS SCENARIO (DES) 2050	KEY ACTIONS
Energy transition strategy and components					
Energy conservation and efficiency	Buildings TFEC (PJ)	583	448	437	• Development and revision of energy efficiency indexes for Air Conditioners (ACs) and refrigerators for the introduction of efficient equipment in the fleet • Gains of energy efficiency in appliances of the commercial building sector • Introduction of LED light bulbs for the substitution of incandescent, halogens and fluorescent bulbs • Continue defining energy standards for remaining countries and other high consumption electric devices • Define building codes for new constructions and retrofitting plans for old units • Implement buildings certifications (*e.g.* LEED) • Evaluate the implementation of a district cooling system starting in 2030 • Efforts for financing investment, studies or creation of incentives for energy efficiency (*e.g.* current initiatives by banks and governments providing benefits to energy efficient buildings) • Implement digitalisation, DSM and micro smart grids in end-use sectors through pilot projects • Implement MRV systems to track performance of energy efficiency measures
Electrification in the end-use sectors	Electricity share in buildings (%)	21%	38%	69%	• Introduction of electric stoves for the substitution of traditional fuelwood or LPG cooking stoves • Introduction of electric water heaters for the substitution of LPG or fuelwood boilers for water heating • Introduction of electric heaters and heat pumps for the substitution of traditional fuelwood for usage for space heating purposes

Table 12: Regional actions for the buildings sector (continued)

ENERGY TRANSITION COMPONENT	INDICATOR (UNIT)	HISTORICAL 2018	MOST AMBITIOUS SCENARIO (DES) 2030	MOST AMBITIOUS SCENARIO (DES) 2050	KEY ACTIONS
Renewables direct use in end-use sectors	Biomass share in buildings TFEC (including traditional) (%)	71%	49%	16%	• Introduction of improved cooking stoves for the replacement of traditional fuelwood stoves
	Solar thermal and geothermal consumption share in buildings TFEC (heating) (%)	0%	1%	3%	• Development of incentive programme for the promotion of low-carbon solar water heating technologies for covering water heating needs in the residential and in the commercial sectors (*e.g.* Termosolar Panama)
CO_2 Emissions					
CO_2 Emissions	Direct ($MtCO_2$/yr)	3.9	3.5	3.1	• Conduct surveys and studies to characterise the energy demand of the sectors • Characterise the health, economic and social status of the population that still use traditional stoves • Assess the current status and identify the best way to transition to cleaner cooking technologies • Develop specific plans and strategies for fostering the clean technologies, from national and regional perspectives (possibility of regional strategy following example of RTCA) • Develop financial incentives for the promotion of clean cooking technologies • Revise current subsidies to fossil fuels for cooking energy carriers • Monitor the progress made during the period to make sure the targets set are met

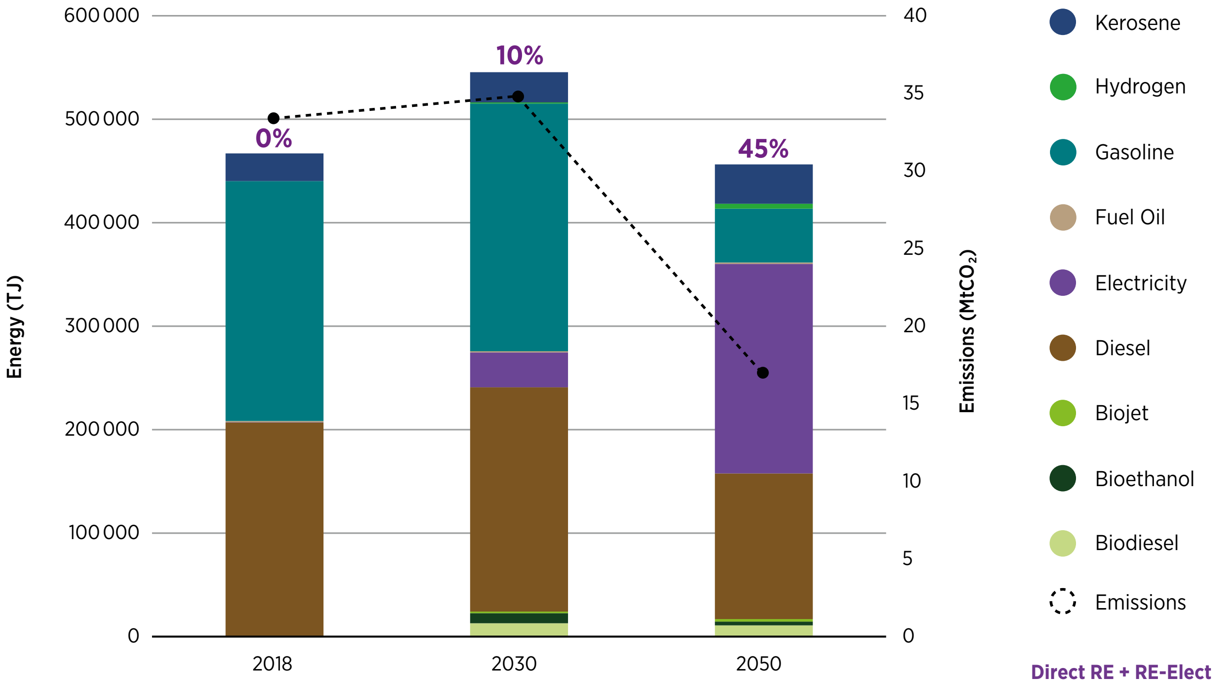
8.2 TRANSPORT

Figure 57: Transport energy demand in 2018 and under the DES in 2030 and 2050, and energy saved compared to the PES



Note: Positive values correspond to the absolute energy demand under DES. Negative values correspond to savings comparing the energy demand of DES with respect to PES. Categories refer to the share of the sub-sectors in the energy demand of transport.

Figure 58: Total final energy consumption by carrier, emissions and share of renewable energy in transport in 2018 and under the DES in 2030 and 2050



Note: Number of EVs in the region in 2018 according to databases used are less than 50 units. Thus, the low share of electricity use with respect to fleet and final energy consumption of the sector.

Table 13: Regional actions for the transport sector

TRANSPORT: INDICATOR OF PROGRESS - STATUS IN 2018 AND TARGETS FOR 2030 AND 2050

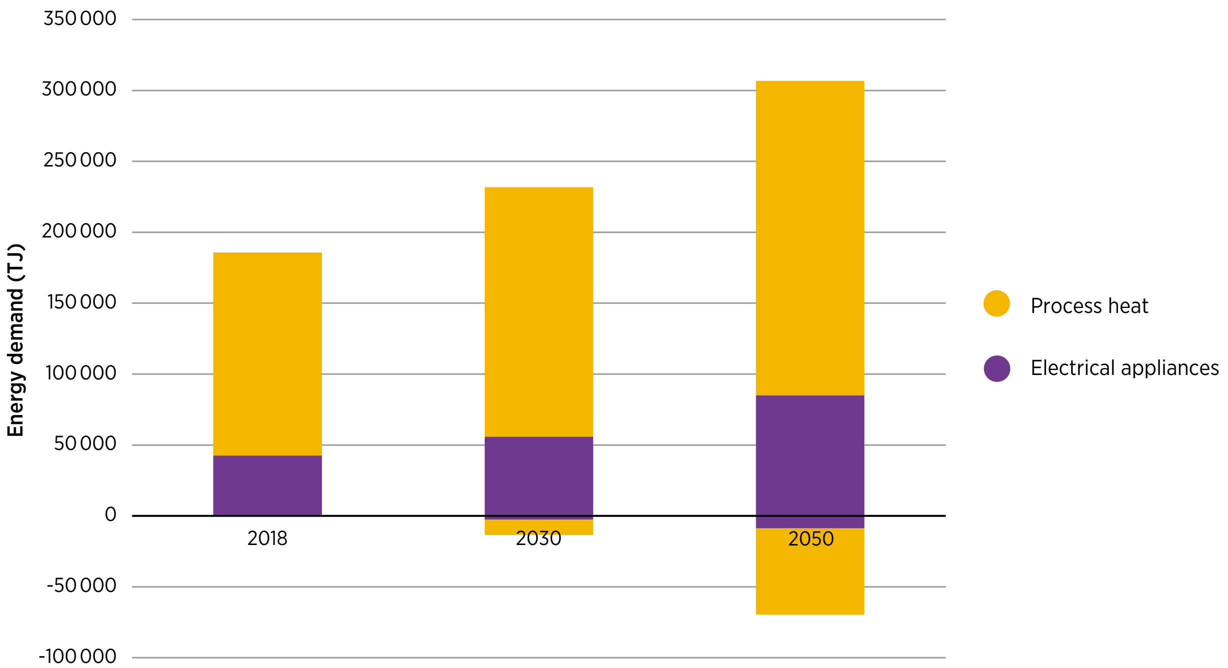
ENERGY TRANSITION COMPONENT	INDICATOR (UNIT)	HISTORICAL 2018	MOST AMBITIOUS SCENARIO (DES) 2030	2050	KEY ACTIONS
Energy transition strategy and components					
Energy conservation and efficiency	Transport TFEC (PJ)	467	546	456	• Improvement of the fuel consumption energy efficiency of ICE vehicles • Reduce transport volume and congestion by modal shift (2.5% of distance travelled from cars switched to bikes, 5% of distance travelled from cars switched to E-Buses)
Electrification in the end-use sectors	Electricity share in transport (%)	0%	6%	44%	• Introduction of electric vehicles to the fleet by 2030, particularly: motorcycles, cars, SUVs, minibuses, buses, light and heavy-duty trucks. • Efforts for financing investment in electromobility (*e.g.* current initiatives by banks and governments providing clients with special bank loans conditions for EVs acquisition (PNUMA, 2021). • Deploy smart charging solutions and design tarifs framework with local and regional funcionalities • Business models and regulation for EV charging • Accelerate the shift to electromobility by giving EVs priority in city access starting in 2030
Renewables direct use in end-use sectors	Biofuels share in transport TFEC (%)	0%	4%	4%	• Introduction of biofuel blending, particularly bioethanol, biodiesel and biojet in gasoline, diesel and jet fuel respectively.
Hydrogen and its derivatives	Green hydrogen share in transport TFEC (%)	0%	0%	1%	• Develop specific plans and strategies for green hydrogen production and distribution • Deploy production, distribution and fueling infrastructure to supply heavy duty fleet • Implement pilot projects • Deploy fueling infrastructure and design tarifs framework with local and regional funcionalities

Table 13: Regional actions for the transport sector (continued)

ENERGY TRANSITION COMPONENT	INDICATOR (UNIT)	HISTORICAL 2018	MOST AMBITIOUS SCENARIO (DES) 2030	MOST AMBITIOUS SCENARIO (DES) 2050	KEY ACTIONS
CO_2 Emissions					
CO_2 Emissions	Direct ($MtCO_2$/yr)	30	34	17	• Organise working commitees integrating public and private institutions and possible technical/finance partners • Assess current situation of the sector to identify barriers and define priorities • Develop specific plans and strategies for sustainable mobility (*e.g.* Costa Rica, Panama) • Implement pilot projects (*e.g.* Costa Rica, Panama) • Improve transport infrastruture, network systems and stock • Establish regulations for second-hand vehicles imports and emissions standards to control the quality of the market

8.3 INDUSTRY

Figure 59: Industry energy demand in 2018 and under the DES in 2030 and 2050, and energy saved compared to the PES



Note: Positive values correspond to the absolute energy demand under DES. Negative values correspond to savings comparing the energy demand of DES with respect to PES. Categories refer to the share of the energy service in the energy demand of industry. Further measures for emission reduction and renewable penetration in the sector are available in Box 3.

Figure 60: Total final energy consumption by carrier, emissions and share of renewable energy in industry in 2018 and under the DES in 2030 and 2050

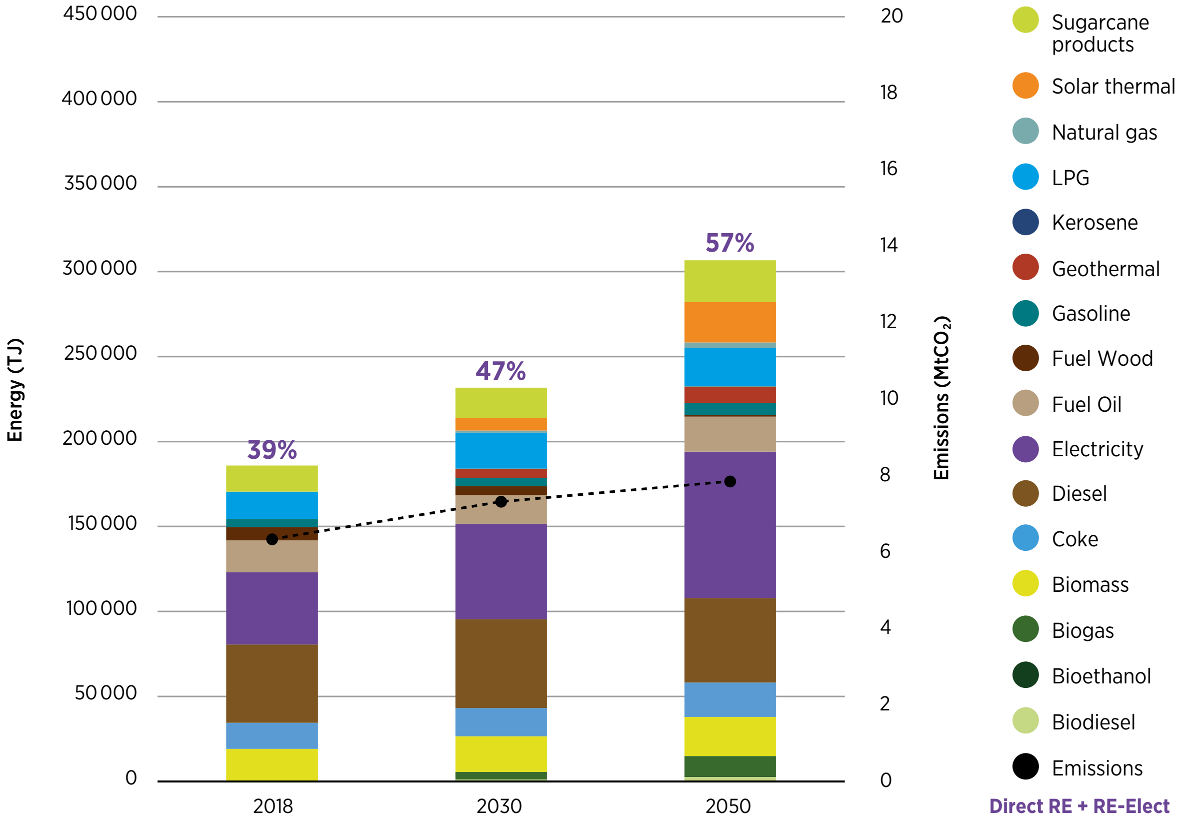


Table 14: Regional actions for industry

INDUSTRY: INDICATOR OF PROGRESS - STATUS IN 2018 AND TARGETS FOR 2030 AND 2050

ENERGY TRANSITION COMPONENT	INDICATOR (UNIT)	HISTORICAL 2018	MOST AMBITIOUS SCENARIO (DES) 2030	MOST AMBITIOUS SCENARIO (DES) 2050	KEY ACTIONS
Energy transition strategy and components					
Energy conservation and efficiency	Industry TFEC (PJ)	186	232	307	• Reduce energy intensity of the industry sector in ca. 8% by 2030 and double factor by 2050 (improvement of infrastructure design and materials for energy recovery, better practices in O&M, improvement of production processes, etc.) • Implement digitalisation, DSM and micro smart grids in end-use sectors through pilot projects • Implement MRV systems to track performance of energy efficiency measures
Electrification in the end-use sectors	Electricity share in industry (%)	23%	24%	28%	• Electrification of industrial low temperature process heating applications

ENERGY TRANSITION COMPONENT	INDICATOR (UNIT)	HISTORICAL 2018	MOST AMBITIOUS SCENARIO (DES) 2030	2050	KEY ACTIONS
Renewables direct use in end-use sectors	Modern bioenergy share in industry TFEC (%)	19%	19%	20%	• Develop specific plans and strategies for biofuels blending (diesel and gasoline) • Introduction of the use of biogas • Use of biomass for high temperature thermal processes (i.e. cement production)
	Solar thermal and geothermal consumption share in industry TFEC (heating) (%)	0%	5%	11%	• Acceleration of low-carbon technology deployment for industrial process heating, particularly of solar water heating and geothermal solutions • Provision of financial help to face the upfront costs of these technologies
CO_2 Emissions					
CO_2 Emissions	Direct ($MtCO_2$/yr)	8.1	7.3	7.8	• Organise working commitees integrating public and private institutions and possible technical/finance partners • Develop an industry characterisation study • Develop specific plans and strategies for industry decarbonisation (*e.g.* Costa Rica) • Identification of specific projects by industry sector to facilitate access to finance

8.4 POWER SECTOR

Figure 61: Electricity generation by technology, emissions and share of renewable energy in the power sector in 2018 and under the DES in 2030 and 2050

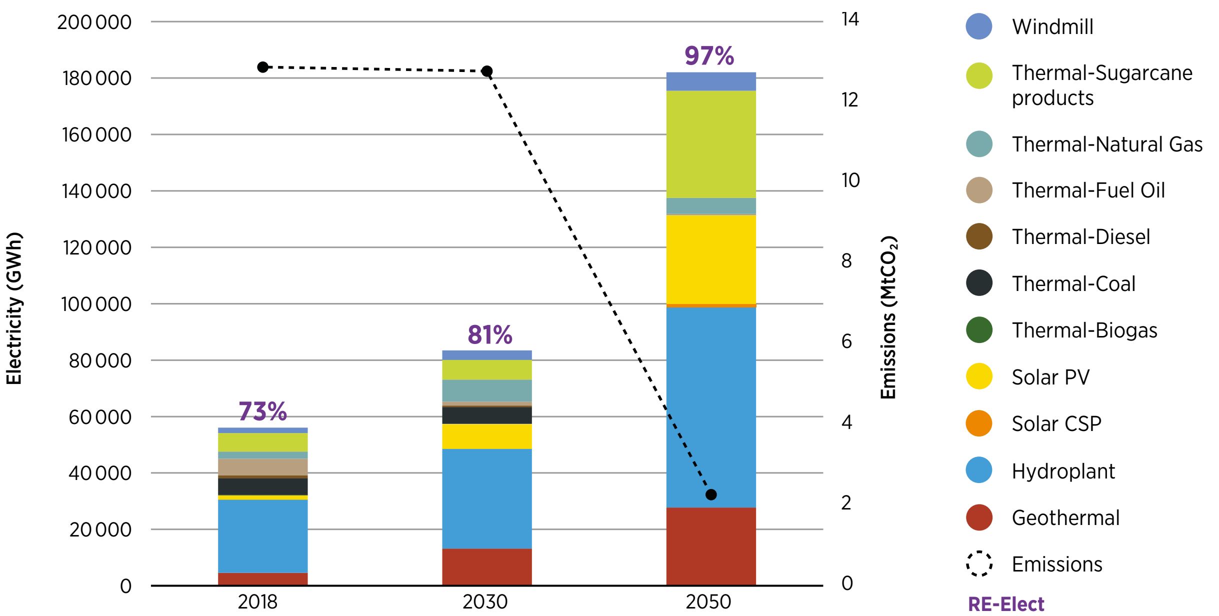


Table 15: Regional actions for the power sector

POWER SECTOR: INDICATOR OF PROGRESS - STATUS IN 2018 AND TARGETS FOR 2030 AND 2050

ENERGY TRANSITION COMPONENT	INDICATOR (UNIT)	HISTORICAL 2018	MOST AMBITIOUS SCENARIO (DES) 2030	MOST AMBITIOUS SCENARIO (DES) 2050
Energy transition strategy and components				
Renewables in the power sector	Total Installed capacity (GW)	17	27	65
	Total electricity generation (TWh)	56	83	182
	Renewables share in capacity (%)	67%	73%	91%
	Variable renewables share in capacity (%)	13%	27%	46%
	Renewables share in generation (%)	73%	81%	97%
	Variable renewables share in generation (%)	6%	14%	21%
CO_2 Emissions				
CO_2 Emissions	Direct ($MtCO_2$/yr)	12.9	12.8	2.3

KEY ACTIONS

Distributed energy resources

- Introduction of distributed PV solar generation systems for the generation of electricity in buildings

Planning

- Prepare and plan for development of a set of robust renewable energy projects, reinforcing SICA's role as higher shares of variable renewable energy are more closely incorporated with integrated system planning.

Trade agreement

- Introduction of a regional market as main day-ahead market
- Implementation of a regional balancing and ancillary services market, to share operational reserves and non-energy services

Regulation – Price

- Regulation to ensure there is harmony between price/tariff regulations to prevent unfair competition in the region. This should also bring fair trade between different countries and have enforcement strength, there should be proper regional agreements to deal with such situations, so benefits of lower electricity prices and costs of regional integration are fairly distributed.

Grids and storage

- Increase of SIEPAC line interconnection capacity from 300 MW to up to 2 GW
- Installation of storage to aid integration of renewables by shifting solar PV production to night periods
- Flexibilisation of electric vehicles by introducing smart charging strategies
- Develop and deploy increased monitoring and observability of transmission and distribution systems to aid integration of distributed technologies and harness innovations in flexibility.
- Installation of electrolysers for domestic production of green hydrogen and power system flexibility

Finance

- Prepare for a doubling of the finance required in the region, up to a total of USD 72 billion, for the power sector to ensure delivery of renewable projects, storage, domestic and international transmission to provide lower cost power supply and deliver significant local economic benefits

Box 8. Insights of countries and regional institutions of the Renewable Energy Roadmap for Central America analysis

A final regional workshop was organised in November 2021 after sharing a preliminary draft of the report with the Central American countries and multilateral regional institutions. The objective of the workshop was to provide the countries and multilateral institutions with a space to share their experience during the project and their insights about the results of the study.

The close engagement and co-operation during the process was acknowledged by countries. The analysis provided valuable inputs for the definition of national plans, including the update of country NDCs. For instance, the analysis inputs served as a basis for the definition of the end-use and power sector emissions targets in Belize's updated NDCs. Likewise, El Salvador considered the results of the analysis to set more ambitious power sector targets in the NDCs and to include additional ones in the transport sector.

The technologies and measures that were presented in the most ambitious scenarios in both the demand and supply side, opened a range of new sustainable possibilities for some countries. This set of actions was highly appreciated by certain countries, which are now planning to deepen their knowledge in these topics. Keeping a balance between having a cost effective, sustainable, and reliable energy mix was considered as a key point for the development of country´s energy systems.

Throughout the project, an exercise of capacity building and knowledge transfer was carried out, which is considered essential for the countries to be able to follow up with the analysis and to keep on working independently in similar initiatives.

The data rich nature of the analysis was highly appreciated by countries, as it provides grounds for the development of policies with clear and measurable objectives. The importance of defining plans and actions that ensure the implementation of the policies and the compliance of the objectives was highlighted. A comprehensive monitoring of its achievement is considered crucial to have a clear understanding of its related impact.

Once the specific plans, actions and responsible actors for their implementation are defined, access to finance and technical co-operation becomes then a key challenge, according to countries. Stakeholders of the region believe that the availability of funds and private-public instruments for the development of pilot projects would greatly foster the use of renewable energy technologies and energy efficiency measures in all sectors. For instance, in the cases of Guatemala and Honduras these feasibility mechanisms could support the countries to transition to cleaner technologies for cooking.

During the panel discussion it was emphasised that having a regional perspective of the operation and expansion of the energy system could help countries to further exploit their local resources and look for complementarity from other available resources in neighbouring countries. According to Nicaragua, there could be challenges for the commissioning of projects to expand the transmission network, as these projects need to be approved by the regional interconnection entity based on their derived social benefits. The analysis complements this requirement providing several operational benefits, including the reinforcement of the energy security of the region.

Additionally, countries positively consider the importance of working together on joint initiatives and sharing good practices. Some examples of ongoing bilateral co-operation include the joint project between Panama and El Salvador for the certification of energy efficiency professionals and enterprises; in terms of electromobility, it could be highlighted the triangular co-operation of Germany, Costa Rica and Honduras to deploy this technology in the latter country, and the fostering project between Costa Rica and Panama, in which electric chargers have been installed along the ca. 900 km route that connects the capital cities, San José and Ciudad de Panamá.

In conclusion, the Renewable Energy Roadmap for Central America constitutes a data rich study that provides an outlook of the regional energy system, focusing at the same time on the context of each country, and that aims to identify and address the main challenges of concern. During its development there was an exercise of knowledge transfer, which has been greatly appreciated by countries. Additionally, it provided a space for dialogue and experiences sharing that is facilitating the development of a sustainable and reliable energy system in the region.

REFERENCES

Akhairi, M.A.F. and Kamarudin (2016), "Catalysts in direct ethanol fuel cell (DEFC): An overview," *International Journal of Hydrogen Energy*, Vol. 41, No. 7, www.sciencedirect.com/science/article/abs/pii/S0360319915027846 (accessed 17 November 2021).

Autoridad del Canal de Panamá (2019), "Reminder concerning Fuel Requirements in the Panama Canal," www.pancanal.com/common/maritime/advisories/2019/a-39-2019-1.pdf (accessed 14 September 2021).

BNEF (2020), "Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh," https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/ (accessed 27 September 2021).

BNEF (2021 a), "BNEF," https://about.bnef.com/ (accessed 7 October 2021).

BNEF (2021 b), "Electric Vehicle Outlook 2020," https://about.bnef.com/electric-vehicle-outlook/ (accessed 27 September 2021).

Climate Watch (2021), "Historical GHG Emissions," www.climatewatchdata.org/ghg-emissions?breakBy=countries&chartType=area&end_year=2018&regions=BLZ%2CCRI%2CSLV%2CGTM%2CHND%2CNIC%2CPAN&sectors=agriculture%2Cindustrial-processes%2Cwaste%2Cbuilding%2Celectricity-heat%2Cfugitive-emissions%2Cmanufacturing-construction%2Cother-fuel-combustion%2Ctransportation%2Cbunker-fuels&start_year=1990 (accessed 14 September 2021).

COMIECO (2020), "RTCA 23.01.78.20," members.wto.org/crnattachments/2020/TBT/GTM/20_7238_00_s.pdf (accessed 4 October 2021).

ECLAC (2020), "Mujeres y energía, (Women and energy)," www.cepal.org/es/publicaciones/45377-mujeres-energia (accessed 7 September 2021).

ECLAC (2021), "Estadísticas del subsector eléctrico de los países del Sistema de la Integración Centroamericana (SICA), 2019 y avances a 2020 (*Statistics of the electric subsector of the SICA countries 2019 and 2020 progress*)," www.cepal.org/es/publicaciones/47019-estadisticas-subsector-electrico-paises-sistema-la-integracion-centroamericana (accessed 24 September 2021).

Empresa Eléctrica Quito (2021), "Programa de Cocción Eficiente - PEC, cocinas de inducción (*Efficient cooking program, induction cook stoves*)," www.eeq.com.ec:8080/energia-renovable-y-eficiencia/programa-de-coccion-eficiente-pec (accessed 2 November 2021).

Energía Estratégica (2021), "Estas son las ofertas de energías renovables con los precios más bajos en Panamá, (*These are the renewable energy offers with lower prices in Panama*)," www.energiaestrategica.com/estas-son-las-energias-renovables-que-ofrecieron-los-precios-mas-bajos-en-panama/ (accessed 12 October 2021).

ENTSO-E (2018), *Electricity Balancing in Europe - An overview of the european balancing market and electricity balancing guideline*, European Network of Transmission System Operators for Electricity, https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/Network%20codes%20documents/NC%20EB/entso-e_balancing_in%20_europe_report_Nov2018_web.pdf.

FAO (2021), "FAOSTAT Statistical Database [Sugarcane production in Central America in 2019]," www.fao.org/faostat/ (accessed 17 November 2021).

GINN (2021), "Improving Women's Empowerment with Clean Cookstoves," https://navigatingimpact.thegiin.org/strategy/gli/improving-womens-empowerment-with-clean-cookstoves/ (accessed 23 November 2021).

GIZ (2020), "Promotion of geothermal energy in Central America," www.giz.de/en/worldwide/78071.html (accessed 2 November 2021).

Global Infrastructure Connectivity Alliance (2017), "SIEPAC Electrical Interconnection System," www.gica.global/initiative/siepac-electrical-interconnection-system.

Hydrogen Council (2017), "Hydrogen scaling-up - A sustainable pathway for the global energy transition," hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf.

IDB (2017), "Central American Electricity Integration - Genesis, Benefits and Outlook of the SIEPAC Project," https://publications.iadb.org/publications/english/document/central-american-electricity-integration.pdf.

IRENA (2017), *Electricity storage and renewables: Costs and markets to 2030*, International Renewable Energy Agency.

IRENA (2018), *Power System Flexibility for the Energy Transition. Part I: Overview for Policy Makers*, IRENA.

IRENA (2019a), *Innovation landscape for a renewable-powered future*, IRENA, Abu Dhabi.

IRENA (2019b), *Innovation Outlook: Smart charging for electric vehicles*, IRENA, Abu Dhabi.

IRENA (2020), *The Post-COVID Recovery: An agenda for resilience, development and equality*, IRENA, Abu Dhabi.

IRENA (2021a), *Renewable Power Generation Costs in 2020*, IRENA, Abu Dhabi.

IRENA (2021b), *World Energy Transitions Outlook: 1.5°C Pathway*, IRENA, Abu Dhabi.

IRENA (2021c), *Renewable energy statistics 2021*, IRENA, Abu Dhabi.

IRENA (2021d), *Reaching zero with renewables: Biojet fuels*, IRENA, Abu Dhabi.

IRENA and IEA-ETSAP (2013), *Production of Bioethylene: Technology brief*, IRENA, IEA-ETSAP, Abu Dhabi, Paris.

S. Moores (2021), "The Global Battery Arms Race: Lithium-Ion Battery Gigafactories and their Supply Chain," www.oxfordenergy.org/wpcms/wp-content/uploads/2021/02/THE-GLOBAL-BATTERY-ARMS-RACE-LITHIUM-ION-BATTERY-GIGAFACTORIES-AND-THEIR-SUPPLY-CHAIN.pdf (accessed 27 September 2021).

MOVE Latam (2021), "MOVE - Movilidad eléctrica en América Latina y el Caribe, (*MOVE - Electric Mobility in Latin America and the Caribbean*)," https://movelatam.org/.

NISSAN (2019), "e-Bio Fuel-Cell: A fuel cell system that generates electricity from bioethanol to power a vehicle," www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/e_bio_fuel_cell.html (accessed 17 November 2021).

PAHO (2020), "Respuesta a los huracanes Eta e Iota - noviembre de 2020, (*Response to the Eta and Iota hurricanes - November 2020*)," www.paho.org/es/respuesta-huracanes-eta-iota (accessed 19 November 2021).

PNUMA (2021), "Movilidad Eléctrica - Avances en América Latina y El Caribe 4ta. edición (*Electric Mobility - Progress in Latin America and the Caribbean 4th edition*)," https://movelatam.org/4ta-edicion/ (accessed 19 August 2021).

Ricardo Energy and Environment (2020), "Zero-Carbon for Shipping - Propelling investment in South and Central America with hydrogen-based shipping solutions," www.researchgate.net/publication/344554235_Zero-Carbon_for_Shipping_Propelling_investment_in_South_and_Central_America_with_hydrogen-based_shipping_fuels.

Seabra J.E.A. *et al.*, (2011), "Life cycle assessment of Brazilian sugarcane products: GHG emissions and energy use," *Biofuels, Bioproducts and Biorefining,* Vol. 5, No. 5, pp. 519–532, https://doi.org/10.1002/bbb.289.

SICA (2020), "Estrategia Energética Sustentable 2030 de los países del SICA, (*Sustainable Energy Strategy 2030 of the SICA countries*)," www.cepal.org/es/publicaciones/46374-estrategia-energetica-sustentable-2030-paises-sica.

SNE (2020), "Lineamientos Estratégicos de la Agenda de Transición Energética 2030, (*Strategic Guidelines of the Energy Transition Agenda 2030*)," www.gacetaoficial.gob.pa/pdfTemp/29163_B/81944.pdf.

Trahey, L. *et al.*, (2020), "Energy storage emerging: A perspective from the Joint Center for Energy Storage Research," *Proceedings of the National Academy of Sciences,* Vol. 117, No. 23, pp. 12550–12557, https://doi.org/10.1073/pnas.1821672117.

WHO (2021), "Concentrations of fine Particulate Matter (PM 2.5)," www.who.int/data/gho/data/indicators/indicator-details/GHO/concentrations-of-fine-particulate-matter-(pm2-5) (accessed 19 August 2021).

ANNEX A. OVERVIEW OF MAIN ONGOING INITIATIVES AND PLATFORMS IDENTIFIED IN CENTRAL AMERICA[24]

Initiative	Description
SUSTAINABLE ENERGY STRATEGY 2030 – EES2030 (SICA)	• Set of regional actions by 2030 in the SICA countries grouped in 14 topics, including energy sources (diversification of the energy matrix – fuels and new renewables), energy access, regional integration, transport sector, regulations and standardisation, rational and efficient use of energy, smart grids, financing and institutions. www.cepal.org/es/publicaciones/46374-estrategia-energetica-sustentable-2030-paises-sica
RTCA (SICA)	• Technical Regulations of Central America in terms of energy efficiency indexes for high-demand electric devices (i.e. space cooling, refrigeration, lighting, motors). www.sica.int/download/?gofd_116071_1_26112018.pdf
RATIONAL USE OF FUEL WOOD (SICA)	• Project that supports Guatemala, Honduras, Nicaragua and Belize in their national initiatives to curb the consumption of fuel wood. www.sica.int/iniciativas/usososteniblelenia
GEOTHERMAL ENERGY DEPLOYMENT (SICA)	• Regional project as part of the Geothermal Development in Central America programme, carried out within the framework of the German Climate Technology Initiative (DKTI). www.sica.int/iniciativas/fogeo
MOVE LATAM (UNEP)	• Platform for electro-mobility in Latin America and the Caribbean. • Regional reports of status of normatives, statistics, incentive frameworks, recommendations for further deployment, and other topics related to electro-mobility and air quality (four editions). https://movelatam.org
EUROCLIMA+ PROJECTS	• Lines of action in the European region, including plans and policies, climate financing, transparency, Intersectoral, multi-level and multi-stakeholder co-ordination, action for climate empowerment, gender and vulnerable groups. https://euroclimaplus.org/en/lines-of-action/plans-and-policies
GEOTHERMAL PROGRAMME (GIZ)	• Promotion of geothermal development in Central America, specifically in Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama. www.giz.de/en/worldwide/78071.html
NOTABLE NATIONAL/BILATERAL PLANS/STRATEGIES/ PROGRAMMES	• Decarbonisation Plan (Costa Rica) • Industry demand characterisation (Costa Rica) • Electro-mobility/Sustainable mobility strategies (Costa Rica, Panama) • Solar thermal market development (Panama, El Salvador) • Energy efficiency indexes and/or capacity building (Panama, Costa Rica, El Salvador)

[24] National/bilateral initiatives considered are currently published or approved.

ANNEX B. KEY ASSUMPTIONS OF TECHNOLOGY COSTS AND FOSSIL FUEL PRICES

The key assumptions for the investment analysis are presented in Table 16, which includes among others: investment costs of main renewable electricity technologies and natural gas, average acquisition costs of selected end-use sector technologies with high energy consumption or affordability impact in the region (*e.g.* vehicles and its charging infrastructure[25] costs) and average fossil fuels prices, mainly used in end use sectors. Further inputs in terms of technical features or activity level required for the energy modelling will be available online.

Table 16: Key assumptions of technology costs and fossil fuel prices

		2018	2030	2050	REFERENCES
Electricity generation parameters					
Renewable-based technology investment cost (USD/kW)	Hydropower	1 445	1 445	1 430	• EC JRC (2017), "Cost development of low carbon energy technologies," https://publications.jrc.ec.europa.eu/repository/bitstream/JRC109894/cost_development_of_low_carbon_energy_technologies_v2.2_final_online.pdf
	Solar PV – utility	1 200	590	320	
	Solar PV – distributed generation	1 400	680	375	
	Bioenergy and waste	1 500	1 500	1 500	
	Geothermal	4 600	4 175	3 860	
	Wind onshore	1 420	1 300	1 220	
	Solar CSP	7 350	5 355	4 535	
Fossil fuel-based technology investment cost (USD/MW)	Natural gas (Combined Cycle)	890	890	890	• EIA (2021), "Cost and Performance Characteristics of New Generating Technologies, Annual Energy Outlook 2021, www.eia.gov/outlooks/aeo/assumptions/pdf/table_8.2.pdf
Economics	Discount rate	10%	10%	10%	• IRENA assumption.

[25] Small private chargers refer to home chargers of typically 3.6 kW to 7 kW for motorcycles, cars and sport utility vehicles (SUVs); small public chargers refer to chargers of typically 22 kW. Large private and public chargers refer to chargers of <50 kW for vans, mini-buses, buses, and small and large trucks.

Table 16: Key assumptions of technology costs and fossil fuel prices (continued)

End-use sectors technologies parameters		2018	2030	2050	REFERENCES
Residential technology cost (USD/unit)	LPG stove	450	450	450	• Average value of data consulted in main commercial stores of each country.
	Electric stove	725	725	725	
Transport technology costs (USD/unit)	Electric motorcycle	2 000	1 473	1 200	• Average value of data consulted, and quotations requested in main vehicle distributors of each country.
	Electric car	30 000	20 000	15 000	
	Electric SUVs	60 000	45 000	39 785	
	Electric minibus	70 000	50 000	40 000	
	Electric bus	160 000	100 000	80 000	
	Electric small truck	60 000	40 000	30 000	
	Electric large truck	150 000	100 000	75 000	
Transport technology costs (USD/unit)	Small private charger	1 000	1 000	1 000	• IRENA research. Average value of data consulted.
	Small public charger	3 000	3 000	3 000	
	Large private and public charger	42 500	42 500	42 500	
	Conventional motorcycle (gasoline)	1 500	1 500	1 500	• Average value of data consulted, and quotations requested in main vehicle distributors of each country.
	Conventional car (gasoline)	15 000	15 000	15 000	
	Conventional car (diesel)	18 000	18 000	18 000	
	Conventional SUV (diesel)	40 000	40 000	40 000	
	Conventional minibus (diesel)	35 000	35 000	35 000	
	Conventional bus (diesel)	80 000	80 000	80 000	
	Conventional small truck (diesel)	30 000	30 000	30 000	
	Conventional large truck (diesel)	75 000	75 000	75 000	

Table 16: Key assumptions of technology costs and fossil fuel prices (continued)

Fossil fuels prices

		2018	2030	2050	REFERENCES
Electricity generation (USD/TJ)	Natural gas	7 580	7 580	7 580	• IRENA assumption.
End-use sectors (USD/TJ)	Diesel	14 356	15 226	17 970	• CCHAC "Precios promedio de combustibles al consumidor en Centroamérica" (reports of 2018, 2019, 2020, 2021) • ECLAC (2020), "Centroamérica y la República Dominicana: estadísticas de hidrocarburos, 2019." • EIA (2020), "Table 3. Energy Prices by Sector and Source," • EIA (2021), "U.S. Natural Gas Prices".
	Fuel oil	10 638	10 871	15 221	
	Gasoline	15 495	14 940	18 272	
	Kerosene	15 750	17 051	22 365	
	LPG	22 755	26 051	32 443	
	Natural gas	-	9 367	9 926	

ANNEX C. DATA REFERENCES FOR THE REMAP ANALYSIS

The energy modelling, emissions and investment analysis of the region required the revision of various documents and databases from the countries, regional entities, and multilateral organisations, as well as international references to complement the study.

ENERGY MODELLING

Regional

ACP (2021), "Trafico por el Canal de Panamá por segmento de mercado. Años fiscales 2020-2019, *(Panama canal trafic by market segment. Fiscal years 2020-2019)*."

AMP (2021), "Venta de combustible marino a través de barcaza, *(Marine fuel sales through barge)*."

R. Berger (2017), "Fuel Cells and Hydrogen Applications for Regions and Cities Vol 1."

CEPAL (2017), "Estadísticas del subsector eléctrico de los países del Sistema de la Integración Centroamricana (SICA) 2015, *(Statistics of the electric subsector of the SICA countries 2015)*."

CEPAL (2019), "Evaluación de escenarios para la formulación de la Estrategia Energética Sustentable SICA 2030, *(Scenarios evaluation for the formulation of the sustainable energy strategy SICA 2030)*."

CEPAL (2020a), "Estrategia Energética Sustentable 2030 de los países del SICA, *(Sustainable energy strategy 2030 of the SICA countries)*."

CEPAL (2020 b), "Sociodemographic Statistics," www.cepal.org/en/datos-y-estadisticas.

CEPAL (2020 c), "Census Statistics - REDATAM," www.cepal.org/en/topics/redatam.

EC JRC (2017), "Cost development of low carbon energy technologies," p. 77.

EIA (2021), "Cost and Performance Characteristics of New Generating Technologies, Annual Energy Outlook 2021," p. 4.

Element Energy Ltd (2019), "Hydrogen in transport: Hydrogen cars, vans and buses."

IDB (2017), "La Red del Futuro: Desarrollo de una red eléctrica limpia y sostenible para América Latina, *(The grid of the future. Development of a clean and sustainable electric grid for Latin America)*"

IPCC. (2020), "IPCC Data on Emission Factors," www.ipcc.ch/data/.

Kim, K. *et al.*, (2020), "A Preliminary Study on an Alternative Ship Propulsion System Fueled by Ammonia: Environmental and Economic Assessments," *Journal of Marine Science and Engineering*, Vol. 8, No. 3, p. 183, https://doi.org/10.3390/jmse8030183.

MOVE (2020), "Reporte de Movilidad Eléctrica, *(Electric mobility report)*."

OLADE (2004), "Guía M-5 Metodología de Conversión de Unidades, *(M-5 guide. Methodology for unit conversion)*."

OLADE (2018), "Energy Balances."

OLADE (2020), "Energy Outlook of Latin America and the Caribbean 2019."

Ø. Sekkesæter (2019), "Evaluation of Concepts and Systems for Marine Transportation of Hydrogen."

Transport & Environment (2020), "Comparison of hydrogen and battery electric trucks: Methodology and underlying assumptions."

World Bank (2021), "Sociodemographic Statistics," https://data.worldbank.org/.

Belize

Ambrose Tillett, J. Locke and J. Mencias (2012), "National Energy Policy Framework," p. 368.

BEL (2018), "2018 Annual Report - Power sector."

K. Bunker and R. Torbert (2018), "Belize Consolidated Project Plan," p. 134.

CASTALIA (2015), "Belize Sustainable Energy Strategy."

CCCCC and M. Linders (2016), "Potential Study on producible Biogas and Renewable Energy from Biomass and Organic Waste in Belize," p. 44.

EGIS (2018), "Preparation of a Comprehensive National Transportation Master Plan for Belize.pdf."

MPSEPU (2018), "Belize - Annual Energy Statistics Report."

SIB (2010), "Belize Population and Households Census 2010."

UNDP (2019), "Nationally Appropriate Mitigation Action (NAMA) for Belize."

Costa Rica

BCCR (2021), "Programa macroeconómico 2021-2022, *(Macroeconomic program 2021 - 2022)*," p. 108.

GIZ (2019), "Inventario de GEI de Refrigeración y AC para Costa Rica 2012-2016, *(Refrigeration and AC GHG inventory for Costa Rica 2012-2016)*."

Gobierno de Costa Rica (2016), "Contribución prevista y determinada a nivel nacional, *(Intended national determined contribution)*," p. 19.

Gobierno de Costa Rica (2019), "Plan de descarbonización 2018 - 2050, *(Decarbonization plan 2018 - 2050)*."

ICE (2019a), "Plan de expansión de la generación 2018-2034, *(Generation expansion plan 2018-2034)*."

ICE (2019b), "Proyecciones de la Demanda Eléctrica de Costa Rica 2019-2040, *(Electricity demand projections for Costa Rica 2019-2040)*."

MINAE (2013), "Encuesta de consumo energético nacional en el sector transporte, *(Transport sector national energy consumption survey)*."

MINAE (2014a), "Encuesta de consumo energético nacional en el sector industrial, *(Industry sector national energy consumption survey)*," p. 181.

MINAE (2014b), "Encuesta del consumo energético nacional en el sector comercio y servicios privados, *(Commercial and private services sector national energy consumption survey)*."

MINAE (2017), "Hoja de Ruta de tecnología solar para calentamiento de agua, calefacción y refrigeración de ambientes en Costa Rica al 2030, *(Solar technology roadmap for water heating, space heating and cooling in Costa Rica for 2030)*."

MINAE (2019a), "Estudio para la caracterización del consumo energético en el sector residencial, *(Study for the characterisation of the energy consumption in the residential sector)*," p. 150.

MINAE (2019b), "Plan nacional de transporte eléctrico 2018-2030, *(Electric transport national plan 2018-2030)*."

PEN (2018), "Diagnóstico sobre la situación del transporte y de la movilidad en Costa Rica, *(Diagnosis about the transport and mobility situation in Costa Rica)*," 2018, p. 21.

RECOPE (2018), "Plan de descarbonización del sector transporte terrestre, *(Decarbonization plan of overland transport)*," p. 92.

SEPSE (2018), "Balance Energéticos, *(Energy Balances)*," https://sepse.go.cr/nuestros-productos/balances-energeticos/.

El Salvador

CEPAL (2016), "Informe nacional de monitoreo de la EE en El Salvador, *(National energy efficiency monitoring report in El Salvador)*."

CNE (2010), "Caracterización de la demanda y uso final de la energía en el sector industria, *(Energy demand and final use characterisation in the industry sector)*."

CNE (2012), "Resumen de documento - Plan maestro para el desarrollo de la energía renovable en El Salvador, *(Document summay - Master plan for the renewable energy development in El Salvador)*."

CNE (2018a), "Balance energético, *(Energy Balance)*."

CNE (2018b), "Plan indicativo de la generación de la expansión 2019-2028, *(Indicative generation expansion plan 2019-2028)*."

Digestyc (2018), "Encuesta de Hogares de Propósitos Múltiples, *(Multiple purposes households survey)*," p. 553.

MARN (2015), "Contribución prevista y determinada a nivel nacional de El Salvador, *(Intended national determined contributions of El Salvador)*," p. 15.

Multiconsult (2011), "Estudio caracterización de la curva de demand y uso final de la energía para ser aplicados al desarrollo de proyectos de eficiencia energética, *(Characterization study of the energy demand curve and final use for their application to energy efficiency projects development)*," p. 47.

SIGET (2019), "Boletín de Estadísticas Eléctricas No. 21 Año 2019, *(Electrical Statistics bulletin No. 21 Year 2019)*."

Guatemala

CNEE (2012), "Informe de Análisis del Consumo de Electricidad, *(Electricity consumption analysis report)*."

CNEE (2020), "Plan de expansión indicativo del sistema de generación 2020 - 2050, *(Indicative expansion plan of the generation system 2020-2050)*," p. 72.

INE (2018a), "Censo 2018 - Cuadro B4. Hogares según tipo de alumbrado, fuente principal de energía para cocinar y disponibilidad de cuarto exclusivo para cocinar, *(Census 2018 - Table B4. Households according to type of lighting, main cooking carrier and availability of a room for cooking)*."

INE (2018b), "Censo 2018 - Cuadro C1. Tipo de vivienda y condición de ocupación, *(Census 2018 - Table C1. Household type and occupation condition)*."

INE (2019), "Estimaciones y proyecciones de población a largo plazo 1950-2050, *(Long term population estimations and projections 1950 - 2050)*."

MEM (2014), "Política energética 2013-2027, *(Energy policy 2013-2027)*."

MEM (2015), "Modelo de análisis de la demanda de energía Guatemala 2015 - 2050, *(Energy demand analysis model for Guatemala 2015-2050)*."

MEM (2017), "Plan nacional de energía 2017 - 2032 Guatemala, *(National energy plan 2017-2032 for Guatemala)*."

MEM (2018), "Política Energética de Guatemala 2019 - 2050, *(Energy policy of Guatemala 2019-2050)*."

MEM (2019), "Plan Indicativo de Electrificación Rural 2020 - 2032, *(Indicative plan of rural electrification 2020-2032)*."

MEM (2020a), "Balance energético nacional 2018, *(National energy balance 2018)*."

MEM (2020b), "Reporte final de resultados de proyecto piloto movilidad verde 2020, *(Final report of the green mobility pilot project results 2020)*."

Honduras

ENEE (2019), "Proyección de la demanda de energía eléctrica 2019-2033, *(Electricity demand projection 2019-2033)*."

T. Faller et al (2017), "La geotermia en Honduras: diagnóstico del clima de inversión y oportunidades, *(Geothermal energy in Honduras: diagnosis of the investment climate and opportunities)*."

Fundación Bariloche (2019), "Prospectiva Energética de Honduras 2017-2038, *(Honduras Energy Outlook 2017-2038)*."

INE (2017), "Encuesta permanente de hogares de propósitos múltiples 2017, *(Ongoing survey of multipurpose households 2017)*."

INE (2019), "Encuesta permanente de hogares de propósitos múltiples 2019, *(Ongoing survey of multipurpose households 2019)*."

ODS (2019), "Plan Indicativo de Expansión de Generación 2020-2029, *(Generation Expansion Indicative Plan 2020-2029)*."

SEN (2018), "Balance Energético 2018, *(Energy Balance 2018)*.

SEN (2019a), "Balance Energético 2019, *(Energy Balance 2019)*."

SEN (2019b), "Informe Estadístico Anual del Subsector Eléctrico 2019, *(Annual Statistical Report of the Electricity Subsector 2019)*."

Nicaragua

BCN (2020), "Sector real, *(Real Sector)*."

BCN (2021a), "Producto interno bruto: enfoque de la producción (en millones de córdobas de 2006), *(Gross domestic product: production approach (in 2006 millions cordobas)*."

BCN (2021b), "Consumo facturado de energía eléctrica por bloque económico, *(Billed electricity consumption by economic block)*."

BCN (2021c), “Transporte de pasajeros, *(Passenger transport)*.”

INIDE (2017), “Informe de vivienda: encuesta continua de hogares (ECH) 2009-2016, *(Housing Report: Continuous Household Survey (ECH) 2009-2016)*.”

INTUR (2018), “Boletín de Estadísticas de Turismo Nicaragua 2018, *(Nicaragua Tourism Statistics Report 2018)*.”

MARENA (2018), “Contribución Nacionalmente Determinada Nicaragua 2018, *(Nationally Determined Contribution Nicaragua 2018)*.”

MARENA (2021), “Contribución Nacionalmente Determinada Nicaragua 2020, *(Nationally Determined Contribution Nicaragua 2020)*.”

MEM (2017a), “Programas y Proyectos Nacionales, *(National Programs and Projects)*.”

MEM (2017b), “Programas y Proyectos Regionales, *(Regional Programs and Projects)*.”

MEM (2020), “Balance Energético Nacional 2019, *(National Energy Balance 2019)*.”

MEM (2021), “Gráfico cobertura eléctrica enero-2021, *(Electricity coverage graph January-2021)*.”

MTI (2014), “El Proyecto para el Estudio del Plan Nacional de Transporte En la República de Nicaragua, *(The Project for the Study of the National Transportation Plan in the Republic of Nicaragua)*.”

MTI (2019), “Anuario de Aforos de Tráfico 2018, *(Traffic Gauging Yearbook 2018)*.”

Panama

ETESA (2020), “Tomo II_Plan Indicativo de Generación 2019-2033, *(Volume II_Generation Indicative Plan 2019-2033)*.”

INEC (2010), “Cuadro 1. Estimación de la población total en la República según área, sexo y grupos de edad, años 2000-10, *(Table 1. Estimation of the total population in the Republic according to area, sex and age groups, years 2000-10)*.”

MiAmbiente (2016), “Contribución Nacionalmente Determinada a la Mitigación del Cambio Climático (NDC) de la República de Panamá ante la Convención Marco de Naciones Unidas sobre Cambio Climático (CMNUCC), *(Nationally Determined Contribution to Climate Change Mitigation (NDC) of the Republic of Panama under the United Nations Framework Convention on Climate Change (UNFCCC))*.”

MiAmbiente (2020), “Contribución Determinada Nacional de Panamá (CDN1) Primera actualización diciembre 2020, *(National Determined Contribution of Panama (CDN1) First update December 2020)*.”

PNUD (2020), “Evaluación Económica Inicial Covid19 y el Alcance de las Opciones de Política en Panamá, *(Initial Economic Assessment of Covid19 and the Scope of Policy Options in Panama)*.”

SNE (2016a), “Guía de Construcción Sostenible, *(Sustainable Construction Guide)*.”

SNE (2016b), “Plan Energético Nacional 2015-2050, *(National Energy Plan 2015-2050)*.”

SNE (2019a), “4-CEE-1970-2019-DE-Distribución-Eléctrica, *(Distribution Statistics 1970-2019)*.”

SNE (2019b), “Estrategia Nacional de Movilidad Eléctrica, *(National Electric Mobility Strategy)*.”

SNE (2019c), “Guía manual del programa de etiquetado de Eficiencia Energética, *(Energy Efficiency Labelling Programme Guide)*.”

SNE (2020a), "Balances de Energía 1970-2019, *(Energy Balances 1970-2019)*."

SNE (2020b), "Lineamientos Estratégicos de la Agenda de Transición Energética 2030, (Strategic Guidelines of the Energy Transition Agenda 2030)."

Termosolar Panamá (2020), "Análisis del potencial de desarrollo del mercado de calentadores solares de agua en Panamá, *(Analysis of the development potential of the solar water heater market in Panama)*."

UNEP (2021), "The energy transition as a key driver of the COVID-19 economic recovery in Panama."

INVESTMENT ANALYSIS

BUN-CA (2013), "Estufas mejoradas de leña en Centroamérica: detonando los mercados, *(Improved cookstoves in Central America: triggering the markets)*."

CCHAC (2018), "Precios promedio de combustibles al consumidor en Centroamérica: SP-ESA-CCHAC-01-2018, *(Average consumer fuel prices in Central America: SP-ESA-CCHAC-01-2018)*."

CCHAC (2019), "Precios promedio de combustibles al consumidor en Centroamérica: SP-ESA-CCHAC-51-2019, *(Average consumer fuel prices in Central America: SP-ESA-CCHAC-51-2019)*."

CCHAC (2020), "Precios promedio de combustibles al consumidor en Centroamérica: PPT-NIC-CCHAC-25-2020, *(Average consumer fuel prices in Central America: PPT-NIC-CCHAC-25-2020)*."

CCHAC (2021), "Precios promedio de combustibles al consumidor en Centroamérica: PPT-Costa Rica-CCHAC-20-2021, *(Average consumer fuel prices in Central America: PPT-Costa Rica-CCHAC-20-2021)*."

ECLAC (2020), "Centroamérica y la República Dominicana: estadísticas de hidrocarburos, 2019, *(Central America and the Dominican Republic: hydrocarbon statistics, 2019)*."

EIA (2020), "Table 3. Energy Prices by Sector and Source."

EIA (2021), "U.S. Natural Gas Prices."

ETSAP (2010), "Geothermal Heat and Power."

D. Hall and N. Lutsey (2019), "Estimating the infrastructure needs and costs for the launch of zero-emission trucks."

D. Hall and N. Lutsey (2020), "Electric vehicle charging guide for cities."

Hydrogen Council (2020), "Path to hydrogen competitiveness - A cost perspective."

C. Razo et al. (eds.) (2007), "Producción de biomasa para biocombustibles líquidos: el potencial de América Latina y el Caribe, *(Biomass production for liquid biofuels: the potential of Latin America and the Caribbean)*", Naciones Unidas, CEPAL, Unidad de Desarrollo Agrícola, Div. de Desarrollo Productivo y Empresarial.

World Bank (2013), "¿Qué hemos aprendido del uso de biomasa para cocinar en los hogares de América Central?, *(What have we learned from the use of biomass for cooking in Central American households?)*."

World Bank (2019), "Green your bus ride: Clean buses in Latin America."

R. A. Yépez-García and F. J. Anaya (2017), "La nueva opción energética: Gas natural para Centroamérica, *(The new energy option: Natural gas for Central America)*", Inter-American Development Bank.

ZEBRA (2020), "Accelerating a market transition in LAC: New business models for e-bus deployment."

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