

ZERO CARBON

L A T I N A M E R I C A A N D T H E C A R I B B E A N

**"THE OPPORTUNITY, COST AND BENEFITS OF THE COUPLED
DECARBONIZATION OF THE POWER AND TRANSPORT SECTORS
IN LATIN AMERICA AND THE CARIBBEAN"**

UN 
environment
programme



THE OPPORTUNITY, COST AND BENEFITS OF THE COUPLED
DECARBONIZATION OF THE POWER AND TRANSPORT SECTORS
IN LATIN AMERICA AND THE CARIBBEAN.

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ACKNOWLEDGEMENTS

Lead authors

- Walter Vergara

Senior fellow with WRI, under a sabbatical assignment with UNEP for the purposes of report analysis and preparation.

- Jorgen Fenhann

Senior scientist at the Technical University of Denmark. He is a member of the UNEP DTU partnership. He is the creator and manager of GACMO.

- Silvia R. Santos da Silva

Researcher with the Global Change Center at the University of Maryland.

UN Environment Programme's Latin America and the Caribbean Office Coordinating review committee.

Climate Change Unit:

Led by: **Gustavo Mañez**, Climate Change Coordinator, Latin America and Caribbean Office.

Contributing authors: **Mercedes García Farina**, **Elizabeth Font**.

Reviewers: **Esteban Bermudez**, **Sebastián Carranza**, **William Holness**, **Rosilena Lindo**, **Agustín Matteri**, **Juan Luis Pardo** and **Jonnatan Rico**.

Delegated Chief Scientist:

Francesco Gaetani, Environment under review subprogram regional coordinator, UNEP.

Regional Gender Focal Point:

Piedad Martin, Deputy Regional Director.

External reviewers

Monica Araya, Co-founder of Costa Rica Limpia.

John Christensen, Director of UNEP DTU Partnership.

Gianni Lopez, Director at Mario Molina Center of Chile. **Marta Martínez**, Head of Studies at the Energy Policies and Climate Change Division, Iberdrola.

Horst Pilger, Head of the Climate Change and Environment Section at the European Commission's Directorate-General for International Cooperation

and Development (DG DEVCO). **Miguel Ángel Rubio**, CEO of Acciona Energía Mexico. **Carlos Salle**, Director of Energy Policy and Climate Change at Iberdrola. **Thorsten Schulz**, Investment Manager at Aravis Ventures. **Ignacio Santelices Ruiz**, Director Ejecutivo Agencia de Sostenibilidad Energética de Chile.

External contributors

UNEP/DTU partnership team in Copenhagen, led by its Director John Christensen. Iberdrola's **Energy Policy and Climate Change team** led by its Director Carlos Salle. **Jennifer Layke**, **Alex Perera** and **Katie Pastor** at WRI. **Johannes Friedrich** and **Mengpin Ge** at WRI for their help with information from and access to the CAIT database. **Sergio Avelleda** for information from the BRT database. **Tina Huang** and **Emily Nilson** for assistance with retrieval of information from Resource Watch. **Katherine Segura** and **Byron Chiliquinga** for their assistance in the collection of the load curves of power demand in the region. **Tulio Alves** Executive Director of the Commission for Regional Energy Integration. **Fernando Miralles**, Executive Director, Cooperative Institute for Climate and Satellites and Interim Director of the Earth System Science Interdisciplinary Center at the University of Maryland and **Leon Clark** at the Pacific Northwest National Laboratory for facilitating access to GCAM.

Case studies' contributors

Mónica Araya, **Andrés Barentin**, BMW, EPEC (Argentina), La Casa de las Baterías (Panama), Ministry of Industry and Energy (Uruguay), ENSA (Panama), Ministry of Production and Labor (Argentina), NAVANTIA, Neoenergía.

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Ivonne M. Rodríguez, UN Environment Programme

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Karla Delgado, UN Environment Programme

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ABBREVIATIONS

BAU	Business as Usual	kWh	Kilo watt hour
BEV	Battery Electric Vehicle	LAC	Latin America and the Caribbean
BRT	Bus Rapid Transit	LCOE	Levelized Cost of Energy
CAPEX	Capital expenditure	LCOT	Levelized Cost of Transport
COP	Conference of the Parties	MW	Mega watts
CSP	Concentrated Solar Power	NDC	Nationally Determined Contributions
DER	Distributed Energy Resources	O&M	Operation and Maintenance
DG	Distributed Generation	PM	Particulate matter
DLT	Distributed Ledger Technology	PPA	Power Purchase Agreement
EJ	Exajoule	PPP	Public Private Partnership
EV	Electric Vehicle	PV	Photovoltaic
GACMO	Greenhouse Gas Abatement Cost Model	RE	Renewable Energy
GCAM	Global Change Assessment Model	RCP	Representative Concentration Pathway
GDP	Gross Domestic Product	R&D	Research and Development
GFW	Global Forest Watch	TCO	Total Cost of Ownership
GHG	Greenhouse Gas	TWh	Tera watt hour
GW	Giga watt	T&D	Transmission and Distribution
GWh	Giga watt hour	UNEP	United Nations Environment Programme
HVDC	High Voltage Direct Current	V2G	Vehicle to Grid
ICE	Internal Combustion Engine	V2X	Vehicle to Everything
IPCC	Intergovernmental Panel on Climate Change	VRE	Variable Renewable Energy
IPP	Independent Power Producer	WHO	World Health Organization
KPI	Key performance indicator		

FOREWORD

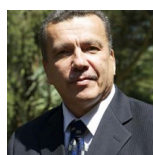
BY THE UNITED NATIONS ENVIRONMENT PROGRAMME

This report has been prepared as a follow up to the analysis entitled Zero Carbon Latin America: a pathway for net decarbonization of the regional economy by mid-century, released at COP 21 (November 2015). The new analysis focuses on the advantage, cost and benefits from a coupled transition of the power and transport sectors in the region by 2050.

The report comes at a critical time when the world is on the brink of missing the opportunity to limit global warming to 1.5°C. Temperatures have already increased 1.1°C above pre-industrial levels and if we rely on current climate commitments, temperatures are expected to rise to 3.2°C. Climate change is becoming a national security threat in the region and therefore, the time to act is now. The Emissions GAP report states that in order to limit global warming to 1.5 °C by 2030, we must reduce emissions at an annual rate of 7.6%.

Government commitments need to increase by 5-fold to maintain the global temperature under 1.5 °C. There are countries in the LAC region that are showing great efforts towards achieving this target. This report shows that the transformational change needed to meet the Paris Agreement and reach net zero emissions by mid-century can be critically supported by coupling the decarbonization of the power and transport sectors. A coupled transition of both sectors would not only contribute to drastically reduce emissions but also has the potential to grow the region's economy and improve public health.

"Zero Carbon Latin America & the Caribbean" shows that the required changes for a coupled transition are mutually supportive, technically viable and financially attractive. The report presents examples from successful policies to business models which, if escalated, can put us in a virtuous scenario and raise the ambition of next generation NDCs.



LEO HEILEMAN

REGIONAL DIRECTOR AND REPRESENTATIVE



FOREWORD

BY THE EUROPEAN COMMISSION

As the world stands at a critical point, heading into uncharted territories, Europe is committed to leading global efforts to step up on climate action. Starting at home, the European Union is taking measures to ensure Europe will be carbon-neutral by 2050.

Over the past two decades, the European Union has decoupled greenhouse gas (GHG) emissions from economic growth. Since 1990, the region has reduced emissions by 22%, while economic growth was 58%. Yet despite these achievements, we recognise the need for continued stronger, urgent action. Scientists, youth, activists, policymakers, industry leaders, and citizens from all walks of life agree: climate action must be taken, now.

The new European Green Deal is the EU's strategy for green growth, whereby the continent will have net GHG emissions by 2050, economic growth is fully decoupled from resource use, and no person and no place is left behind. The EU is also increasing its climate ambition through policy reforms and by setting a GHG emission reduction target of 50% by 2030. The European Green Deal focuses on: (i) decarbonizing the energy system with emphasis on energy efficiency and a renewable-based power sector; (ii) setting a circular economy action plan for industries to reduce waste and promote sustainable products; (iii) renovating public and private buildings to increase energy performance; (iv) shifting transport towards smart and sustainable mobility; (v) developing the "farm to fork" strategy to create a more sustainable food system; (vi) developing a biodiversity strategy to protect and restore ecosystems. It will also pursue initiatives for green financing and investments, and develop mechanisms to ensure a just transition to carbon neutrality.

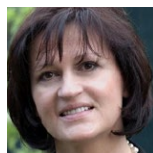
Europe's commitment goes beyond our borders, and includes our international partners, with whom we will strengthen our climate diplomacy efforts and build regional and global alliances to accelerate the transition to decarbonization.

Launched in 2010, EUROCLIMA is the EU's flagship regional climate change programme in Latin America. Providing financial and technical cooperation in the region, EUROCLIMA+ focuses principally on supporting countries to both renew and achieve their Nationally Determined Contributions - their commitments to reducing emissions under the COP21 Paris Agreement.

Transport and power sectors account for two thirds of emissions of fossil CO₂ and about one quarter of the total GHG emissions in Latin America - key sectors that must decarbonize if the region is to meet its collective NDCs. Through EUROCLIMA+, the EU has contributed, for example, to the development of National Electric Mobility Strategies and has helped countries to access climate financing for electric mobility. Amongst other initiatives, EUROCLIMA+ will continue to work on accelerating sustainable urban mobility solutions that can foster innovation and promote new business and job creation while improving public health.

As part of the EU's efforts to support climate action in the region, and on behalf of the European Commission, I am pleased that the EUROCLIMA+ Programme can support this flagship publication, that sets out a path to electrify the transport sector coupled with a transition towards a fully renewable power sector, which will contribute to cost-efficient decarbonization in Latin America. In addition, the document provides a roadmap for Latin American countries to take advantages of synergies and interlinkages between sectors of the economy that will contribute to potentially higher economic benefits and a greater mitigation impact.

The current COVID-19 crisis has demonstrated the value of collective action, and the social and economic cost of inaction in addressing global crises. May we all learn from this, and apply lessons of solidarity, multilateralism and global cooperation to the slow-burning, but no less urgent climate crisis we now face.



JOLITA BUTKEVICIENE
DIRECTOR OF DEVELOPMENT AND COOPERATION IN LATIN AMERICA
AND THE CARIBBEAN



FOREWORD

MINISTRY FOR THE ECOLOGICAL TRANSITION AND THE DEMOGRAPHIC CHALLENGE,
GOVERNMENT OF SPAIN.

Climate neutrality is an act of responsibility towards our present and our future. A commitment that we acquire following what science has been telling us for years and what our societies demand: adequate conditions so that this generation and, above all, the next generations can live in safe and healthy conditions.

There is full awareness of the challenge ahead and proof of this is the Paris Agreement, a milestone in the multilateral negotiations, which is the roadmap for climate action for governments but also for private sector, civil society and actors of all kinds. The commitment to limiting the global temperature increase to 1.5 degrees Celsius brought a measurable horizon, a quantification of the risk, a worldwide understanding that we need to act together against a threat that will affect us all and may jeopardize our quality of life and our survival in this planet.

At the same time, the goal of zero carbon emissions is an opportunity. Or, rather, a wide range of business opportunities and innovations to generate stable and quality jobs, to develop new high added value industries and support the sustainable transition of the existing fundamental sectors in our economies. Considering that two-thirds of greenhouse gas emissions originate from the energy sector, in response to the threat of climate change, we should place the focus on efficiency, renewables and rapid electrification, in particular electric mobility. Renewable technologies today are the cheapest way to produce power. In addition to decarbonisation, they come with a plethora of co-benefits, creation of high skilled jobs, improve the competitiveness of companies and modernise the value chains of our industries. Finally yet importantly they are key to achieve energy for all and alleviate energy poverty.

These mature technologies that, now more than ever, are key to getting our societies and economies back on track. However, this response must happen on an unprecedented scale and at speed if the world is to avoid the most catastrophic consequences of climate change.

Sectors that we know we need to achieve climate neutrality, that are key to our well-being and that contribute decisively to solving problems such as energy poverty. Climate change adaptation refers to actions that reduce the negative impact of climate change, while taking advantage of potential new opportunities. To activate decarbonisation and take advantage of all the opportunities it offers, it is essential to have long-term strategies that provides a sense of direction towards ambitious and achievable goals, based on science. They need to establish a clear roadmap for all sectors of the economy, with no exemption. In Spain, we presented our National Energy and Climate Plan 2021-2030 in April 2020. This is our framework to outline our climate and energy goals, policies and measures for the upcoming decade. It came soon after the Spanish Government declared the climate emergency, which aimed at granting the political relevance and urgency that the climate crisis actually has. The next step, very soon, will be to present our long-term decarbonisation strategy to 2050. This will allow us for anchoring the key target we have defined to honour our commitments under the Paris Agreement – climate neutrality by 2050 – and focus on back-casting right from there.

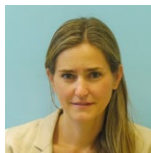
These policy documents are straightforward. They recognise first the importance of energy efficiency. There is a great-untapped potential to use best available technologies and practices to reduce consumption, halt waste and use the energy more intelligently. Second, setting the enabling environment to ensure

100% renewable energy in our electricity mix and almost 100% of the total energy consumption. We know renewable energy is indeed, the cheapest, most competitive, cost-efficient and job-intensive source of energy we have to meet our objectives. Let us then use it. Last but not least, our policy framework acknowledge the importance of paying due attention to embarking in a just transition, by protecting the most vulnerable and leaving no one behind.

Multilateralism and regional cooperation, to which Spain has shown its commitment, are not less important. The organization of COP25 in Madrid, under the Chilean Presidency, was one example, as our participation in the framework of the Ibero-American Summit. The cooperation between the Spanish Office for Climate Change and the Ibero-American Network of Climate Change Offices on climate change and sustainable development policies, sharing experiences and creating strong alliances and scientific collaborations, was an illustration of how we should work globally together.

It is in this sense that the UNEP Zero Carbon Latin America & the Caribbean Report may serve as a fundamental tool for disseminating the benefits and costs of a coupled transformation of the transport and energy sectors. I believe it proves, with sound scientific and economic data, that such a transition is not only technically possible, but also financially attractive. The report, which focuses on the Latin American and Caribbean region, shows the socio-economic opportunities that arise from this transition, while providing specific recommendations for the joint decarbonization of these two sectors in conjunction with digitalisation as a link.

Continuing to work together, identifying opportunities, strengthening multilateral collaborations to achieve our common goals is essential, now more than ever. It is time to rise ambition.



SARA AAGESEN

SECRETARY OF STATE FOR ENERGY. MINISTRY FOR ECOLOGICAL TRANSITION AND DEMOGRAPHIC CHALLENGE, GOVERNMENT OF SPAIN.

PROLOGUE

In November 2019, in a letter to the journal *Bioscience*, over 11,000 scientists from 184 nations issued an alarm on the failure of the global community to address the global climate emergency. It summarizes the situation by stating that on-going consequences of climate impacts "...could cause significant disruptions to ecosystems, society, and economies, potentially making large areas of Earth uninhabitable..." The notice comes a few months after the IPCC special report on Global Warming of 1.5 °C which outlined that there are no avenues left other than full decarbonization to avert major irreversible impacts from climate change on our biosphere.

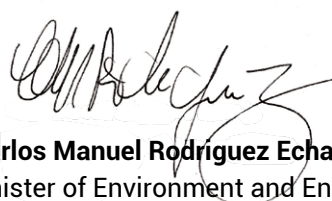
Evidence on the pace and scope of climate impacts in our oceans, cryosphere, forests, and urban spaces, not only provide urgency to efforts to delink carbon emissions from our economic activities but also requires all elements of the global community to accelerate the pace of mitigation and adaptation activities. This is the time for complete delinking of economic activities from the use of carbon. There is no room left to consider options to full decarbonization.

It is in the context of this threat and opportunity that the current report on "The opportunity, cost and benefit of the coupled decarbonization of the power and transport sectors in Latin America and the Caribbean" is being released at COP 25 in Madrid. It provides a detailed pathway to link decarbonization activities in these sectors and assesses its costs and benefits. It concludes that a coupled transition of the power and transport sectors toward full decarbonization by mid-century would result in substantial economic and environmental benefits to the region. The report argues that the value of benefits resulting from the coupled decarbonization of both sectors far outweighs its costs. The benefits considered include improved air quality in urban areas, far greater energy efficiency of the economy, reduced costs of electricity generation and transport for passengers and cargo, generate millions of jobs and catalyze economic activity and enterprise generation. This transition represents an important opportunity to raise the level of ambition of Nationally Determined Contributions (NDCs) and long-term strategies with many no-regret¹ options to meet international climate commitments, established under the Paris Agreement and to support the achievement of Sustainable Development Goals.

Chile and Costa Rica have already embarked on this pathway. Chile is already along a rapid path of transition in its power sector and trying Costa Rica's power sector, for a couple of years now is in practice decarbonized, decarbonization strategies are in place for all other sectors of the economy to become carbon-free. Chile and Costa Rica are not alone. Other countries in the region, like Uruguay have announced plans to reach full decarbonization by mid-century, while others are taking steps in that direction. We invite all countries in the region, irrespective of its current decarbonization stage to consider the practical and financially attractive measures and policy actions described in this report.



Carolina Schmidt Zaldívar
Minister of Environment
Chile



Carlos Manuel Rodríguez Echandi
Minister of Environment and Energy
Costa Rica

1. No regret options are responses to climate change that deliver net economic benefits, and hence represent a low-risk, attractive strategy for governments, firms, or households.

SUMMARY FOR DECISION MAKERS

The UNEP has developed the “Zero Carbon Latin America and the Caribbean: the opportunity, cost and benefits of the coupled decarbonization of the power and transport sectors” report as a follow up to an earlier analysis released at COP 21 (December 2015) on a pathway for full decarbonization of the regional economy in Latin America (UNEP Zero Carbon Latin America, 2015). The report will be followed by an analysis on land use options and oceans as a central anchor for decarbonization strategies in Latin America and the Caribbean, scheduled to be completed by COP 26 (December 2020).

The objective of this report is to illustrate the opportunity, costs and benefits of the coupled decarbonization of the power and transport sectors in the Latin America and the Caribbean (LAC) region by mid-century. The report also presents on the ground examples, from successful policies to business models, which signal a potential coupled decarbonization transition. If escalated, would put the region in a virtuous scenario, raising the ambition of next generation of Nationally Determined Contributions to the Paris Agreement (NDCs).



Cerro Pelado, Costa Rica.
Photo by Juliana Barquero on Unsplash.

1. Introduction

This analysis has been conducted in the context of calls for immediate and drastic action to arrest the continuing increase of CO₂ concentration in the atmosphere, which at the beginning of 2019 reached 409 parts per million (ppm) (NOAA, 2019).

Global temperatures have already increased 1.1 °C above pre-industrial levels. If current trends continue, temperatures can be expected to rise to 3.2°C this century (IPCC, 2018; W. Steffen et al, 2018, UNEP Emissions Gap Report, 2019). The situation has prompted warnings from the scientific and global governance community that the biosphere may be reaching a point of no return (Aegenheyster M. et. al, 2018, UNEP, 2018).²



We are on the brink of missing the opportunity to limit global warming to 1.5°C. It is imperative to act now while we still have the chance.

While there will still be climate impacts at 1.5°C, this is the level scientists say is associated with less devastating impacts than higher levels of global warming (IPCC, 2018). Countries need to take a quantum leap in reducing emissions— globally a 7.6% reduction every year from 2020 to 2030 (UNEP Emissions Gap Report, 2019). Scientists have spoken, now is the time for governments and industries to take the lead and assure a transition path consistent with the 1.5 °C track. Economies must shift to a decarbonization pathway now.

Under a 1.1°C increase temperature, climate change has become a national security threat to the LAC region.

Climate impacts have affected not only the ecology of the systems impacted but also the livelihoods and sustenance of millions in the region, even forcing migrations from affected areas.



Climate is already starting to threaten the foundations of the region's economy, with droughts, hurricanes and/or floods. If the global temperature continues to rise, climate impacts will be increasingly severe and expensive. The entire LAC region has a relatively small contribution in the global carbon footprint (9.5%)³ with approximately the same percentage of global population.⁴ However, the regional average greenhouse gases (GHG) emissions per capita (7tons of CO₂-eq)⁵ is greater than the global figure (5 tons of CO₂-eq)⁶. The region has a significant and growing carbon footprint in its transport sector, as well as a comparable emissions footprint from the power generation sector that together are responsible for 25% of GHG in 2019. According to this report, under the business as usual (BAU) scenario, emissions from both sectors are expected to double by 2050 (Figure 1 and 2). This will place the region further away from the 1.5°C pathway.

Transformational change needed to meet the Paris Agreement and reach net zero emissions by mid-century can be critically supported by coupling the power and transport sectors.



Furthermore, LAC is the most urbanized region on the planet - 80% of its population lives in cities.⁷

Consequently, most of the energy consumption and road activity are concentrated in urban areas.

2. Global peaking of emissions by 2020 is crucial for achieving the temperature targets of the Paris Agreement, but the scale and pace of current mitigation action remains insufficient. (Emissions Gap Report 2019, UNEP).

3. The Brookings Institution 2014 A New Global Agreement Can Catalyze Climate Action in Latin America https://www.brookings.edu/wp-content/uploads/2016/06/Correct-Climate-LAC-GlobalViews52015_FINAL.pdf

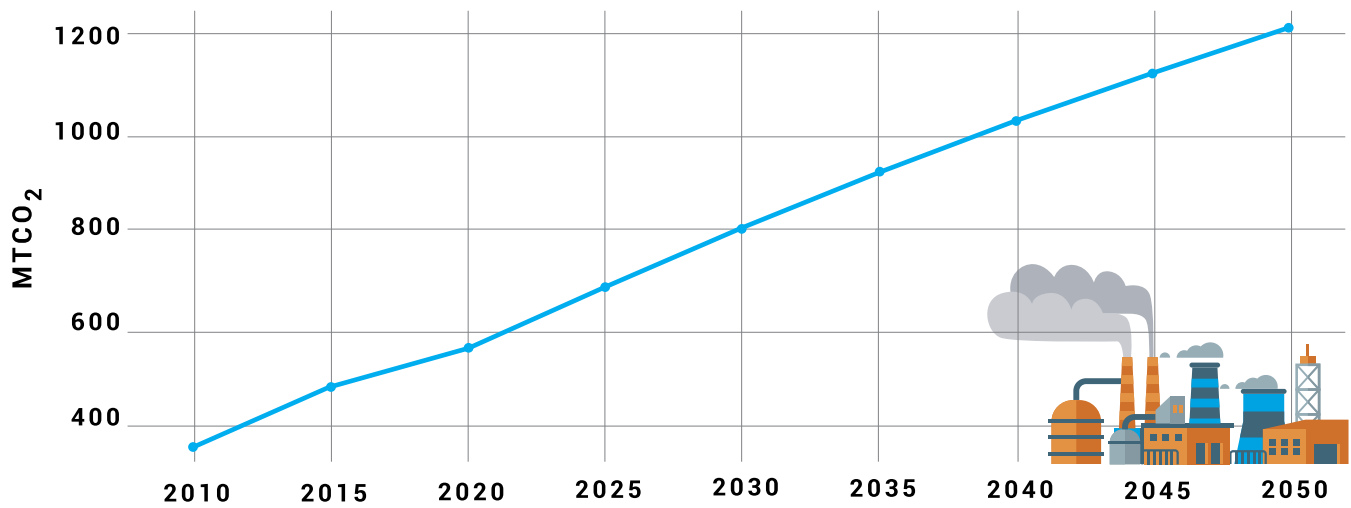
4. World Bank 2018 <https://data.worldbank.org/indicator/SP.POP.TOTL?locations=ZJ-1W>

5. World Resources Institute 2014 Climate Analysis Indicators Tool (CAIT). <http://cait.wri.org>

6. World Bank 2014 <https://data.worldbank.org/indicator/EN.ATM.CO2E.PC>

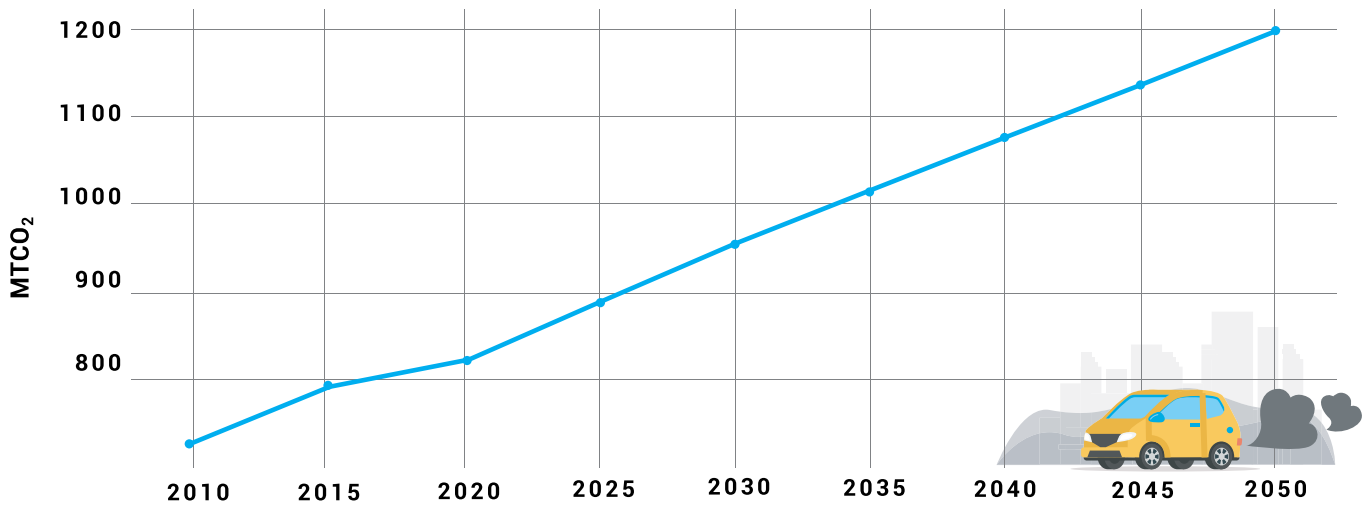
7. World Bank 2018 https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=ZJ&name_desc=false

Figure 1. Projected emissions from the power generation sector, under the GCAM BAU scenario, 2010-2050



Source: As projected under GCAM BAU outputs, August 2019.

Figure 2. Projected associated CO₂ emissions from the transport sector, under GCAM BAU, 2010-2050



Source: As projected under GCAM BAU outputs, August 2019.

This current situation of the region's urban world opens opportunities for rapid and far-reaching environmentally sound and financially attractive actions in both sectors; making cities a key part of the solution. Embarking on the road to electrify the transport sector coupled with the transition towards a fully renewable power sector could contribute to cost-efficient decarbonization. Realizing synergies and interlinkages between sectors of the economy derive in potentially higher economic benefits and greater mitigation impact.

The measures proposed in this report fit into the mold of bold climate action, as called for by the UN Secretary General Climate Summit and the Global Commission on the Environment and Climate (New Climate Economy)⁸ that can result in new jobs, economic savings, market opportunities, and improved well-being. Actions to decarbonize can likewise be framed in the context of a green economy, defined by the UNEP as "one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities" (UNEP, 2012).

The coupled pathway, the intervention scenario of this publication, consists of actions to decarbonize both sectors by mid-century:⁹



Power sector: it is assumed that all future power demand (16.7 EJ) will be met fully by a combination of renewables technologies by 2050.¹⁰ Starting in 2020 no new fossil fuel-based power units would be commissioned. The existing capacity for coal is decommissioned by 2030 and that of gas by 2050. It also considers regional grid integration and local decentralized energy resource (DER) deployment during the period. Considering current trends regarding solar PV distributed, it is estimated that the distributed solar PV will reach a great percentage of the total solar PV installed capacity by 2050.

Transport sector: it is assumed that all modes for cargo and passenger transport, except air travel,¹¹ switch to electric drives by 2050; and no internal combustion engine (ICE) fleet is in operation by then.¹² Specifically, it is considered a shift to electric mode for all existing and new Bus Rapid Transit (BRT) systems by 2025.¹³ Car fleet becomes 10% electric by 2025, 60% electric by 2040 and is fully electrified by 2050. The same conversion rate is expected from light trucks and all buses, while all railroad cargo and passenger transport are electrified by 2040. Also, all marine and heavy road cargo transport is fully electrified by 2050.

8. <https://newclimateeconomy.report/>

9. This scenario was first described by UNEP Zero Carbon Latin America version 1.0.

10. The ratio of new installed capacity considered in the zero emissions scenario is 50% wind, 38% solar PV, 5% solar CSP, 5% geothermal and 2% hydro. (limited availability of new sites and escalating environmental and social concerns will temper past rapid deployment of hydropower capacity. The Solar PV fraction includes utility size and distributed scale. See Chapter 7 and Annex 7 for additional details on the intervention scenario.

11. Air travel was not considered in the intervention scenario (see Chapter 2).

12. The intervention scenario assumes that there is a faster transition to electric drives for cars and buses, a slower transition for trucks and rails and an even slower transition for vessels. Details of the schedule of transition are included in Annex 7.

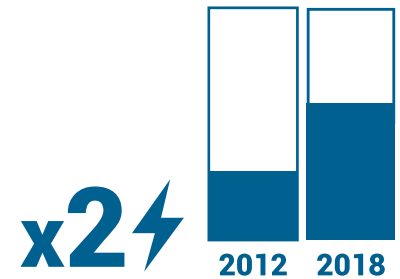
13. While this shift will not produce substantial reductions in fossil fuels, it could be an emblematic change with visible co-benefits in urban areas, as well as stimulate development of the market in electric drives for public transport vehicles.

2. The current status of the power and transport sectors in the LAC region under a BAU scenario

Power sector

The first steps of transitioning toward a fully renewable energy power matrix are already in place in the region. LAC has one of the cleanest power sectors worldwide. Renewables already account for 58% of the total installed capacity with hydropower as the largest source (46%). Non-conventional renewables have doubled their installed capacity since 2012, accounting for 12% of the total in 2018 (Figure 3).

The increase in participation of renewables has clipped the carbon intensity of the sector by 15% in last 3 years (Figure 4); from an already low value of 285 tCO₂/GWh in 2015 to 243 tCO₂/GWh in 2018,¹⁴ one of the lowest worldwide. However, not all subregions or countries represent the overall regional situation. The Caribbean's main source for electricity continues to be fossil fuels at 82 % (McIntyre A., et. al., 2016), with extremely high electricity prices and all countries being energy importers except for Trinidad and Tobago.



Since 2012, **the installed capacity for non-conventional renewables, has doubled** its participation in the regional matrix to 11.8%.

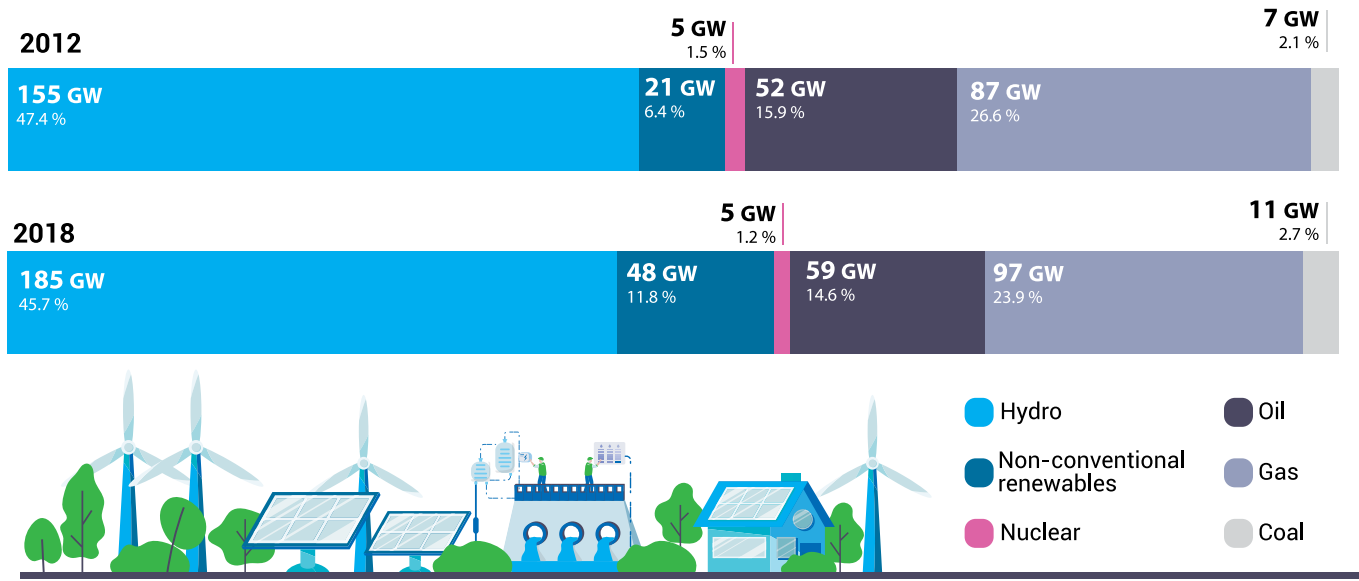
Renewable energy, including hydropower, account for almost **58% of the total in 2018**.



Itaipú. Paraguay-Brazil

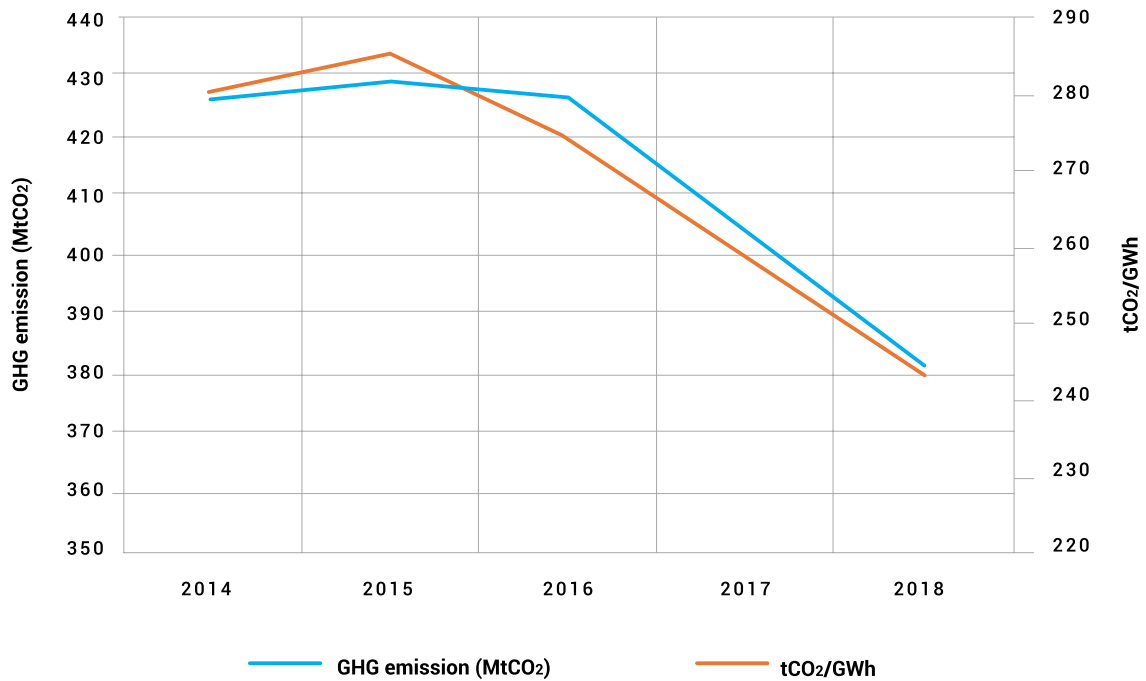
14. GACMO database accessed July, 2019

Figure 3. Evolution of power installed capacity (GW), by source of energy, 2012 to 2018



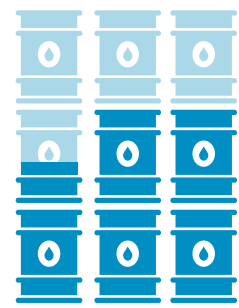
Source: from data in ENERDATA, accessed in August 2019.

Figure 4. Evolution of GHG emissions from the power generation sector, 2014-2018



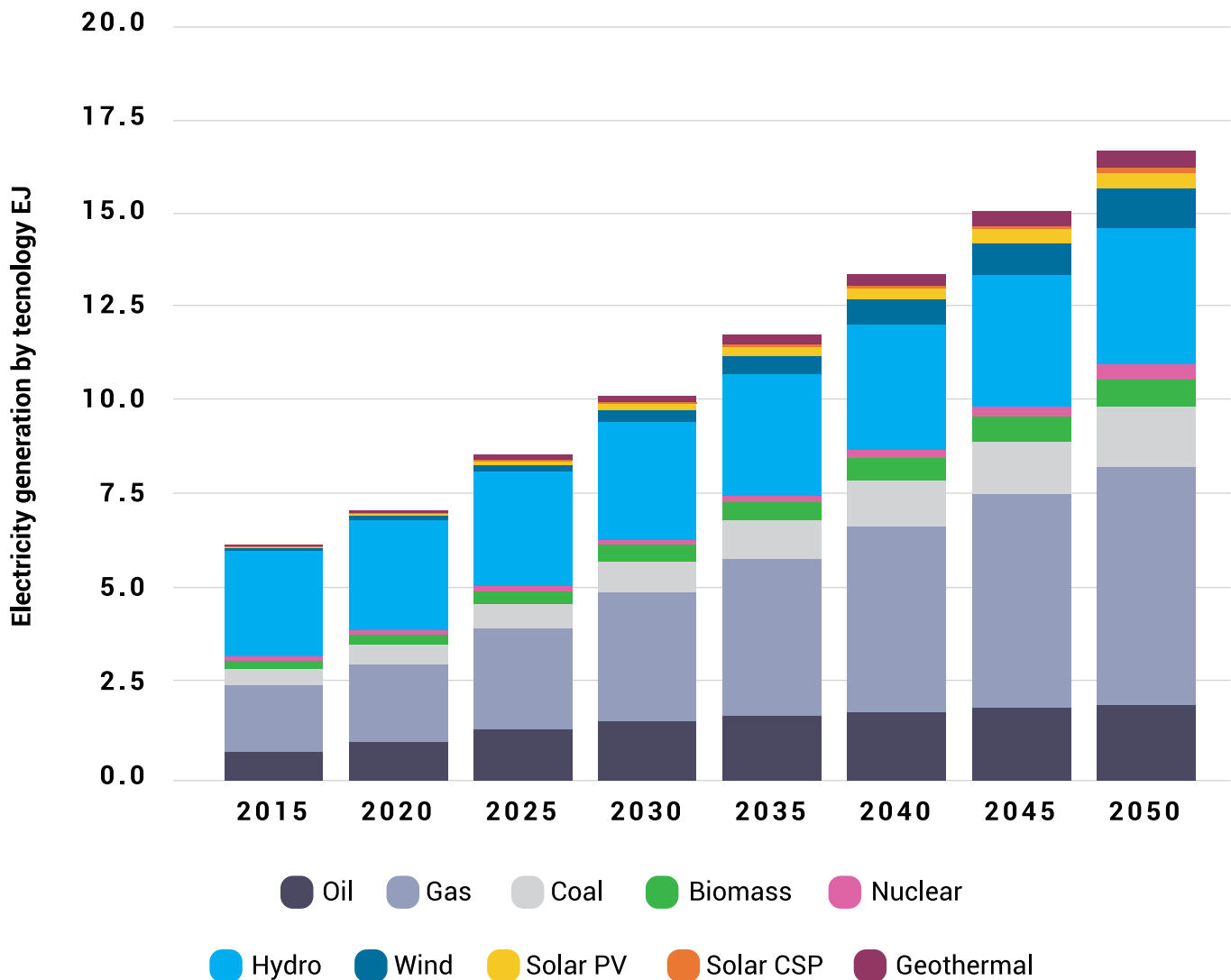
Source: from data in ENERDATA, accessed August 2019.

Although some countries in the region, have reached, or are in the process of attaining 100% renewable power and more are aligning actions and policies toward this goal, it is still a long way from achieving carbon neutrality. If no additional policies and measures to promote non-conventional are developed, the business as usual scenario projects that fossil sources will generate about 60% of electricity by 2050 (Figure 5).



BAU scenario:
Fossil sources generate about **60%** of the electricity by mid-century.

Figure 5. Projected electricity generation by technology under GCAM BAU¹⁵ (net addition)



Source: As projected under GCAM BAU outputs, August 2019.

15. The PV fraction includes utility size and distributed capacity.

Transport sector



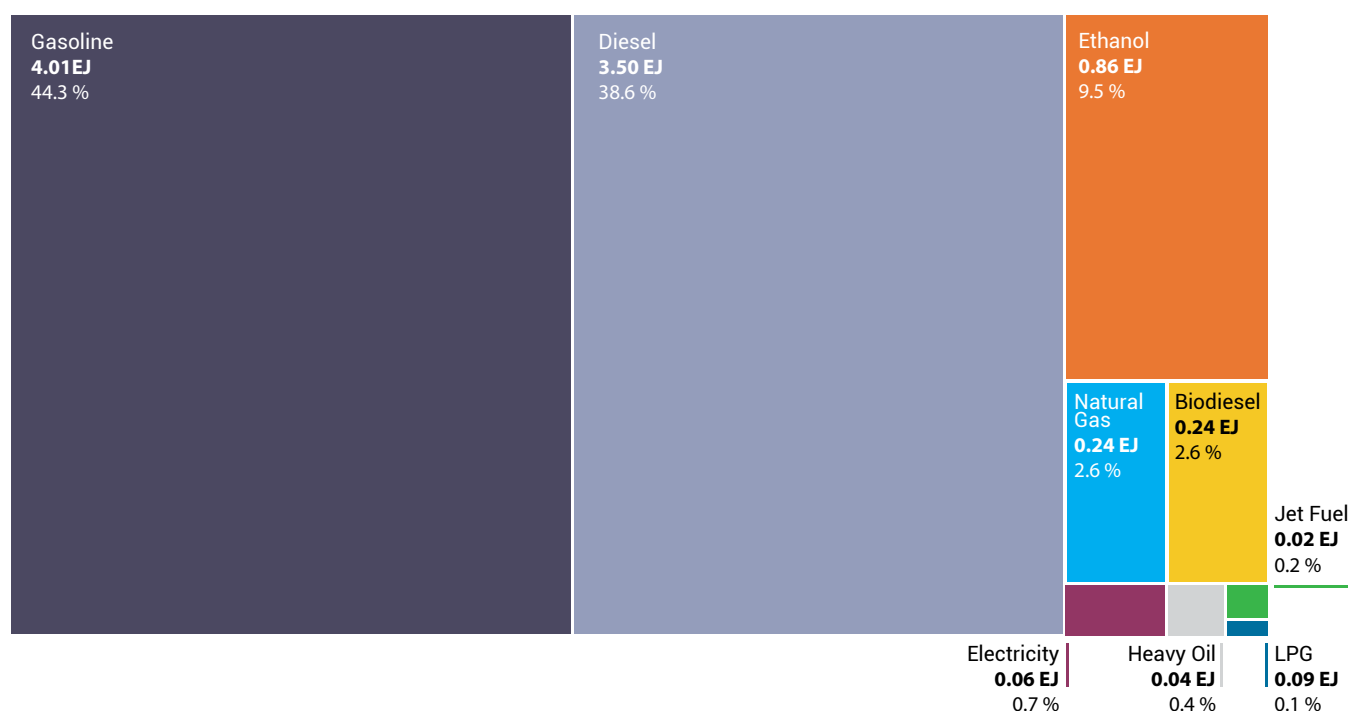
Although electric transport has evidenced a slow-paced adoption in the region, the electricity demand in the transport sector has multiplied by 10-fold in the last 6 years.

The decarbonization of the transport sector has moved more towards improving energy efficiency and carbon emissions standards. However, it remains the sector of the economy with the highest fossil-energy use and, therefore, leading in terms of fossil-fuel related emissions (15% of all regional GHG emissions in 2018).¹⁶ Diesel fuel and gasoline continue to be the fuels most used in transport, accounting for 83% of the total in terms of energy use (Figure 6).

The regional transport sector includes a large fleet of road transport vehicles, where cargo and passenger, participate in approximately equal parts in energy use and GHG emissions. It also includes a significant railroad fleet, concentrated in a few countries (Brazil, Chile, Colombia and Mexico), as well as marine (ocean and fluvial) and air transport components.¹⁷

While buses carry a large number of passenger kilometers and trucks most of the cargo, light vehicles have a similar carbon footprint. Rail and shipping are relevant only in a few countries. As a result, the automobile fleet continues to produce most of the carbon footprint in urban areas, while delivering a minority of the passenger kilometers.

Figure 6. Fuels used in the transport sector, by product, 2018 (Total: 9 EJ)



Source: Compiled from Enerdata through GACMO). Emissions from manufacture of the fuels are not included. Emissions from electricity estimated assuming a 50% renewable power matrix and three times efficiency in delivery of work. Some coal is used in rail operations, but the tonnage is marginal.

16. Compilation in GACMO, accessed August 2019, using data from ENERDATA

17. The overall road transport fleet, cargo and passenger fleet in the region for some countries is presented in annex 5 of the report.



Puerto de San Antonio Chile

Photo by Ministry of Transportation and Telecommunications - Government of Chile

In terms of passenger-kilometers, public transport has the highest share of all modes. The region has one of the largest bus fleets and the highest per-capita bus use in the world.



The region is the world's leader in Bus Rapid Transit (BRT) systems.¹⁸

There are now BRTs in 54 cities in Latin America, which includes 99 BRT routes operating with an extension surpassing 1300 kilometers in 10 countries.¹⁹ At least three BRTs are now including or about to commission electric buses (Santiago de Chile, Bogota and Curitiba) in their core or feeder routes. Santiago de Chile has launched the first 100% electric-fleet BRT²⁰ with 389 electric buses in total and Colombia has just acquired 379 electric buses for the TransMilenio. These cities have the largest electric bus fleets in the world outside of China. There are also 21 additional BRT systems in construction and 10 in expansion in

the region.²¹ The region has also been a pioneer in the development of the institutions, operational protocols and infrastructure for BRT systems, which could be further expanded or replicated in other cities to increase the overall impact on mobility and emissions.

About 70% of cargo transport in the region is carried by trucks. There is a continuous growth in the fleet of trucks of all sizes, and the kilometers travelled by road, in direct response to increases in economic activity and the demand for exports of food, fiber, metals and minerals from the international and domestic markets.

Eliminating emissions from this heterogeneous fleet would require of an enormous effort. Passenger and cargo transport use very different technologies and are driven by a different set of economic factors. Likewise, light and heavy vehicles present widely different market realities. Rail and vessels operate under very different management and operations. But, foremost, there is a large share of the economy that is vested in the current system of transport and must be included in the process to facilitate the changes required.

18. BRTs or Bus Rapid Transit Systems is a bus-based transport system with dedicated transit lanes designed to improve the occupancy of public space and deliver improvements in mobility of passenger transport in cities.

19. <https://brtdata.org/>; consulted August 2019.

20. <https://www.electrive.com/2019/10/16/chile-launches-latin-americas-first-electric-bus-corridor/>

21. <https://brtdata.org/>; consulted August 2019.

3. The evolving economics of renewable energy in the region

The LAC region has a substantial renewable energy resources for power generation. Its resource base has the potential to provide 22 times the electricity needs of the global economy (Vergara, W., 2013). The region has global-class hotspots of solar (Atacama, Sonora-Chihuahua), wind (Patagonia, Atlantic Coast of South America, Isthmus of Tehuantepec, Guajira Peninsula), marine (southern pacific coast of South America), geothermal (Andes, central American Cordillera), and hydropower all over the region.

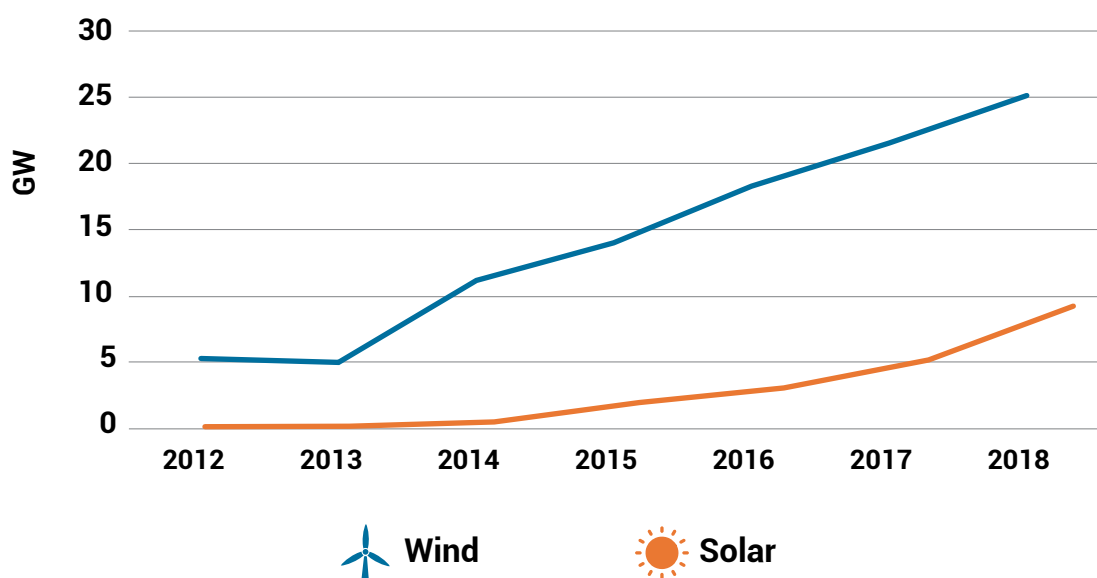


In the last 5 years, the non-conventional renewable energy sector in Latin America and the Caribbean received more than USD\$35 billion in investment (44% of global direct foreign investment flows).

Besides renewable resources endowment, non-conventional renewable energy investment tends to blossom in countries with well-constructed enabling environments, which means clear and consistent renewable energy policies, including well-structured auctions. As is the case in Mexico, Brazil, Chile and Argentina, which received 70% of the region total investment flows.²² Other countries are beginning to attract foreign direct investment 2018 are Colombia, El Salvador and Dominican Republic, since they have built legal and regulatory frameworks that give certainty to private investment.

In terms of non-conventional renewable technologies, 90% of the region total investment flows was destined to solar PV and wind projects. Since 2012, installed capacity for wind energy increased by nearly 400%, and for solar PV increased 29,000% (Figure 7). Currently, wind and solar PV installations together exceed 50GW, which is almost a third of the total generation capacity installed to power Brazil. This growing trend is expected to continue due to the significant pipeline of solar PV and wind projects under construction or contracted, which, in many countries, is higher than the capacity already in operation.

Figure 7. Evolution of wind and solar PV installed capacity (GW) in the region, 2012-2018

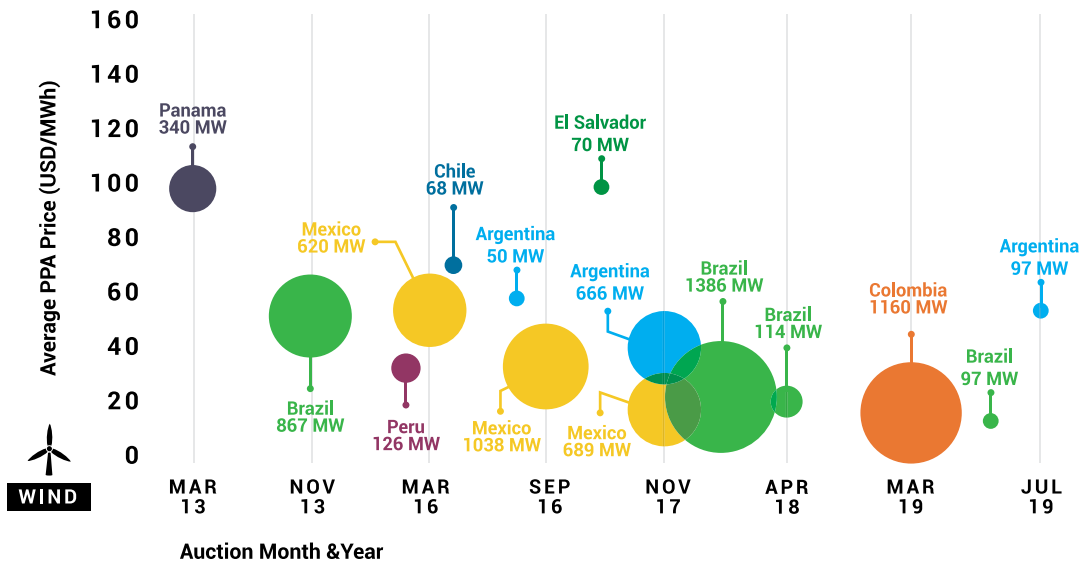


Source: Enerdata.

22. Climatescope, 2019

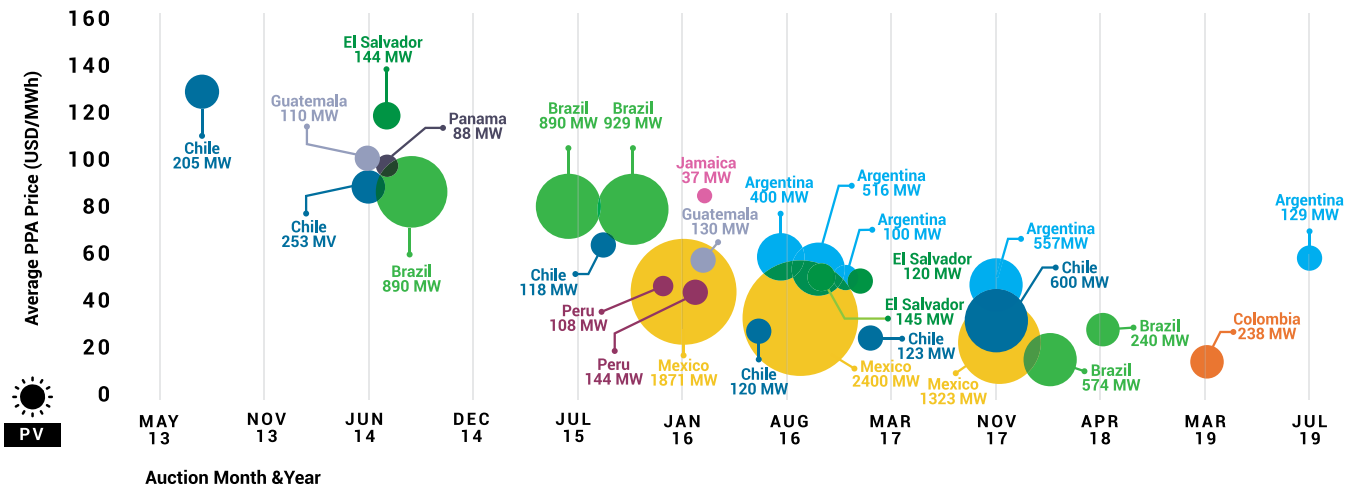
The fast deployment of wind and solar PV energy installations was driven by the significant decrease in costs of main components (wind turbines and PV modules) and technology improvements, which, consecutively, has led to tremendous decline in cost of power generation (LCOE) through these two technologies. Recent auctions for wind and solar PV energy installations in the region confirm the long-term trend of improved economic competitiveness. Auctioned prices have fallen, between 2013 and 2019, by more than 80% for both technologies (Figure 8 and 9).

Figure 8. Evolution of auction prices for wind projects in LAC, 2013-2019



Source: Based on data from Nagendran S., 2017 and industry data.

Figure 9. Evolution of auction prices for solar PV projects in LAC, 2013-2019

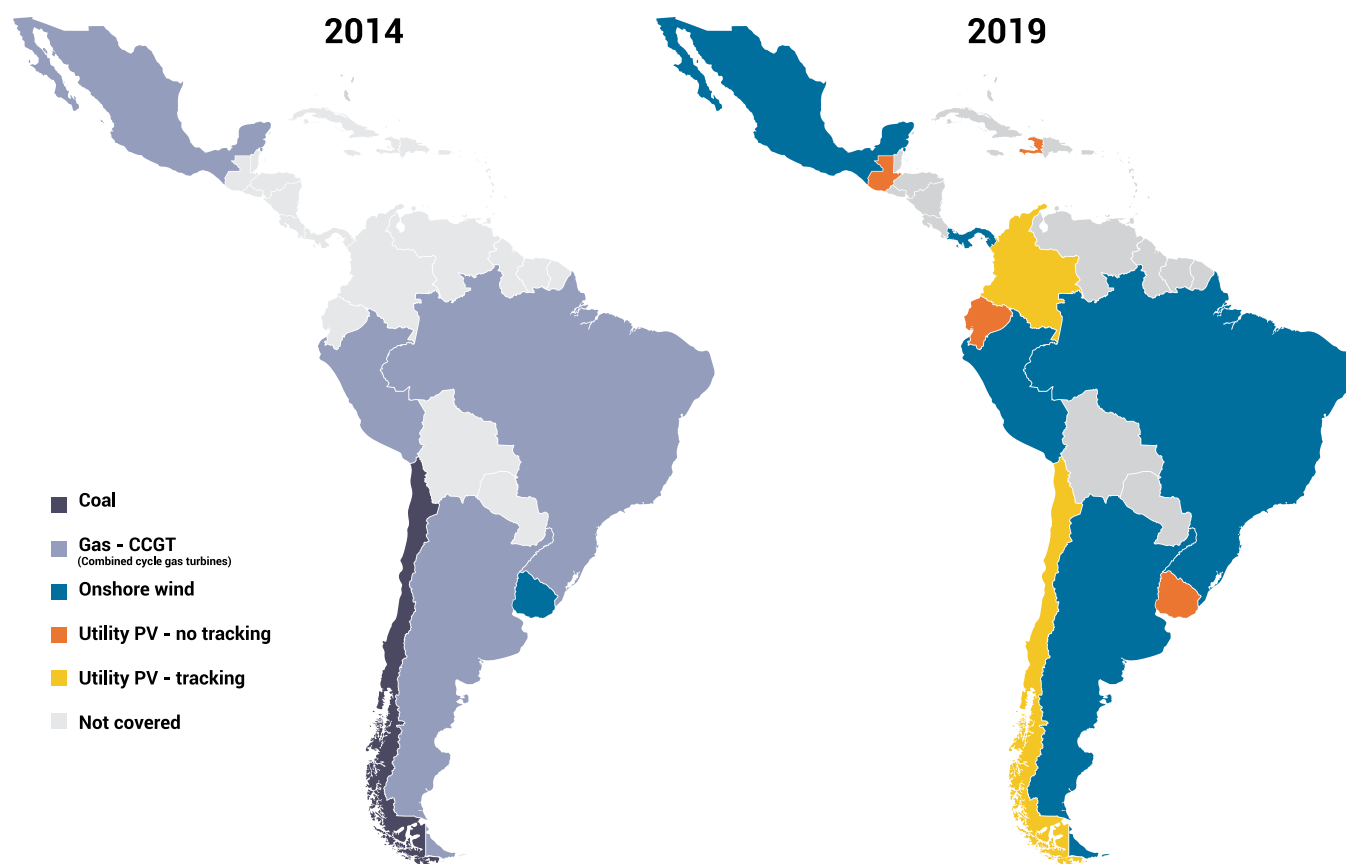


Source: Based on data from Nagendran S., 2017 and industry data.

The LCOE for solar PV and wind power reached cost parity with hydrocarbons-based generation in some LAC countries. New wind and solar PV plants are cheaper than new coal and gas plants in some countries in LAC, making the renewable energy pathway a no regret option. These technologies are winning the race to be the cheapest sources of new generation. In many countries, such as Peru, Mexico, Uruguay, Argentina and Brazil, wind energy is below LCOEs for fossil fuels. In the case of solar PV, Chile has one of the lowest LCOEs in the world meanwhile in Peru, Chile, Colombia and Mexico solar is already cost competitive with fossil fuels. The Figure 10 shows that on purely economic grounds it will be increasingly difficult to justify investments for power generation using fossil fuels in some countries.

While acknowledging the challenges and differences between national circumstances, a full decarbonization of the power sector is found to be technically and economically feasible as well as financially attractive, given the substantial resource endowment, well-structured policy framework, technological improvements, abrupt cost reductions, and strong institutional capacities. Moreover, the fact that 7 countries in the region have been named as attractive markets for clean energy investments is indicative of the opportunities in LAC to achieve the decarbonization of the power sector by 2050. Specifically, Chile, Brazil, Argentina and Peru are in the Top 10 and Colombia, Panama and Uruguay made it to the Top20 most attractive countries for clean energy investments out of 104 nations.²³

Figure 10. Most competitive source of new utility-scale generation in 2014 and 2019



Source: CFLI, 2019. This map shows the technology with the lowest benchmark LCOE in each market, excluding subsidies or tax credits.

23. Climatescope 2019, accessed December 2019 <http://global-climatescope.org/results?region=lac>



Cerro Dominador Solar Power Plant, Chile
Photo by Ministry of National Assets.

However, despite these improvements, the region is currently at a crossroads to make strategic decisions that will define the future of its power system in conditions of efficiency, quality, reliability, safety and sustainability. According to UNEP and OLADE 2017 report, the changes on the duration and intensity of rainfall patterns and drought periods will affect firm capacity of hydropower. At current pace, gas will overcome hydro as the main source of electricity production in about 10 years, by 2030. Apart for the increase in GHG emissions this will create a technology lock-in for many years ahead and likely put the region in a difficult scenario to comply with the Paris Agreement goals. LAC nations should include the highest share of non-conventional renewables in their power matrix, discouraging technologies that contribute to climate change and that pose future economic uncertainties.

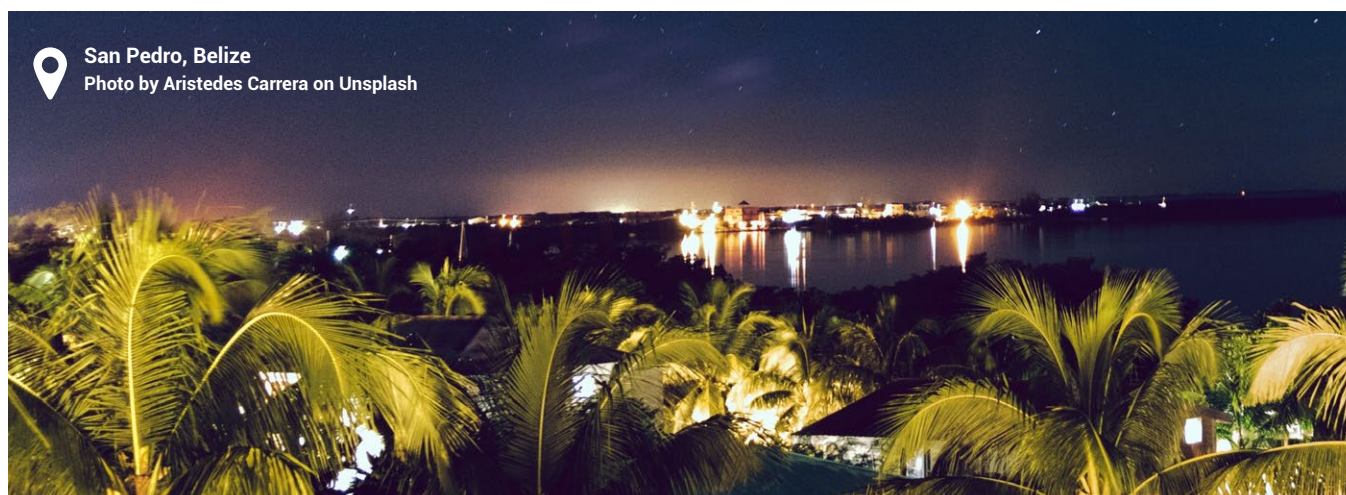
4. Transmission and distribution

Transmission and distribution (T&D) infrastructure is a critical element of the coupled transition process. The report finds that the management, structural and resource elements to support a smart regional

grid are already present in LAC. The hydropower capacity installed in the region and the non-conventional renewable potential makes this a unique avenue to launch a decarbonization pathway taking advantage of the complementarity of the baseload and intermittent renewable resources. Other factor that could underpin the decarbonization of the power sector is the existing interconnected power systems in the region and country-to-country links that form the basis for a larger integration effort. The strengthening of the interconnection of power grids would provide benefits in terms of better supply demand conditions and thus potentially lower overall generation costs.

However, there are still gaps elements, and policy instruments missing that could be used to accelerate the transition toward a smart, regional grid. The report concludes that a regional grid designed to cater to a 100% renewable power system, and a higher level of integration with demand, would further need to:

a) Be able to accept large shares of intermittent or variable renewable energy sources to dampen fluctuations and take advantage of existing complementarities between energy endowments.



- b) Provide a link between major reservoirs in different climatic zones (areas with complementary pluviometry) allowing effective shares of baseload at a regional scale.
- c) Allow the integrated operation of storage systems and demand management systems.
- d) Enable the operation of distributed power in nodes connected to the grid for stability and reliance.
- e) Provide efficient, low loss, competitive, transmission systems over long distances and with sufficient capacity.
- f) Permit the integration and demand/supply management of an extensive fleet of electric vehicles.
- g) Enable a high-level of market transparency with clear rules of access and open competition.

The T&D system will be aided by a more decentralized grid, closer to load centers requiring less infrastructure of this kind. Particularly, renewable distributed generation (DG), mainly distributed solar PV, is starting to gain a larger share of LAC 's renewable market. By the first half of 2019, almost 2GW of distributed solar PV has been installed in the region. Brazil (870MW)²⁴, Mexico (817GW)²⁵, Dominican Republic (119MW)²⁶ and Chile (27MW)²⁷ with the largest share.

Renewable DG, mainly distributed solar PV, is starting to gain a larger share of Latin America and the Caribbean's renewable market.

Almost 2GW of distributed solar PV has been installed in the region by the first half of 2019.



Emerging markets for DG in Latin America are starting to flourish, including Honduras, Colombia and Argentina. A growing number of LAC countries are issuing net-metering/net-billing laws and incentive packages to promote DG deployment. At the end of 2010, only two countries in the region had pledged net-metering/net-billing laws to promote decentralized generation from renewable energy sources. In contrast, in 2019, at least 15 have done so in Latin America (Figure 11).

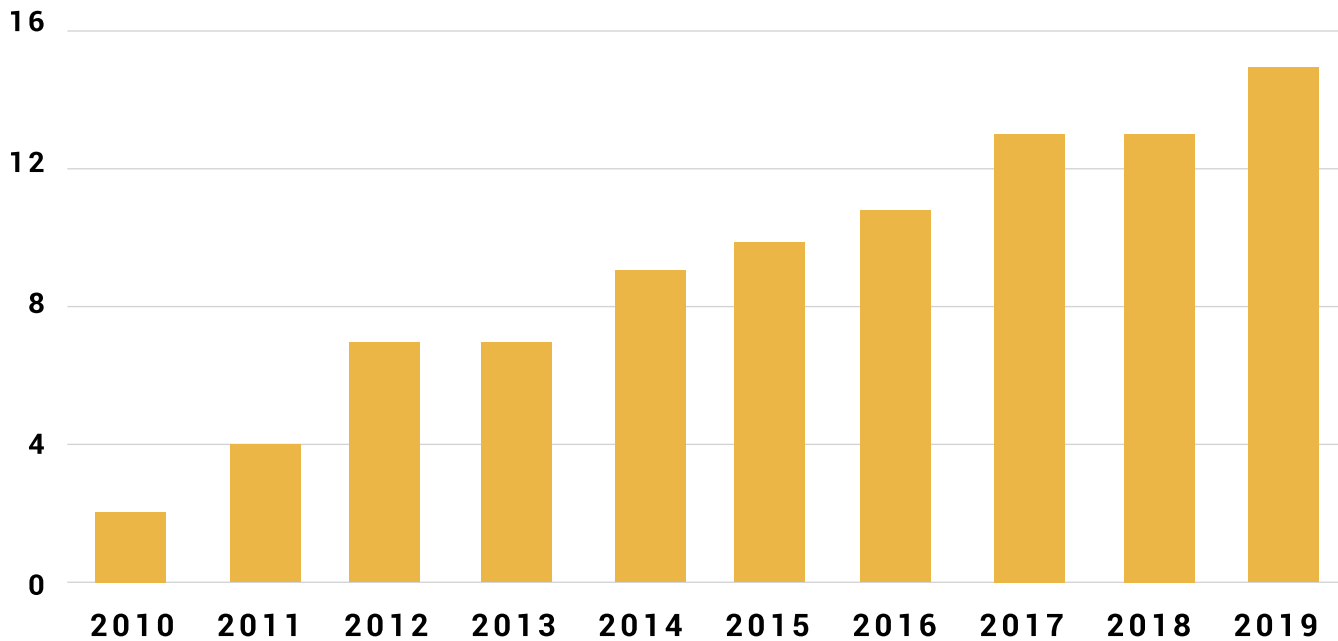
As more players enter the market for provision of services, the electricity system will shift towards decentralization, becoming a system of systems, where the traditional vertically integrated energy scheme will need to adapt to integrate a great number

24. <https://www.aneel.gov.br/>

25. https://www.gob.mx/cms/uploads/attachment/file/483322/Estadisticas_GD_2019-1.pdf

26. <https://www.cne.gob.do/medicion-neta/>

27. <https://acera.cl/wp-content/uploads/2019/11/2019-10-Bolet%C3%ADn-estad%C3%ADsticas-ACERA.pdf>

Figure 11. Number of countries in Latin America with net metering/net billing laws issued, 2010-2019

Source: Author's estimate with policy information from countries.

of DER. Prosumers, electric vehicles, demand-response and many more technologies and agents making use of the grid and providing ancillary services, like storage, generation, flexibility and perhaps even balancing are slowly but steadily becoming a reality. This new meshed system will only be possible with the digitalization of the power system to create a smart grid. It will also open opportunities for traditional utilities to provide services for which they already have the know-how and the technical capabilities.

5. Technology and economic trends of electric transport

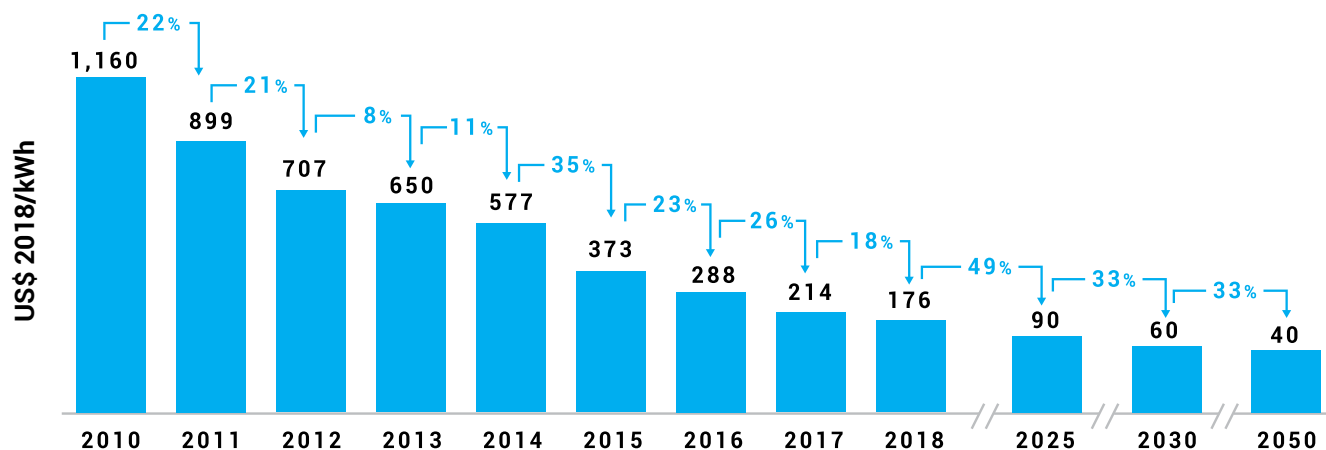
The characteristics of the transport sector of having most road passenger activity concentrated in cities, high bus utilization rate per capita, and well-known patterns of cargo transport are crucial elements to vouch its electrification and develop ancillary industry tailored to regional needs.



Battery prices have fallen nearly 50% in the last 3 years (Figure 12).

The cost of electric vehicles is rapidly decreasing, and new technologies are entering the market, supported also by increased concern on air quality and congestion, make possible to consider faster market entry of electric transport options. Also, increases in energy density of electric batteries have allowed improvements in vehicle autonomy and feasibility of entry of heavy-duty vehicles. Ongoing technology developments include:

- a) Deployment of dual battery systems that could reduce overall battery costs for heavy duty applications.
- b) High-performance charging infrastructure with voltages suitable for heavy vehicles.
- c) Market entry of new high-performance battery systems, eventually enabling denser, lighter batteries.
- d) Development of electric highways for modified electric vehicles to charge while driving.
- e) On the software side, demand management of transport fleets.

Figure 12. Historical and projected costs for lithium-ion packs for electric vehicles, 2010-2050 (US\$ 2018/kWh)

Source BNEF, 2019; Bloomberg, 2019 and author's estimates.

As analyzed, common actions are identified among countries for the promotion of electric mobility. One of them is the electrification of public transport systems. Policy makers continue to push toward zero emissions public transport. Improving economics, while complying KPIs, and growing concern about health and environmental impacts of emissions from internal combustion engines (ICE) buses in cities are the two main drivers. In this respect, momentum for electric buses is beginning to be built regionally.

The total cost of ownership (TCO) of electric buses is reaching cost parity with ICE buses in some cities of the LAC region.



This is mainly due to the development of new business models through tendering process for public bus system that are boosting electric buses adoption, such as in Santiago de Chile and Bogota. The investment decision making under this business models was based on the TCO rather than the purchase price. In this sense, the TCO of electric buses was lower than

that of ICE buses, mainly due to a 70% reduction in operating expenses. The bus characteristics and requirements in the region are different of those under development elsewhere (capacity, climate control, route lengths). Age of bus fleets in Latin America is very diverse; in some cases, reaching up to more than 20 years of operation. For this reason, large number of buses will be tendered throughout the region in the short and medium term. This opens a window of opportunity to increase e-buses deployment. In addition, cities with higher emissions standards (EURO VI) are more easily able to transit to zero emissions public transportation, since purchase price gap between electric buses and ICE buses is reduced.



Policy and regulation will play a critical role to decarbonize public transport systems fully.

Clear targets and roadmap are a must for the development of this brand-new market structure. This entails policies supporting deployment of public electric transport systems and the entrance of new players in the electric market. The promotion of electric mobility implies a cross-cutting coordination between sectors. Although it is seen as a transport issue, it involves the energy sector and all its actors in the electricity subsector, from generators to electricity retailers. Decisions taken today in the transport



sector will define the climate future. Many cities are renewing large fleets of buses with dirty technologies (ICE vehicles), which will be in the market for at least 15 years creating stranded assets. The renewal of fleets is an excellent opportunity to transition to electric vehicles.

In 2019, the electrification of other transport segments, such as official fleets, delivery and cargo fleets, as well as public sanitation, has become more evident. Mostly, consisting of pilot projects to evaluate the performance of the technology for later scale up. The road cargo transport offers opportunities for electrification at the point of use, which is particularly attractive for cities (about 70% of cargo transport in the region is carried by trucks). Electric small size trucks will provide an opportunity for cargo applications, as “last mile” delivery and small logistics, particularly in urban areas. In this segment, the TCOs are starting to reach attractive values compared to those of small ICE trucks and thus same business models are beginning to evolve in the region.

In terms of charging infrastructure for electric vehicles, there has been an increase in the deployment of this type of infrastructure. This charging infrastructure has been developed mostly by strategic investors, such as oil and gas and utility companies and automakers. Mexico stands out in absolute terms, as the country

with the highest number of public cargo centers in the region. While Barbados, stands out as the country with the largest coverage of recharge infrastructure by population density or number of registered electric vehicles. On the other hand, in 2019, Mexico launched the longest electric vehicle corridor (also known as the “electro corridor”) in Latin America and the Caribbean with a distance of 620km. Uruguay was the first country in the region to install its electro corridor, followed by Brazil. For its part, Chile, as well as other countries and cities, are deploying charging infrastructure with the purpose of extending the autonomy radii of electric vehicles (Figure 13).

As electric vehicle fleets and associated charging infrastructure increases, it becomes highly important to foster interoperability, infrastructure standardization and management and recharge commercialization systems. A vital aspect that still has the possibility of being explored more deeply is the integration of the national and local electricity network (distribution) with the necessary recharging infrastructure to allow the development of large-scale electric mobility.

On the other hand, consumer interest in electric vehicles is growing as car manufacturers launch more electric car models. This context signals a promising transition in the transport sector.

Figure 13. Electric corridors for electric vehicles in LAC, 2019



Source: MOVE, 2019

6. Benefits and economic costs of a coupled decarbonization

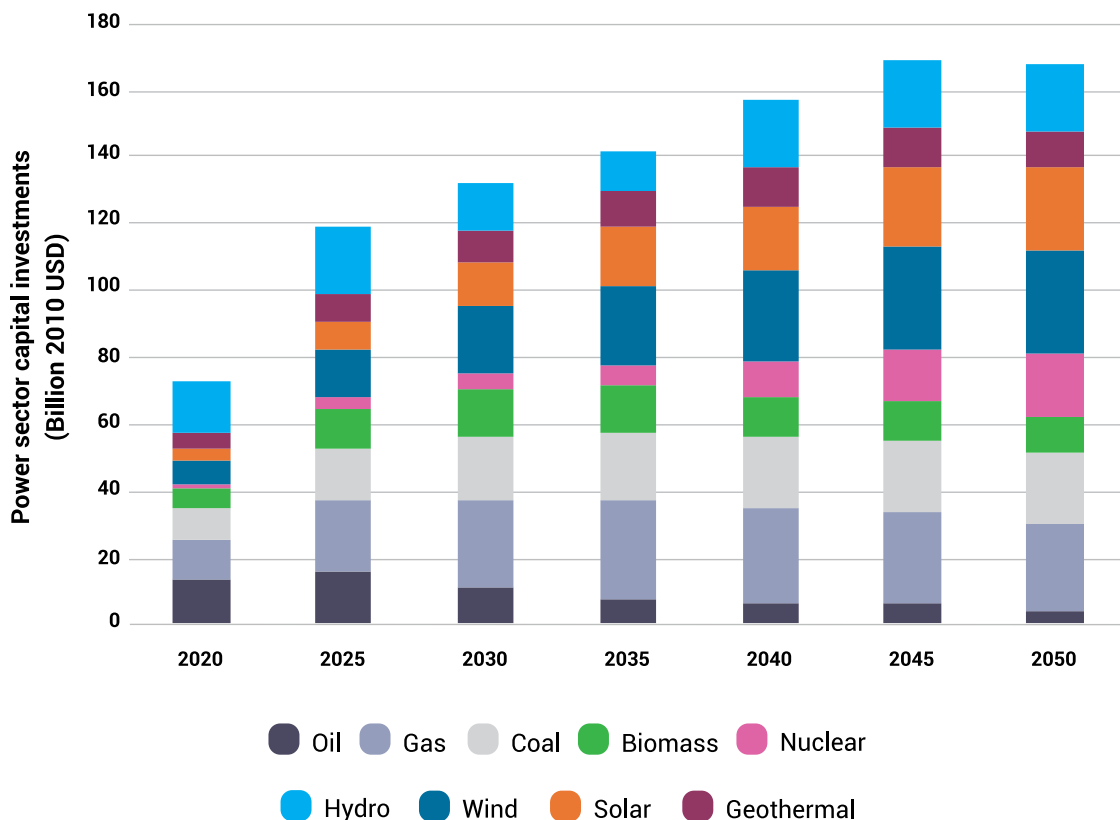
In this report, a coupled transition refers to the combined decarbonization of the power and transport sector taking advantage of the synergies and linkages between these two to accelerate the decarbonization process. A coupled transition not only aims to reach zero emissions by 2050, but it also has the potential to grow the region's economy while improving public health.

Reduced capital investment requirements

By 2050, electricity demand is anticipated to almost triple (16.7 EJ) according to the model results. This does not include the future power demand caused by an electrified transport sector, which will require substantial additional installed capacity. Meeting the 2050 electricity demand under a fossil fuel-based

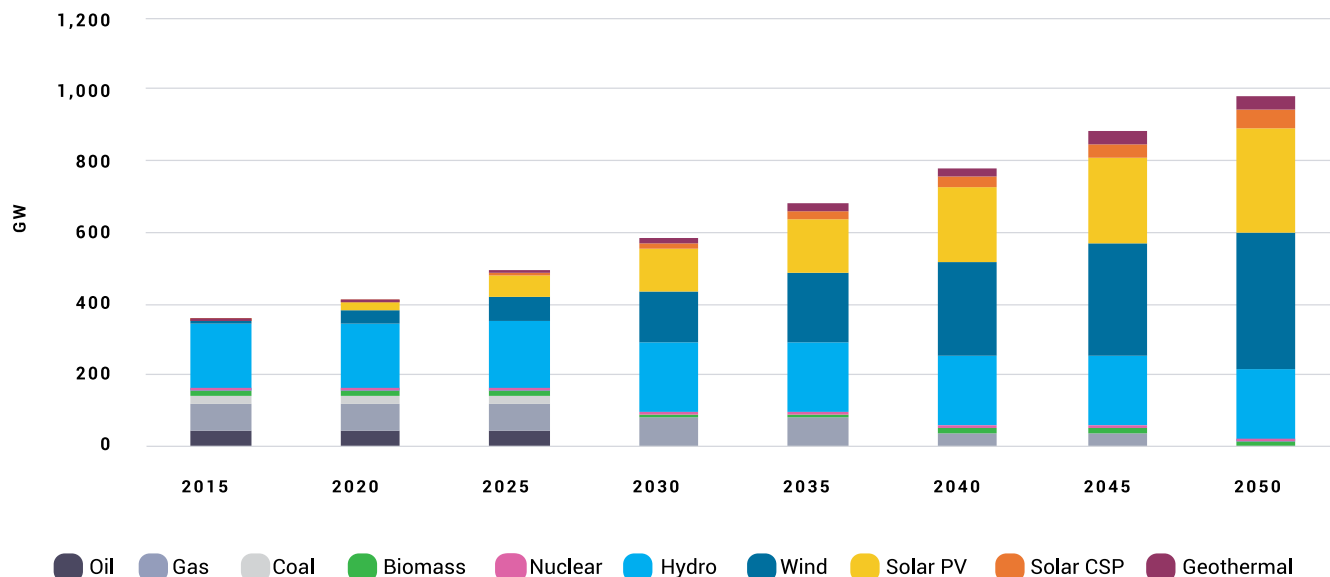
generation matrix (BAU scenario) would increase 2.4 times CO₂ emissions up to 1,200 million tons. This would place the region further away from the Paris Agreement. Additionally, the investment volume required in installed capacity is estimated at US\$ 1083 billion (2018) (Figure 14). A fully renewable energy power matrix, composed as depicted in Figure 15, will deliver zero CO₂ emissions and require substantially less capital investment than a fossil fuel-based generation matrix (US\$ 800 billion), resulting in US\$ 283 billion in capital investment reductions by 2050 (Figure 16). On the other hand, capital investments linked to the scenario with compliance of the Paris Agreement (RCP 2.6), which includes instead heavy reliance on carbon capture and storage while maintaining a hefty participation of fossil fuels, would be considerably higher (US\$ 2,200 billion (2018)) (Figure 17). Clearly a pathway that takes advantage of the competitiveness of renewables in the region is less capital intensive.

Figure 14. Capital investment in the power sector, by 5-year period 2020-2025, under GCAM-BAU scenario



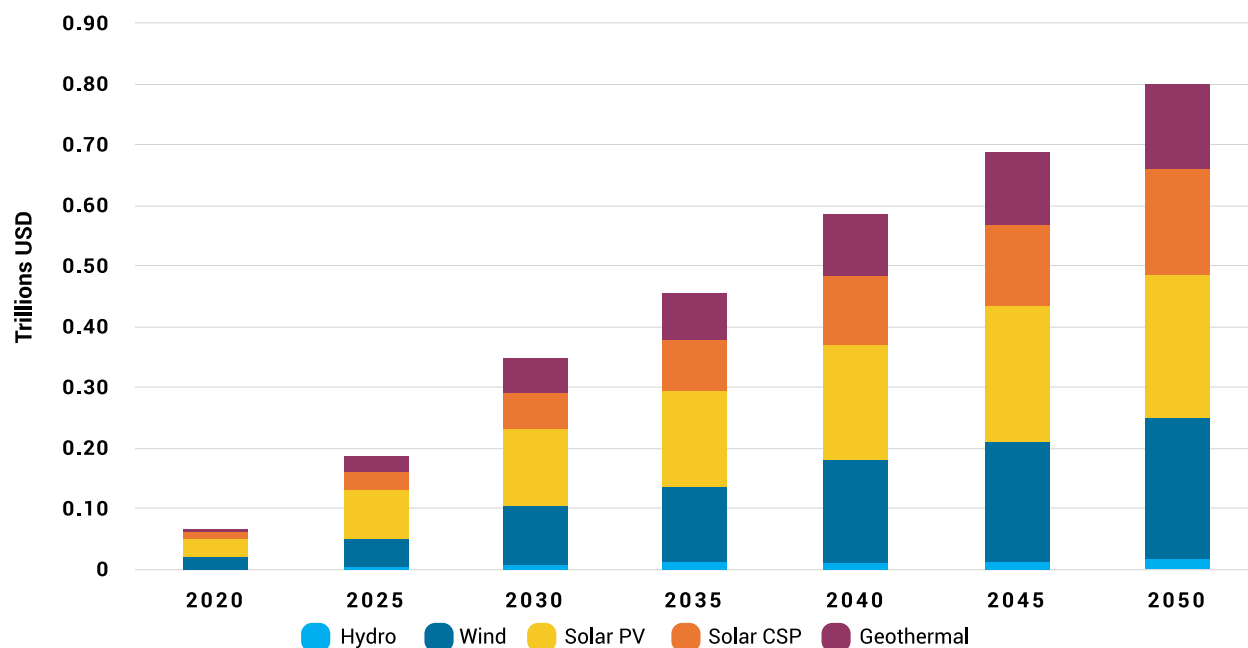
Source: As projected under GCAM BAU outputs, August 2019.

Figure 15. Cumulative installed capacity, by source, under the intervention scenario, 2015-2050 (net additions)



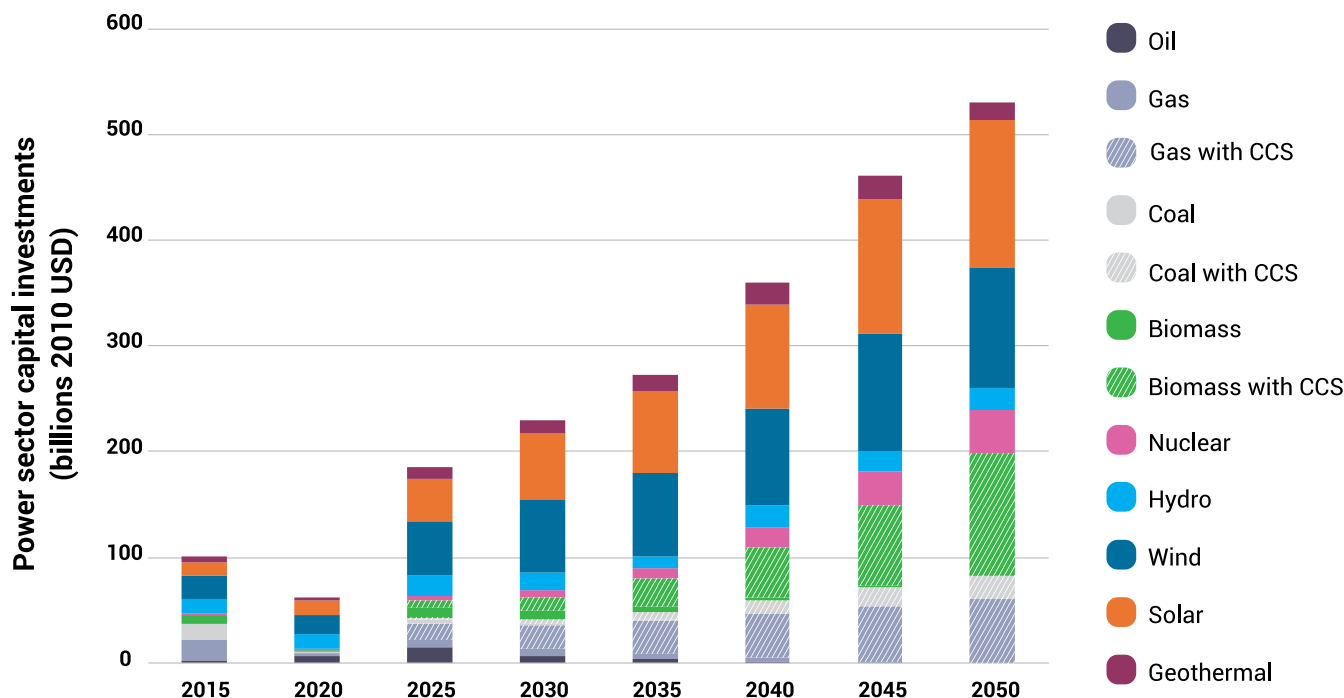
Source: Author's estimates.

Figure 16. Cumulative annual capital investments required in the power sector, 2020-2050, under the intervention scenario



Source: Author's estimates.

Figure 17. Capital investments required in the power sector, 2020-2050, under the Paris Agreement compliance scenario (RCP 2.6)



Source: As projected under GCAM RCP 2.6 scenario, August 2019.

Many countries are developing legal and regulatory frameworks that create the enabling conditions for distributed solar PV deployment. In some nations, distributed PV is already an important market (Mexico, Brazil, Chile and Dominican Republic), in others are rapidly growing (Colombia, Argentina and Honduras). In this sense, if current trends continue, under the intervention scenario, it is expected that the distributed solar PV will reach a great percentage of the total solar PV installed capacity by 2050²⁸ – penetration of decentralization is growing. Just as in the case of large-scale, to unlock solar PV distributed potential is critical to implement robust legal and regulatory frameworks adapted to small-scale installations that tackle main market barriers, such as generation permitting procedures, technical standards, grid connection rules, among others.



The renewable DG sector is a strategic market to foster innovation and promote new business and job creation.

This could be achieved through the development of installer training programs, certification of technology standards and eligibility criteria for installation companies. Developing the local distributed PV industry will help create new sources of employment and increase the countries' competitiveness in an evolving global industry.

28. BNEF New Energy Outlook 2019 estimates the small-scale solar PV share to be 37% of total solar PV capacity by 2050.

Lower electricity and rolling stock costs

The LCOE for solar PV, wind and hydro technologies continue to drop, reaching and surpassing cost parity with hydrocarbons-based generation by 2050 (Figure 18). It is worth noting that LCOEs presented in Figure 18 are an average for the region. LCOE from on-shore wind and solar PV already outperform natural gas and coal while off-shore wind and solar PV with storage are expected to do so before 2030. LCOEs from hydropower and geothermal are already competitive with fossil fuels. Marine energy continues to be relatively expensive but warrants investments in R&D given the sizable resources available in the region.

The comparison of projected LCOEs (Figure 18) indicate that on purely economic grounds it will be increasingly difficult to justify investments for power generation using fossil fuels. Coal is no longer competitive in many countries in the region and there are no sound reasons for new coal plants to be installed. Also, the arguments in favor of new investments in natural gas are questionable. Natural gas is already being outperformed by wind and challenged by solar PV and even if the differences today are small, investments in natural gas capacity already appear not to be competitive (Figure 18).

The deployment of solar PV and wind with storage provides firm capacity to these technologies and is anticipated to also become competitive with natural gas power plants. New technological advances have the potential to accelerate the economic competitiveness gaps.

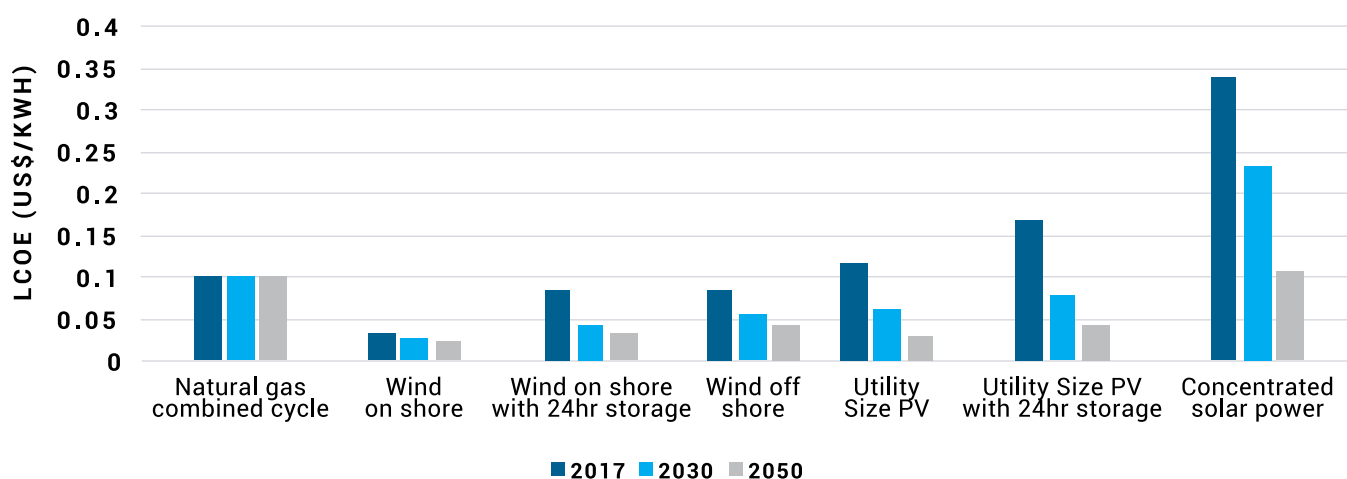
Cheap renewables will pave the road to electricity decarbonization. The lower capital and operational costs associated with wind, solar, geothermal and hydropower are anticipated to result in lower electricity generation costs (LCOEs). The projected LCOE under the intervention scenario by 2050 is estimated to be US\$ 0.048/kWh (50% lower than in the BAU scenario).²⁹ The estimated cost of generation under the BAU scenario is US\$ 0.097/kWh.



Shifting to a renewable energy matrix would result in significant savings in electricity costs to the regional economy in the order of US\$ 222.7 billion by mid-century.³⁰

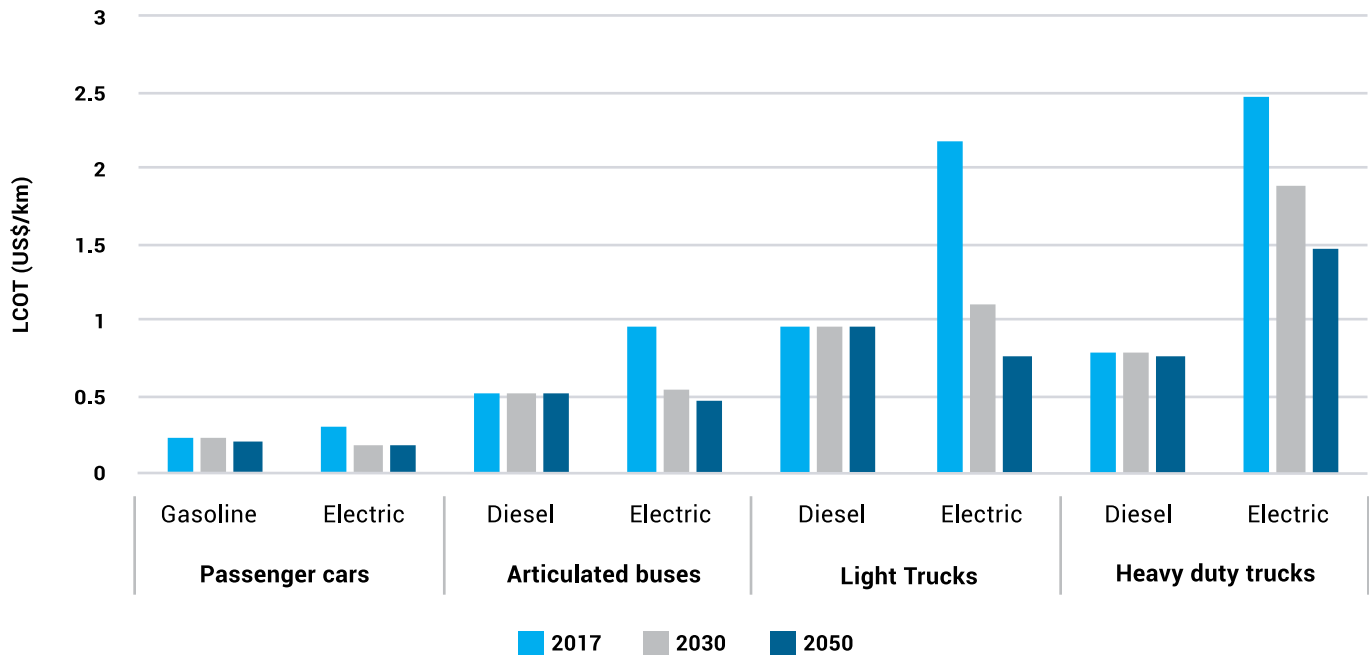
The reductions in generation costs would be directly accrued by electricity consumers making manufacture more competitive and delivering savings to households.

Figure 18. Projected LCOEs, by source of energy, 2017-2050



Source: author's estimates based on GACMO outputs.

29. The LCOE was estimated on the basis of the LCOEs for each technology and the corresponding share of generation under the intervention and BAU scenarios.
30. Based on a demand of 16.7 EJ

Figure 19. Projected LCOTs for electric vs internal combustion vehicles (US\$/km), 2017-2050

Source: Author's estimates based on GACMO outputs.

On the other hand, future costs of electric transportation LCOTs³¹ also continue to drop. The results confirm an expectation of increased competitiveness for all segments of the fleet, with electric cars and buses becoming the cheapest alternative before 2025. It is worth noting that LCOTs presented in Figure 19 are an average for the region. In many cities, such as Santiago de Chile, Chile, and Bogota, Colombia, electric buses have reached cost parity with ICE buses.

Under the intervention scenario, most of the service is projected to be delivered through road transport. For passenger road transport, big reductions in LCOTs are anticipated for electric light vehicles while electric buses will at most have the same costs of the diesel options. The intervention scenario assumes that the car fleet will not increase more than 30% its current size by 2050, while the bus fleet will more than double its size to compensate the reduction in light vehicles transport measured in passenger kilometers. Under these assumptions, it is estimated that the overall

savings in passenger transport costs to the economy would be of the order of US\$ 328 billion in passenger transport. No estimates were made for passenger transport in other modes (rail, vessels).

For cargo transport, the calculated LCOTs for electric light trucks (90% of the road cargo fleet) are also lower while heavy duty vehicles continue to be more expensive by mid-century. The composition of the fleet (90% light trucks; 10% heavy trucks) is kept constant. Under these conditions, it is estimated that the overall savings in capital costs to the economy would be of the order of US\$ 41 billion in cargo road transport. No estimates were made for cargo transport in other modes (rail, vessels).



The reduced cost of rolling stock and electricity will provide savings in road transport at US\$ 369 billion by 2050.

31. LCOTs measure the levelized capital, operation and maintenance charges during the lifetime of the vehicle. The calculation for the LCOT includes depreciation costs, fuel costs, insurance, financing, repairs and maintenance cost. The only difference with total cost of ownership (TCO) is that it does not include fees and taxes. This explains why the LCOT curves for ICE vehicles remains flat in time instead of increasing.

Combined lower energy demand

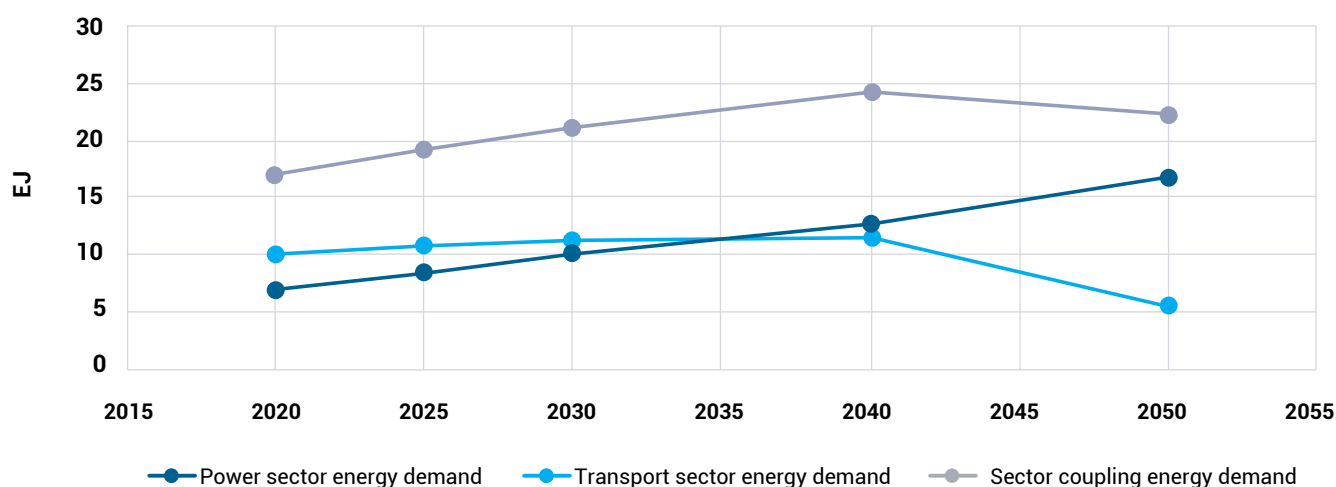
As the energy efficiency of electric drives is 3 times higher than for ICE, the energy demand of the transport sector under the intervention scenario is much lower compared to the BAU scenario. The transition to electric transport has the net effect of reducing total energy demand in the region while increasing future power requirements. A 100% electrification scenario - except air travel - by mid-century would have the net effect of reducing the total energy demand by almost 2,000 million barrels of oil (12 EJ), equivalent to the Canada's annual consumption, while increasing electricity demand by 33% more than the BAU scenario (21.5 EJ). The combined power requirements are shown in Figure 20.

The installed capacity needed to meet the additional power demand is 327 GW mostly required by 2040 and afterwards. If the electrification of transport is coupled to a fully renewable power matrix, the investment associated with the additional power demand is estimated at US\$ 214 billion by 2050.

Otherwise, if the electrification of transport occurs under a BAU power sector scenario, the investment associated with the remainder of the additional power demand is estimated at US\$ 317 billion. The cost of the additional capacity to meet this power demand is lower under the coupled transition because the capital investment associated with power generation under a fully renewable power matrix is lower. The difference in costs is estimated to be US\$ 103 billion. This is an additional benefit of coupling the transition process.

Additionally, as it transitions, the transport sector becomes capable of storing and managing larger amounts of energy. It is difficult to project the role that the storage of power in transport can play under the supply/demand characteristics of the region. For example, it is estimated that the combined electric truck fleet would represent a power storage capacity of the order of 8 GWh by mid-century.³² If properly managed, electric transport demand would also improve the operation of baseload generation capacity through its flattening of demand.

Figure 20. Projected energy demand under a coupled decarbonization of power and transport sectors, 2020-2050 (EJ)



Source: Author's estimates.

32. Based on a fleet of 20,000 trucks each equipped with a battery storage of 400 kWh, for an autonomy of 200 miles. Energy efficiency as calculated by CARB, 2018 for electric trucks (<https://ww3.arb.ca.gov/msprog/actruck/docs/180124hdbevefficiency.pdf>)

Energy security

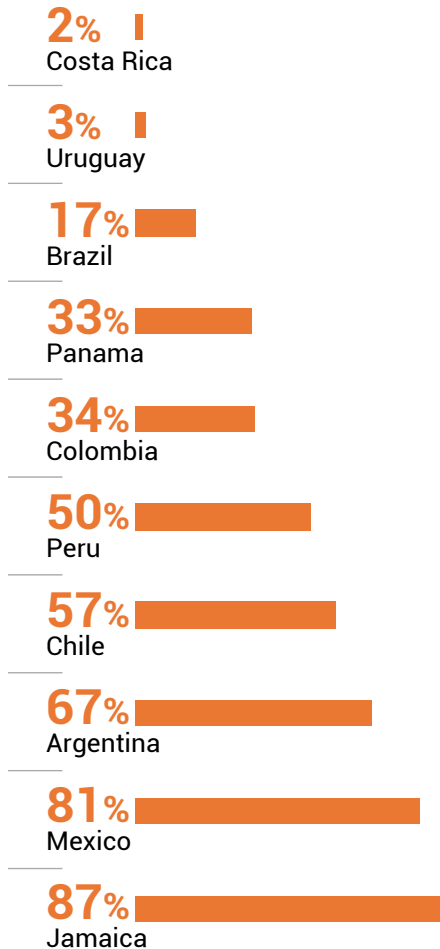
Failure to ensure power supply can result in serious disruptions to national economies. The more nations consume power from local and clean resources, the less exposed they are to external shocks, such as price volatility or political risks from the energy seller country, which may result in an energy crisis for the buyer.

The intervention scenario relies on a fully diverse renewable power matrix and the electrification of the transport sector by 2050. This simultaneous and coupled transition of the power and transport sectors will reduce risks of disruption. Particularly, fossil fuel energy import dependency will be reduced, since it

eliminates fossil fuel use for power generation and transport by 2050. It also minimizes hydropower generation, considering climate change impacts on water availability.

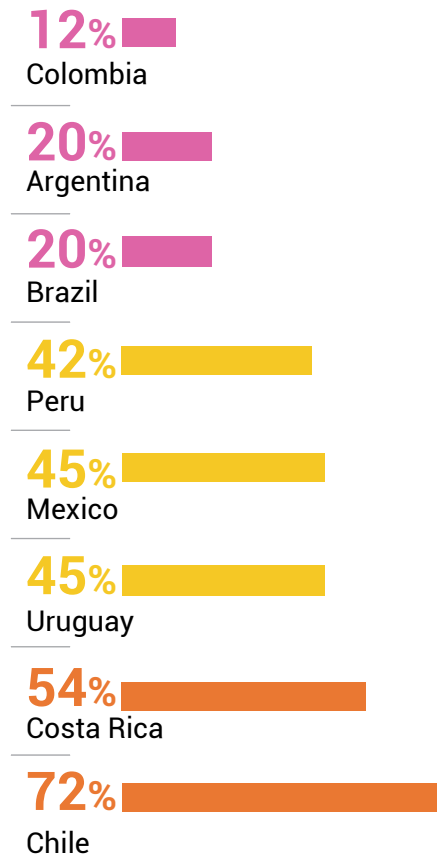
Under the intervention scenario, the largest change in the security indexes, would be experienced by countries with a large dependence on imported fossil resources for power generation - Jamaica, Mexico and Argentina – (Figure 21) and for transport use - Chile, Costa Rica and Uruguay – (Figure 22), followed by countries with reliance on mostly one source of energy, such as Jamaica as the least diverse (87% of generation from oil derivatives) and Costa Rica, Brazil and Colombia (74%, 64% and 63% of generation from hydropower, respectively) (Figure 23).

Figure 21. Share of fossil fuel in electricity generation in selected countries, 2019



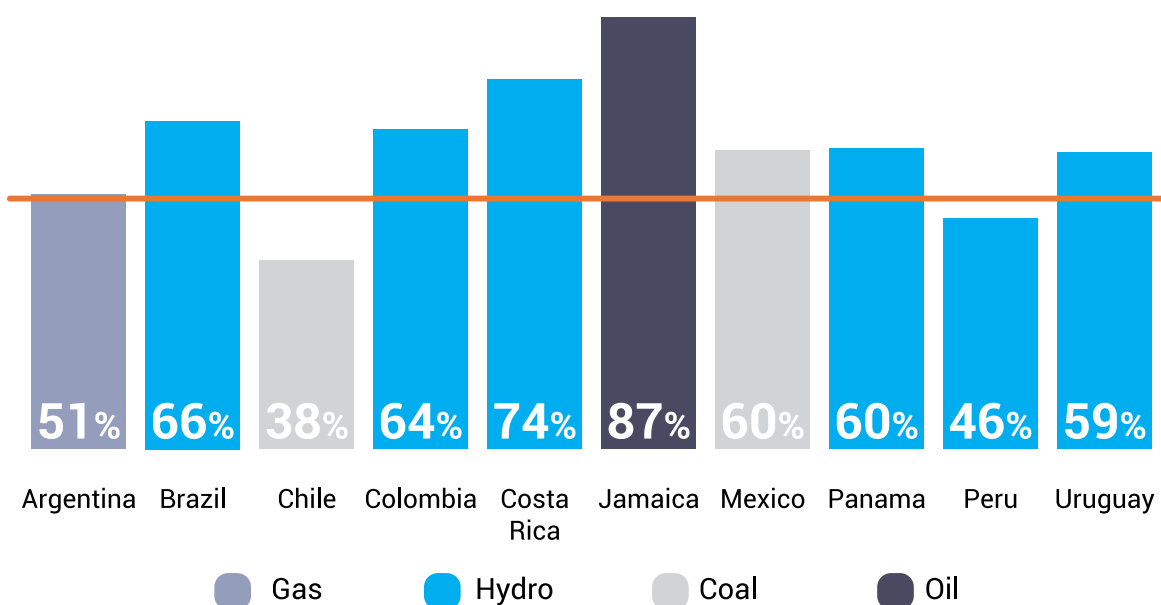
Source: Based on data from ENERDATA consulted September 2019

Figure 22. Imports of energy feedstock as percentage of total primary energy supply (TPES), 2019



Source: Based on data from ENERDATA consulted September 2019

Figure 23. Share of largest generation of power supply in selected countries, 2019



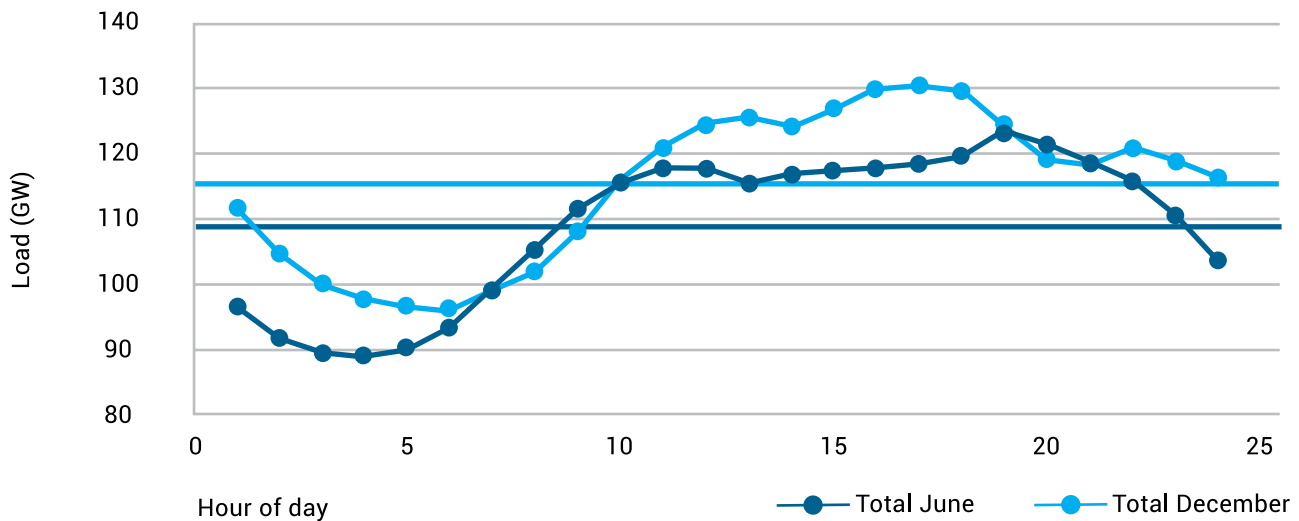
Source: Based on data from ENERDATA consulted September 2019

Impact on power sector loads and size

The entry of a large electric fleet in the region would add additional power demand (estimated by 33% increase in electricity demand by 2050). These new power requirements of electric transport would have the potential to destabilize the grid. Through proper demand management, charging in urban areas could be steered toward periods of lower load, in a process that is known as “valley filling”. In theory this process

would enable the installed capacity to operate at a more efficient level by flattening the demand curve using new transport loads at the most adequate time through robust demand management. The use of the valleys in the load curve (demand flexibility) has been estimated to equal about 10 GW of equivalent capacity (Figure 24). Additional loads of the size required by the electrification of transport will require new capacity but also result in reduced overall energy demand through the higher efficiency expected from electric engines.

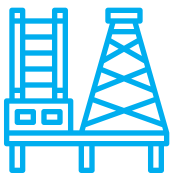


Figure 24. Aggregated load curve for Latin America ³³

Source: Compounded graph from country-based load curves provided through the Latin America Energy Organization (OLADE) in personal communication. Straight line indicates the mean load for each curve, 109 GW in June and 115 GW in December.

Impact on refining operations and stranding of capital assets

The projected decrease in the demand for gasoline and diesel will reduce the need for most refinery operations in the region. Initially, sizable entry of electric fleets, of the magnitude anticipated under the intervention scenario would eliminate the need for additional refining capacity and reduce the need for imports of middle distillates (gasoline and diesel; estimated to be at 0.5 billion barrels per day, bbpd and 1.0 bbpd respectively by 2030 under BAU conditions).



The total electrification of fleets would eventually eliminate the need for refining of middle distillates.

The complete transition of the electricity sector would displace all fossil fuels used in the generation of power.

Consequently, there would be an impact on the use and value of associated production, refining, transport and distribution infrastructure.

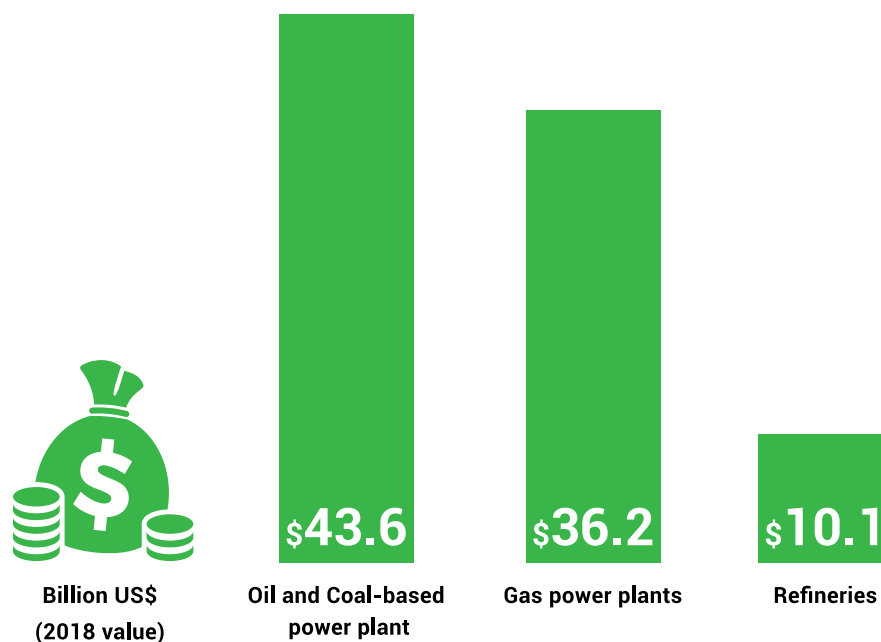
A fully renewable power scenario considers that installed fossil fuel power plants will be decommissioned before the depreciation schedule is completed. The not-depreciated value was estimated at US\$ 80 billion (2018) by 2050. The cost to the economy of these stranded assets are highly compensated by the CAPEX reduction between scenarios. The projected loss of competitiveness represents a clear cautionary signal for fossil fuel investors.

Electrification of transport will also eliminate the need for imports of middle distillates and eventually cause the early retirement of refinery capacity resulting in a loss of non-depreciated value to the order of US\$ 10.2 billion by 2050. Like in the case of power plants, impending market changes in transport should back a cautionary warning against longer-term additional CAPEX in refinery processes for middle distillates.

33. Aggregated load curve for the electricity system in Latin America, prepared assuming full integration at a regional level. Similar conditions prevail at a national level.

The economic consequences of the transition caused by displacement of some of these capital assets in the region can be seen in Figure 25.

Figure 25. Estimated residual value of assets in power generation and refining at time of retirement (in billion US\$ 2018)

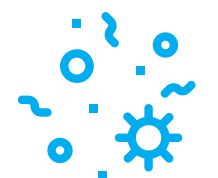


Source: Author's estimates

Health benefits

Urban air pollution in LAC has long been identified as a major health concern.³⁴ The World Health Organization (WHO) has recommended human exposure indicators, including for particulate matter ($PM_{10} = 20 \mu\text{g}/\text{m}^3$ and $PM_{2.5} = 10 \mu\text{g}/\text{m}^3$), that should not be exceeded.³⁵ Exposure to harmful levels of some pollutants (particulate matter and ground level ozone) has been linked to increases in morbidity and mortality levels and losses in productivity. Even lower levels of exposure have some effects on health and productivity.³⁶

Many cities in Latin America exceed the safe thresholds set by WHO and despite efforts to address the problem, unhealthy levels of particulate matter (Figure 26 and 27) and other airborne pollutants continue to prevail. The region is highly urbanized and therefore a high percentage of the total population in Latin American nations is exposed to these effects.



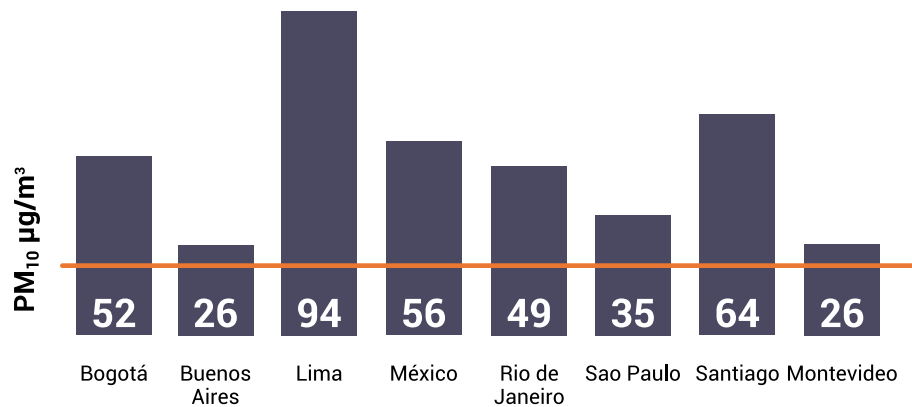
PM_{10} and $PM_{2.5}$ are respirable particulate matter that can penetrate deeply into the lungs producing harmful effects on human health.

34. <https://publications.iadb.org/en/publication/urban-air-quality-and-human-health-latin-america-and-caribbean>

35. https://apps.who.int/iris/bitstream/handle/10665/69477/WHO_SDE_PHE_OEH_06.02_eng.pdf;jsessionid=AFB0FCE10BF597AD230326327D2D5E61?sequence=12

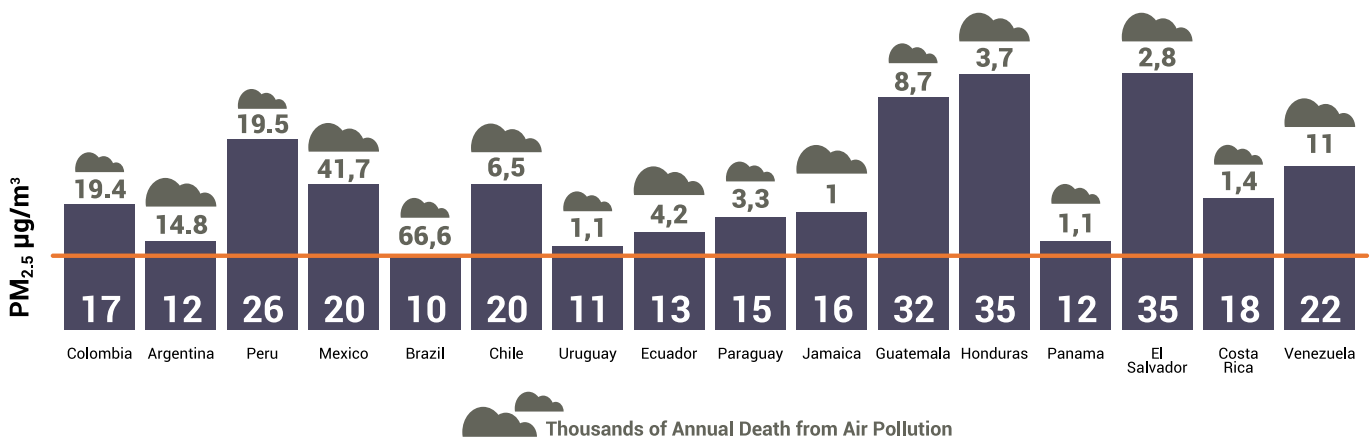
36. A recent study (UNEP, 2018 <https://www.unenvironment.org/news-and-stories/press-release/efforts-reduce-air-and-climate-pollutants-latin-america-could-reap>) estimated that 64,000 people died prematurely in the region from exposure to fine particulate matter ($PM_{2.5}$) and ground level (tropospheric) ozone. Ozone was also responsible for an estimated 7.4 million tonnes in yield losses of soybean, maize, wheat, and rice. If no action is taken to improve air quality, by 2050 annual premature mortality from $PM_{2.5}$ and ozone exposure is expected to almost double while annual crop losses could rise to about 9 million tonnes.

Figure 26. Annual average of PM₁₀ in some cities in Latin America exceeding recommended levels of exposure, 2016



Source: WHO³⁷; Rioja-Rodriguez et al, 2016. WHO Standard for PM₁₀: not to exceed 20 µg/m³ annual mean.

Figure 27. National annual average of PM_{2.5} for some countries in Latin America, 2019



Source: BreathLife campaign. WHO Standard for PM_{2.5}: not to exceed 10 µg/m³ annual mean.

Electrification of transportation in urban areas in a fully renewable energy matrix would eliminate the emissions of particulate matter (PM), a proven human-health risk factor, from mobile sources, mainly by eliminating diesel fuel in transportation. It would also lower ozone formation by eliminating emissions of volatile organic compounds and NO_x. These reductions in emissions and exposure translate into avoided cost of illnesses and overall reductions in morbidity and mortality.

Under the intervention scenario, the elimination of diesel from the transportation sector in urban areas, where exposure to PM is concentrated, is conservatively estimated to trigger annual avoided health costs of US\$ 30 billion (2018) by mid-century.

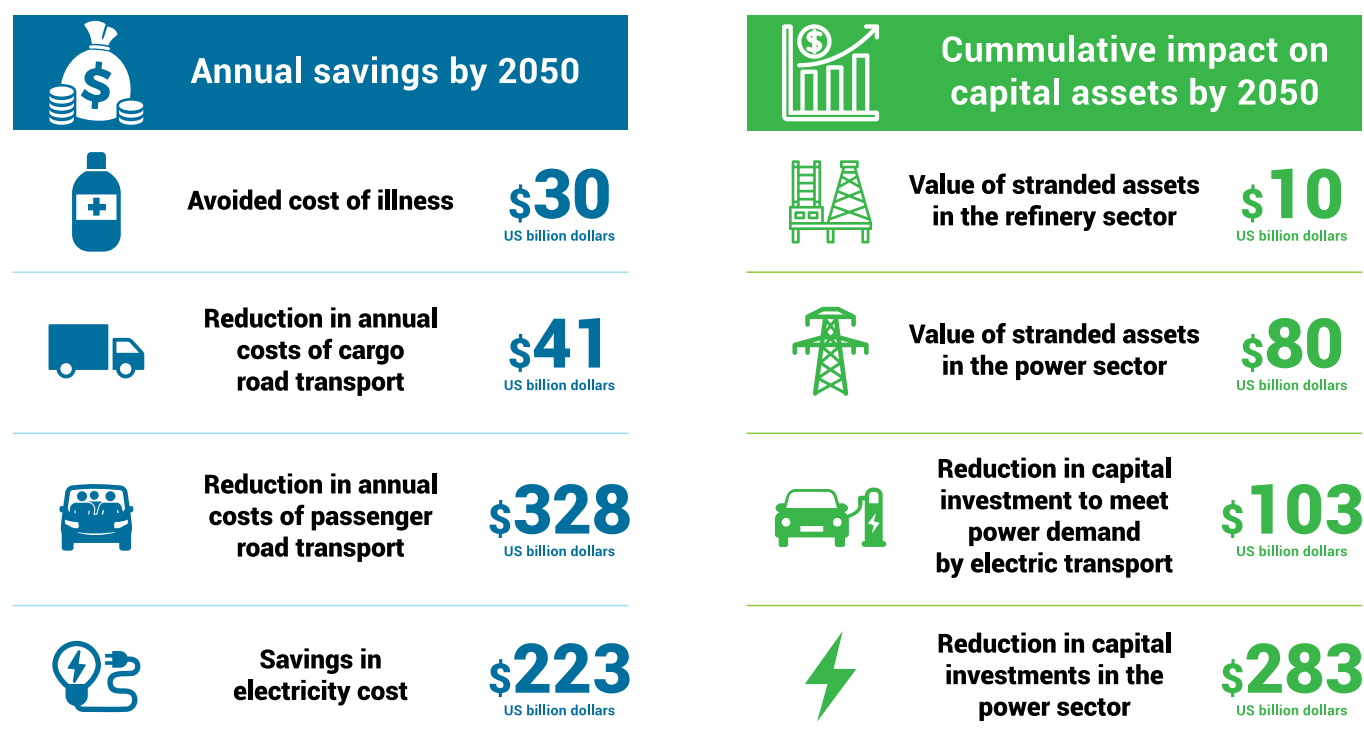
37. https://www.who.int/phe/health_topics/outdoorair/databases/en/; https://apps.who.int/iris/bitstream/handle/10665/69477/WHO_SDE_PHE_OEH_06_02_eng.pdf?jsessionid=AFB0FCE10BF597AD230326327D2D5E61?sequence=

In addition, only by changing the entire vehicle fleet to electric vehicles in five Latin American cities – Buenos Aires, Santiago, San Jose, Mexico City and Cali– would avoid the early deaths of 435,378 people³⁸ due to reduced air pollutants by 2050. The combined costs, benefits and avoided costs of the coupled transition are summarized in Figure 28. Annual savings linked to the coupled transition by 2050 are valued at: US \$621 billion. Net cumulative savings by mid-century on capital assets for the regional economy are estimated at US\$ 296 billion.



Annual savings linked to the coupled transition by 2050 are valued at: US\$ 621 billion. Net cumulative savings by mid-century on capital assets for the regional economy are estimated at US\$ 296 billion.

Figure 28. Combined costs, benefits and avoided costs by mid-century under a coupled power and transport zero emissions pathway (in billion dollars, 2018)³⁹



Source: Author's estimates. *Does not include reduction in electricity costs for the transport sector which are captured in the reduction in costs for road transport. **Is calculated as the difference in capital costs to provide the required energy under the GCAM-BAU power system and the Intervention Scenario.

38. Estimates made by UN Environment Programme through the Methodology for the evaluation of integrated benefits of electric mobility policies, carried out by Clean Air Institute (2019). The estimates assume a gradual electrification of transport in the studied cities reaching 50% electrification by 2030 and 100% by 2050.

39. The table reflects the impact of the coupled transition on costs of delivery of prices and capital flows. It does not include subsidies, levies, tariffs or taxes.

7. Jobs and enterprise creation

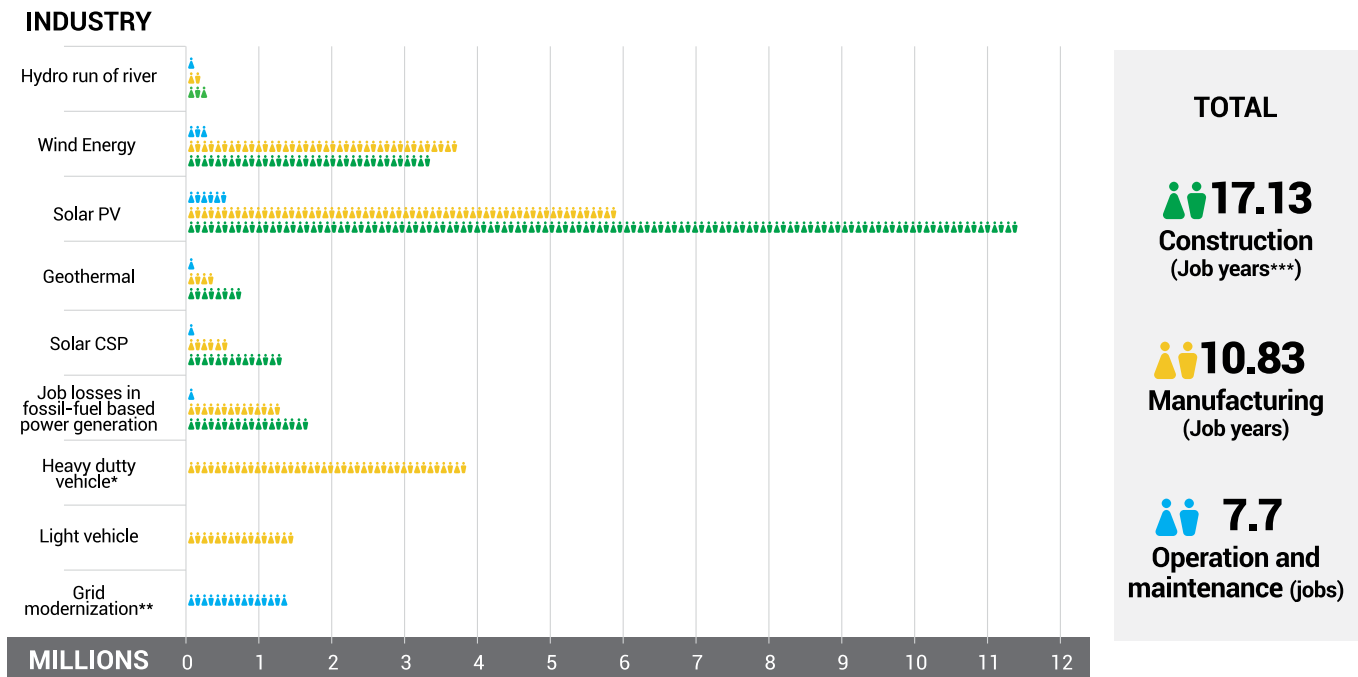
The report estimates that the activities associated with the transition will generate new jobs, educational opportunities and business models for the design, implementation and management of installations, the manufacturing, supply and assemblage of components, and the provision of auxiliary services such as information technologies that will play a major role in the nexus between energy and transport. This transition may be an opportunity for a rekindling of manufacturing, engineering, and financial activity in the region. But it is also a call for new efforts in

education and training which are critical to generate local employment for new technologies in the region. On the other hand, the transition will result in job losses in the fossil fuel industry, including in power generation, refinery operations and distribution and retail fuel sales.



The report estimates that a coupled transition to renewable energy and electric mobility in the region will create over 35 million new jobs by 2050 (Figure 29).

Figure 29. Estimate of additional jobs (millions) generated regionally under the intervention scenario per energy technology by mid century⁴⁰



Source: Author's estimate based on of factors an multipliers reported by Dominish E., et. al. 2018. * Job estimates based on a constant fleet of 150 million cars; 4 million buses and 34 million trucks by 2050. See assumptions and details in Annexes 5 & 12. ** Job estimates based on an investment of 26 billion USD between now and 2030 and using the factors for job creation of a smart energy study⁴¹ ***Job years is a metric used to assess the size of temporary jobs created by activities with a limited time frame.

40. Job estimates on the basis of factors reported by Dominish E., et. al. 2018 https://link.springer.com/chapter/10.1007/978-3-030-05843-2_10 and proposed multipliers to reflect conditions in Latin America. The estimated new jobs in transport electrification are underestimated given that ancillary jobs for this sector such as those associated to charging infrastructure are not considered.

41. <https://www.smart-energy.com/regional-news/north-america/new-study-confirms-job-creation-potential-of-smart-grids-in-u-s/>



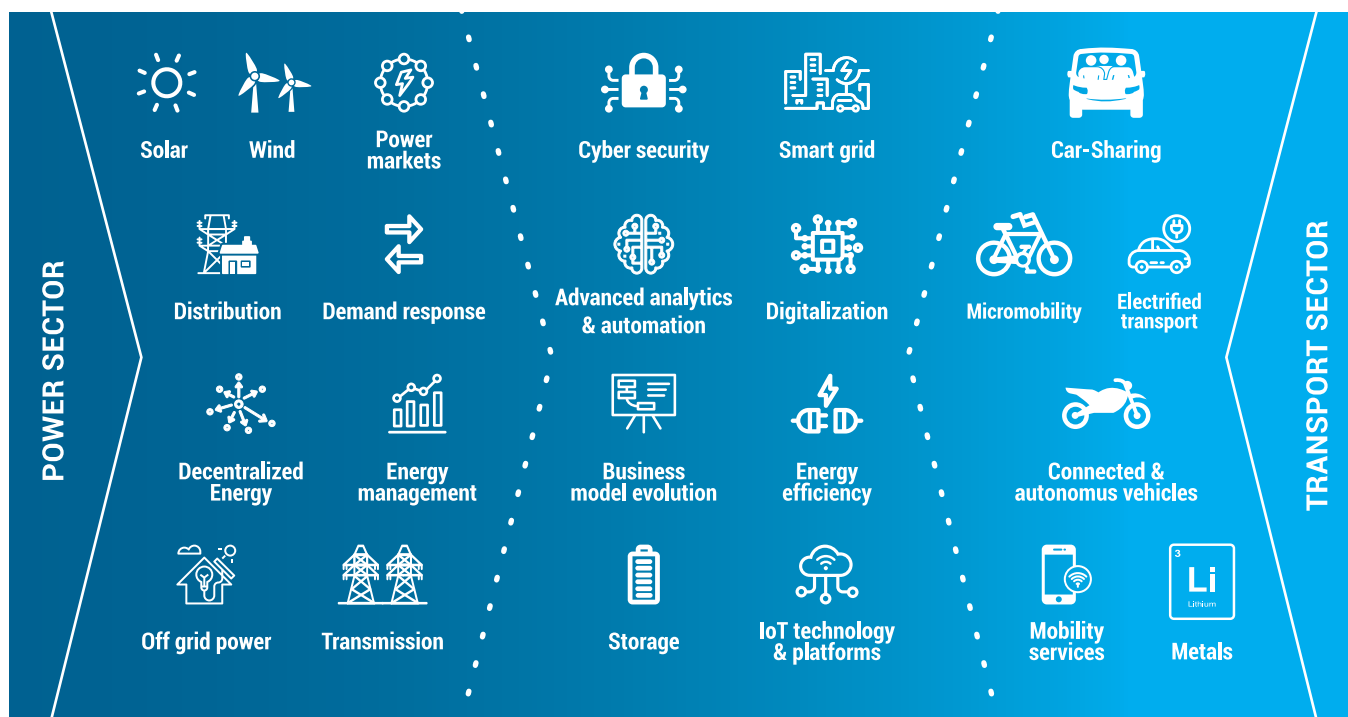
This implies an increase of renewable energy in the power matrix, the installation of DER closer to load centers and the management of this new and connected system through powerful computing tools, respectively. Digitalization is the enabler for a coupled transition of the power and transport sectors towards decarbonization. Figure 30 summarizes the elements of this transition.

Countless business models will be developed in the coupled decarbonization of the transportation and power sectors. Utilities expanding their services, new players entering both markets, development of DER

and digital services are some of the major trends the region is experiencing (described in Chapter 8), showing that the coupled decarbonization has already started in LAC and is picking up fast following global patterns.

The pathway to decarbonization must be planned to deliver a just transition and leave no one behind. Therefore, it is imperative the integration of social and labor policies in climate objectives to provide retraining, skills development and education in new fields while reducing social and economic inequalities. Gender inequalities are socially constructed and therefore can be and are modified over time. The transition to decarbonization comes with the unique chance to balance the gender scale resulting in better economic outcomes for the whole society.

Figure 30. Business opportunities in the coupled decarbonization of power and transport sector



Source: Author's elaboration.



8. Policy options for an accelerated transition

The policy environment has evolved throughout the region in support of a cleaner power matrix, low carbon resilient development, and a cleaner transport system. The trends in technology and economics have contributed to the growth in the use of renewables, utility scale and DG, and are beginning to slowly make a difference in the emergence of electric vehicles. Nonetheless, the degree and speed of change required to a coupled transition by mid-century makes policy leadership critical through a clear, consistent and robust policy agenda.



Therefore, it is critical that decision-makers overcome silos and consider public policies that address these two sectors in a coupled manner.

A well-constructed enabling environment will be critical to attract investment flows towards a coupled transition. The elements of such agenda are summarized in Table 1. Specific examples of each of the public policy instruments mentioned in Table 1 are deeply described in Chapter 9.

In order to assure the long-term electricity supply - in conditions of efficiency, quality, reliability and safety - and reduce the country's vulnerability to the effects of climate change, some countries in the region have developed a legal, regulatory and policy framework that promotes diversification and decentralization of the power matrix by renewable sources. The main existing public policy instruments to achieve the decarbonization of power sectors are summarized in Table 2 as part of two big areas within the sector (decarbonization and decentralization measures).

Table 1. Goals and main instruments of a bold policy agenda in support of the coupled decarbonization of the power and transport sectors

Goal	Policy Actions	Instruments
Reduce the cost of stranded assets in the power generation and refinery sector.	Discourage capital investments in the fossil industry.	<ul style="list-style-type: none"> • Clear energy and transport policy adopting zero emission goals by 2050. • Allow early depreciation of assets. • Eliminate fossil fuel subsidies.
Promote DG, storage capacity and auxiliary services to provide grid flexibility and integration of variable renewable energy.	<p>Promote investments in modern, smart generation, transmission and distribution infrastructure and auxiliary services to integrate VRE.</p> <p>Develop regulations on demand management, storage, self-generation and distributed options.</p>	<ul style="list-style-type: none"> • National targets on DER. • Development of technical standards for DG. • Development of public and private financial mechanisms. • Clean energy certificates and programs. • Permitting procedures for DG installations. • Net metering/net billing/self-consumption schemes. • Renewable energy mandate for new construction. • RE and/or storage auctions. • Update regulation to include RE in government procurement. • Industrial policies for renewable energy. • Distributed solar PV installers certification programs. • Fiscal incentives.
Optimize generation and transmission to meet demand.	Promote regional grid integration.	<ul style="list-style-type: none"> • Market-based power exchange with neighboring countries. • Regional integration of transmission system.
Internalize health and climate costs in transport emissions.	Develop fiscal or carbon pricing measures that allocates the costs of health and climate impacts.	<ul style="list-style-type: none"> • Fiscal measures to pass costs to emitters of air pollutants and GHGs. • Carbon emissions trading systems. • Use revenues to promote public investments in enabling infrastructure.
Facilitate market entry of electric transport.	Removal of regulatory and policy barriers.	<ul style="list-style-type: none"> • National targets on EV by segments. • Prohibitive measures over ICE vehicles. • Electric tariff incentives for EV owners. • Review/modify road standards. • Regulations for standardization and interoperability of charging stations. • Regulate composite fleet emissions. • Enact transit and parking preferences. • Standards for BEV. • Industrial policies for EV manufacture. • Fiscal incentives. • Vehicle emission and efficiency standards. • Ultra low emission zone.
Assure efficiency, quality, reliability and security of a connected power system	Assure resiliency of the system, quality of service and protection of stakeholder information.	<ul style="list-style-type: none"> • Implementation of cybersecurity standards. • Smart grid standard policy. • Stimulate investment in ICT services. • Cooperation between nations in the region and internationally to share information, lessons learnt and good practices.
Promote technology and business development in support of the transition.	Promote investments in R&D and technology development in zero carbon technologies.	<ul style="list-style-type: none"> • Science, technology and innovation policy in favor of zero emission goals by mid-century. • Fiscal measures to support investments in R&D. • Grants to escalate startups with a proven minimum viable product with substantial impact on decarbonization.
Address social and economic inequalities	Assure a just transition.	<ul style="list-style-type: none"> • Policies for social protection. • Ensure green jobs are decent. • Retraining of workers. • Promote inclusive participation in dialogues.

Table 2. Existing energy policies in some countries in the region

	RE National Targets	Net Metering	Accelerated Depreciation	VAT exemption	Import tax exemption	Carbon Tax	Clean energy certificates	Priority dispatch	Auctions
Antigua and Barbuda	■	■	□	□	■	□	□	□	□
Argentina	■	■	■	■	■	□	□	■	■
Bahamas	■	■	□	□	□	□	□	□	□
Barbados	■	■	□	■	■	□	□	□	□
Belize	■	□	□	□	□	□	□	□	■
Bolivia	■	□	□	□	□	□	□	□	□
Brazil	■	■	□	■	□	□	□	■	■
Chile	■	■	■	□	□	■	■	□	■
Colombia	■	■	■	■	■	■	□	□	■
Costa Rica	■	■	□	□	■	□	□	□	■
Cuba	■	□	□	□	□	□	□	□	□
Dominica	■	□	■	□	□	□	□	□	□
Dominican Rep.	■	■	□	■	■	□	□	■	□
Ecuador	■	□	□	□	■	□	□	■	■
El Salvador	■	■	□	□	■	□	□	■	■
Grenada	■	■	□	■	□	□	□	□	□
Guatemala	■	■	□	■	■	□	□	■	■
Guyana	■	□	□	■	■	□	□	□	■
Haiti	■	□	□	□	□	□	□	□	□
Honduras	■	■	□	□	■	□	□	■	■
Jamaica	■	■	□	□	□	□	□	■	□
Mexico	■	■	■	□	□	■	■	■	■
Nicaragua	■	□	□	■	■	□	□	■	■
Panama	■	■	■	■	■	□	□	■	■
Paraguay	■	□	□	■	■	□	□	□	□
Peru	■	□	■	■	□	□	□	■	■
Saint Kitts and Nevis	■	□	□	□	□	□	□	□	□
Saint Vincent and the Grenadines	■	■	□	□	□	□	□	□	□
Saint Lucia	■	■	□	□	■	□	□	□	□
Suriname	■	■	□	□	□	□	□	■	■
Trinidad and Tobago	■	■	□	■	■	□	□	□	□
Uruguay	■	■	□	■	■	□	□	■	■
Venezuela	■	□	□	□	□	□	□	□	□

Source: Climatescope (<http://global-climatescope.org/policies>), Regulatory indicators for sustainable energy (RISE, World Bank - <https://rise.esmap.org/>), IRENA 2015⁴²

42. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_RE_Latin_America_Policies/IRENA_RE_Latin_America_Policies_2015.pdf

Regarding public policy and legal frameworks, countries and cities in the region have sought to guide and stimulate the development of electric mobility in various ways (Table 3). Countries like Colombia and Costa Rica have comprehensive electric mobility laws in force and there are several others with initiatives underway to formulate similar legal instruments. There is also a broader group of countries with partial legal or regulatory instruments, some provide fiscal and non-fiscal incentives, others regulate the efficiency of the car fleet and others encourage the development of industries and enterprises associated with electric mobility. There is also a broad group of countries with an incipient development of these instruments.

Table 3. Existing transport policies in some countries in the region

	Antigua and Barbuda	Argentina	Brazil	Chile	Colombia	Costa Rica	Ecuador	Mexico	Panama	Paraguay	Peru	Dominican Rep.	Uruguay
Value-added tax	Grey	Grey	Grey	Grey	Blue	Blue	Blue	Blue	Grey	Blue	Yellow	Blue	Yellow
Import tax	Blue	Blue	Blue	Grey	Blue	Blue	Blue	Blue	Yellow	Blue	Yellow	Blue	Blue
Other purchase incentives	Grey	Yellow	Yellow	Blue	Blue	Blue	Blue	Yellow	Yellow	Blue	Grey	Grey	Blue
Property & circulation tax	Grey	Grey	Grey	Grey	Grey	Blue	Grey	Yellow	Grey	Grey	Grey	Grey	Blue
Exemption of tolls and parking fees	Grey	Grey	Yellow	Grey	Blue	Blue	Blue	Yellow	Grey	Grey	Grey	Grey	Grey
Other incentives for use and circulation	Grey	Grey	Grey	Grey	Blue	Blue	Grey	Grey	Grey	Grey	Grey	Grey	Grey
Exemption of vehicular restriction	Grey	Grey	Grey	Grey	Blue	Blue	Grey	Grey	Grey	Grey	Grey	Grey	Grey
Differentiated electric rates	Grey	Grey	Grey	Blue	Grey	Blue	Blue	Blue	Grey	Grey	Grey	Grey	Yellow
Regulation for charging stations	Grey	Grey	Blue	Blue	Blue	Blue	Grey	Blue	Yellow	Yellow	Grey	Grey	Grey
National electricomobility strategy	Grey	Yellow	Grey	Blue	Blue	Blue	Grey	Yellow	Blue	Yellow	Grey	Grey	Grey

■ Completed incentive for electric vehicles / Approved and running instrument.
■ Partial incentive for electric vehicles / Instrument in design phase.

Source: MOVE, UNEP, 2019.

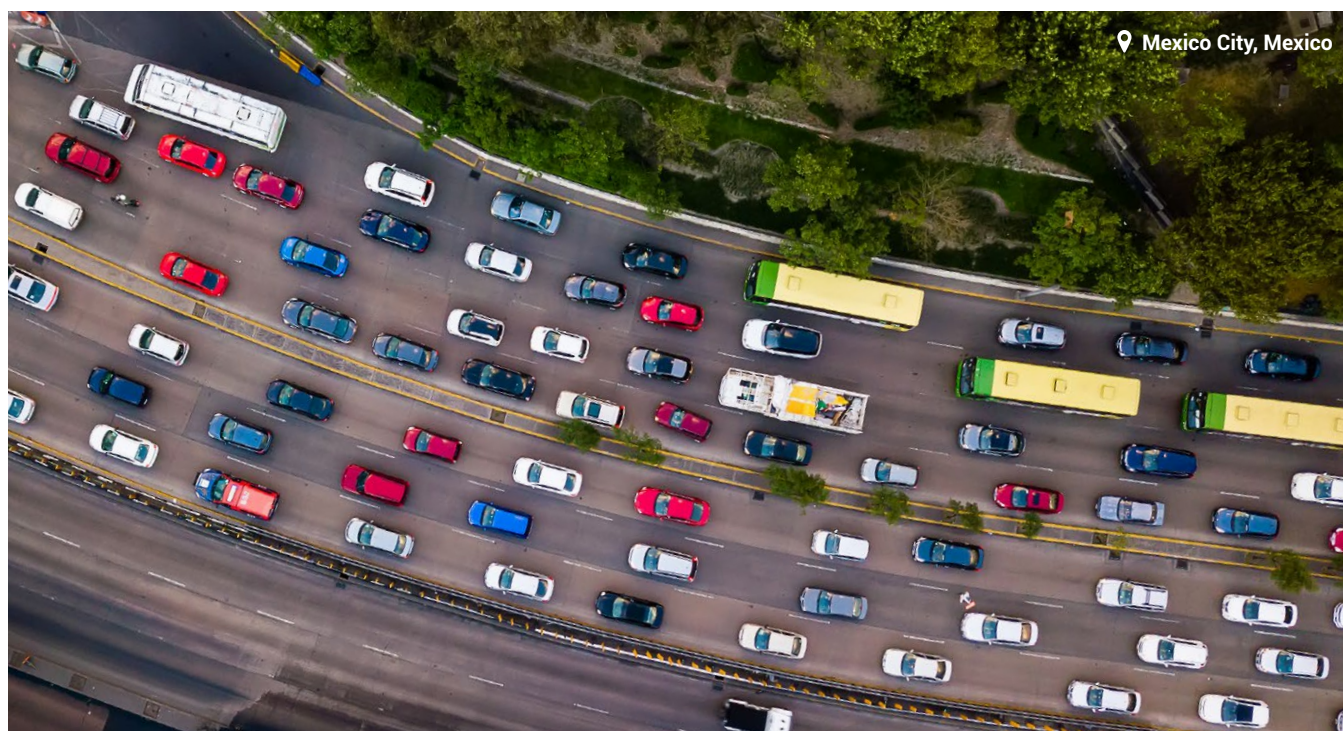
On the other hand, countries such as Colombia, Chile, Costa Rica and Panama already have national electric mobility strategies or plans - Argentina, Mexico and Paraguay are in the process of formulating their own strategies. In this regard, it is worth mentioning the emergence of goals (Table 4) associated with the deployment of electric mobility by countries and cities, derived from the legal instruments or strategies mentioned above.

The transition to electric transport is incipient and will require a much more forceful support agenda. The region is at an early stage to assess the impact of these public policy instruments and legal framework. It is concluded that there is no single solution or approach in this regard and that there is great interest in the region to continue creating an enabling environment for the development and regulation of technologies such as electric mobility. Undoubtedly, it is worthwhile to monitor the impact of these types of instruments through periodic reviews to align the enabling environment with technological developments and the context and priorities of each country and city in the region.

Table 4. Electric transport targets of some countries in LAC, 2019

<p>Barbados</p> <p>National Energy Policy for Barbados 2019-2030</p> <p>100% of renewable energy and carbon neutrality for 2050</p>	<p>Ecuador</p> <p>Draft Energy Efficiency Law</p> <p>EVERY vehicle incorporated in the public transportation should be electric and will have preferential differentiated energy fees from 2025</p>
<p>Chile</p> <p>National Electromobility Strategy</p> <p>100% of public transportation electrified by 2050</p> <p>40% of the private transportation electrified by 2050</p>	<p>Mexico</p> <p>Integrated mobility programme for Mexico City</p> <p>500 trolleybuses for the Zero Emissions Corridor of STE (Electric Transportation Services) in CDMX for 2024</p>
<p>Colombia</p> <p>National Development Plan</p> <p>600 thousand electric vehicles for 2030</p>	<p>Panama</p> <p>National electromobility Strategy of Panama</p> <p>10-20% of the total of private vehicle fleet will be electric for 2030</p> <p>25-40% of the private vehicle sales will be electric for 2030</p> <p>15-35% of the buses of the conceded authorized fleet will be electrified by 2030</p> <p>25-50% of the public fleet will be electric vehicles for 2030</p>
<p>Costa Rica</p> <p>Decarbonization Plan</p> <p>70% of buses and taxis with zero emissions by 2035</p> <p>100% of buses and taxis with zero emissions by 2050</p> <p>25% of the light-duty vehicle fleet will be zero emissions by 2035</p> <p>60% of the light-duty vehicle fleet will be zero emissions, with higher percentages for commercial and governmental use by 2050</p>	<p>Paraguay</p> <p>National Energy Policy 2040 (PEN 2040)</p> <p>20% of the state vehicles will be electric by 2020</p>

Source: MOVE, UNEP, 2019.



A policy environment to develop a coupled transition should be dynamic and country customized. The economics of the transition are not set in stone as technology prices are coming down fast, new elements come into play and the impacts of climate change keep evolving. Therefore, policies should be reviewed periodically in order to help countries achieve their NDCs and long-term strategies (LTSSs), and meet decarbonization objectives by 2050, as well as the SDGs in a changing environment.

All countries in the region have presented NDC⁴³ setting priorities for mitigation and adaptation to climate change. Measures in the energy sector are present in all NDCs, which highlights the importance of the sector in the region in the achievement of the Paris Agreement. Since the presentation of NDCs several countries have strengthened their commitments in the renewable energy and electric transport sectors in their National Energy Plans, Decarbonization Plans and/or in other energy and environmental policy instruments (Table 2, 3 and 4). The goal of the study in this respect is to support countries efforts, for the next round of NDCs, to consider the coupled benefits of addressing these two sectors conjunctively to further advance their climate goals.

43. The NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. The Paris Agreement (Article 4, paragraph 2) requires each Party to prepare, communicate and maintain successive nationally determined contributions, NDCs that it intends to achieve. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions.

CHAPTER 1

INTRODUCTION

Despite the signing of the Paris Agreement by most nations, in late 2015, global emissions of GHG have continued to increase. At the start of 2019, CO₂ concentration in the atmosphere reached 409 ppm (NOAA, 2019) with emissions sized at 53 GT CO₂-eq per year (Mc Cracken, 2019). This level of CO₂ concentration was last seen in the mid-Pliocene (3 million years ago), a period that saw an iceless Arctic and sea levels at 15 to 20 meters above current measurements. Global temperatures have already reached 1.1°C above pre-industrial levels. If current trends continue, temperatures can be expected to rise to 3.2°C by the end of the century (IPCCC, 2018; W. Steffen et al, 2018, UNEP Emissions Gap Report, 2019). The situation has prompted warnings from the scientific and global governance community that the biosphere may be reaching a point of no return (Aegenheyster M., et. al, 2018, UNEP, 2018).⁴⁴



Perito Moreno Glacier footbridges, Argentina
Photo by Matt Broch, Unsplash

44. Global peaking of emissions by 2020 is crucial for achieving the temperature targets of the Paris Agreement, but the scale and pace of current mitigation action remains insufficient. (Emissions Gap Report 2018, UNEP).

Present Context

We are on the brink of missing the opportunity to limit global warming to 1.5°C, the time to act is now. While there will still be climate impacts at 1.5°C, this is the level scientists say is associated with less devastating impacts than higher levels of global warming (IPCC, 2018). Countries need to take a quantum leap in reducing emissions— globally a 7.6% reduction every year from 2020 to 2030 (UNEP Emissions Gap Report, 2019).

Evidence has become available on the changes and disruption in the global climate system affecting the Latin America and Caribbean (LAC) region. For example, extensive, unprecedented, fires were experienced in temperate forests in Chile and Argentina, burning close to half a million hectares (ha) (CONAF, 2019) during 2016/2017; large-scale fires affected Brazil and Bolivia, destroying nearly 5 million ha in 2019 (NPR, 2019). Coral bleaching in the Caribbean has now affected most reefs (Siegel, K., 2019), many in an irreversible manner. The tropical glaciers in the region continue to disappear with remnants only left for those at under 5000 m. Concerns continue over the long-range impact of increasing soil and atmospheric temperatures on the productivity and location of large swaths of agricultural land as well as on the stability of forests in the continent (Ripple et al, 2017).



These changes affect not only the ecology of the systems impacted but also the livelihoods and sustenance of millions in the region, even forcing migrations from affected areas and threatening the foundations of the regional economy.

Under the current 1.1°C increased temperature, climate change has become a national security threat to the countries of the region. If the global temperature continues to rise, the effects of climate change will be increasingly severe and expensive.

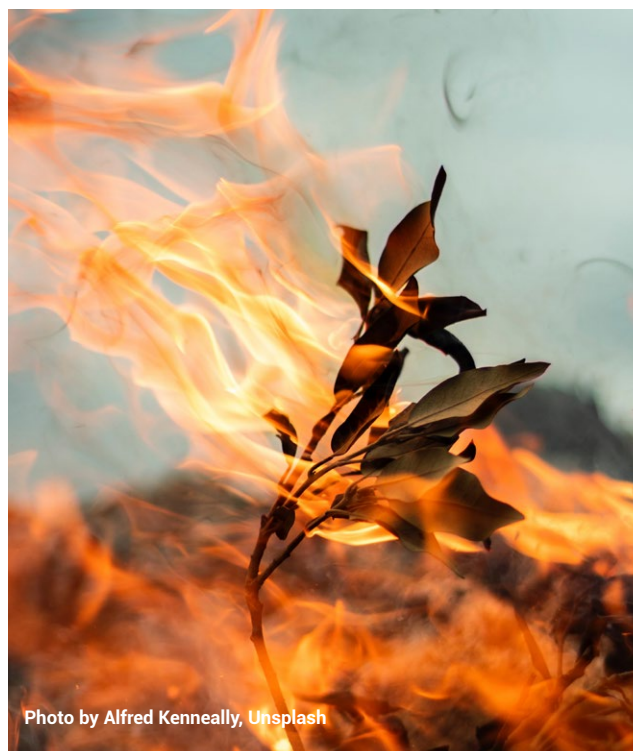


Photo by Alfred Kenneally, Unsplash

The Intergovernmental Panel on Climate Change (IPCC; Allen et al 2018) and others (McCracken, 2019) have concluded that in order to limit global warming to 1.5 °C forceful and immediate actions in all sectors are required to stop emissions and spare the global community from the worse effects of climate destabilization. Calls for net decarbonization of the regional economies are now being made with increased frequency (Vergara W., et al, 2015; Bataille C., et al, 2016)⁴⁵ and are being embraced by a growing number of nations in Latin America.⁴⁶ Rapid and systematic transitions to zero emissions in the provision of services are now seen by many not only as feasible and reachable but also as necessary. Scientists have spoken, now is the time for governments and industries to take the lead and assure a transition path consistent with the 1.5 °C track. Economies must shift to a decarbonization pathway now.

In this sense, climate transformational change needed to meet the Paris goals and to reach zero emissions by mid-century can be critically supported by coupling the power and transport sectors. The objective of

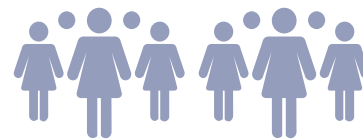
45. <https://initiative20x20.org/news/buenos-aires-declaration-restoration>

46. For example, Costa Rica, Uruguay, Chile, Colombia have all announced steps toward complete decarbonization.

this report is to illustrate the opportunity, costs and benefits of the coupled decarbonization of the power and transportation sectors in the Latin America and the Caribbean (LAC) region by mid-century. The report also presents on the ground examples, from successful policies to business models, which signal a potential coupled decarbonization transition. If escalated, would put the region in a virtuous scenario, raising the ambition of next generation of Nationally Determined Contributions to the Paris Agreement (NDCs).

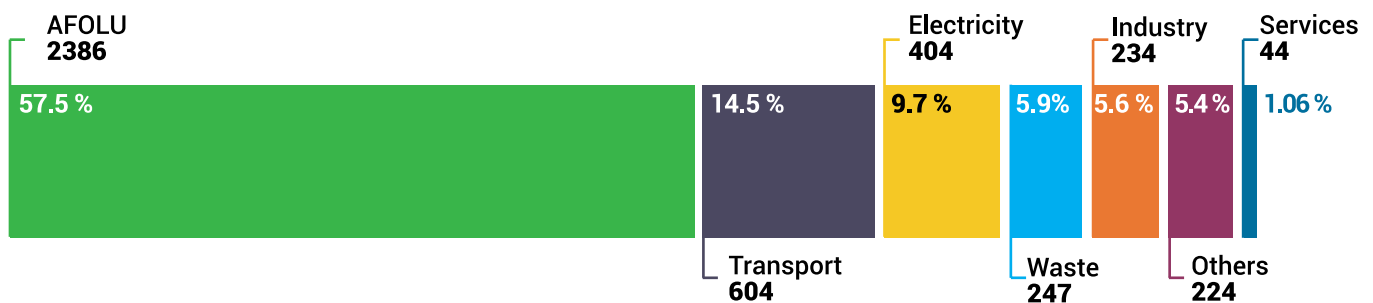
The actions reviewed in this report fit the mold of bold climate action, as called for by the Global Commission on the Environment and Climate (New Climate Economy) on the basis of benefits in terms of new jobs, economic savings, competitiveness, market opportunities, and improved well-being. Actions to decarbonize can be likewise be framed in the context of a green economy, defined by the United Nations Environment Program (UNEP) as “one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities” (UNEP, 2012).

The entire region has a relatively small contribution in the global carbon footprint (9.5%)⁴⁷ with approximately the same percentage of global population.⁴⁸ However, the regional average GHG emissions per capita (7tons of CO₂-eq)⁴⁸ is greater than the global figure (5 tons of CO₂-eq).⁵⁰ Since 2012, the regional emissions have decreased from 4.6 GT CO₂-eq, to 4.3 GT CO₂-eq by 2017, despite an upsurge in deforestation.⁵¹ Still, the region has a significant and growing carbon footprint in its transport sector (Figure 1), as well as a comparable emissions footprint from the power generation sector that together account for two thirds of emissions of fossil CO₂ and about one quarter of the total GHG emissions in the region.



LAC is the most urbanized region on the planet, 80% of its population lives in cities.⁵² Consequently, most of the energy consumption and road activity is concentrated in urban areas.

Figure 1. GHG emissions in LAC (MTCO₂-eq), 2017



Source: GACMO, consulted, October, 2019; CAIT, Climate Data Explorer, for fugitive emissions and bunker fuels, included as others, <http://cait.wri.org> and GFW for deforestation rate of 3.2 M ha of primary forest in 2018.

47. The Brookings Institution 2014 A New Global Agreement Can Catalyze Climate Action in Latin America https://www.brookings.edu/wp-content/uploads/2016/06/Correct-Climate-LAC-GlobalViews52015_FINAL.pdf
 48. World Bank 2018 <https://data.worldbank.org/indicator/SP.POP.TOTL?locations=ZJ-1W>
 49. World Resources Institute 2014 Climate Analysis Indicators Tool (CAIT). <http://cait.wri.org>
 50. World Bank 2014 <https://data.worldbank.org/indicator/EN.ATM.CO2E.PC>
 51. Based on data for Latin America from GACMO accessed October 2019, CAIT, and FAOSTAT, accessed October 2019 and deforestation rates from GFW (Global Forest Watch). Deforestation in 2017 is estimated at 3.2 M ha; in 2018 it decreased to 2.1 M ha., but the recent forest fires are likely to impact the total again in 2019.
 52. World Bank 2018 https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=ZJ&name_desc=false



Santiago, Chile
Photo by Marcela Castillo

The region has an expanding power sector, which added about 80 gigawatts (GW) of installed capacity between 2012 and 2018. While acknowledging the challenges and differences between national circumstances, Latin America and the Caribbean has been characterized (Vergara W., et al, 2014, IDB 2019) as having the necessary conditions (resource endowment, attractive economics, business acumen and institutional capacity) to transition to a system entirely based on renewable sources. Furthermore, over the past few years, political, economic and technical feasibility of solar energy, at utility-scale and small-scale, wind energy and power storage technologies have considerably improved. These improvements signal a transition in electricity generation. It can also be argued that today's majority role of hydropower in the electricity sector constitutes a convenient starting point on which to launch a regional renewable energy transition.

The characteristics of the transport sector, with most road passenger concentrated in cities, high bus utilization rate per capita and concentration of cargo transport in trucks provide initial conditions for an alike evolution of the sector. Additionally, policy makers continue to push toward lower carbon public transport. Improving economics and growing concern about health and environmental impacts of emissions from internal combustion engine (ICE) buses in cities are the two main drivers.



Momentum for electric buses is beginning to be built regionally.

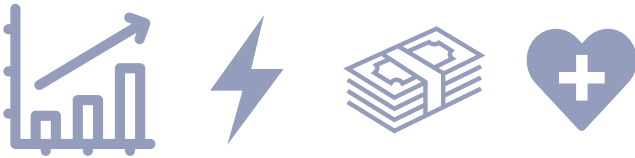
Buses are going electric faster than any other vehicle segment. Additionally, consumer interest in electric vehicles is growing as car manufacturers launch more electric car models. This context signals a potential transition in transport.

Economic, institutional and socio-cultural barriers may inhibit power generation and transport transitions, depending on national, regional and local circumstances, capabilities and the availability of capital. The use of petroleum-derived liquid fuels for transport, remains a key barrier for elimination of fossil sources of energy in the primary energy matrix. The use of gasoline, diesel and other fuels used in the transport sector would necessitate of their import or production even if the power sector were to completely transition to renewable sources. Therefore, decarbonizing the power sector today is not enough to move the economies much closer towards a zero emission status. If other sectors of the economy, could simultaneously transition to electricity as this sector is decarbonized, the process would advance much further.

The report focuses on a review of the prospects for a simultaneous, coupled, transition of the power and transport sectors as the first step of a potential strategy to provide greater flexibility to the region's efforts to decarbonize in a more cost-effective way. Sector coupling can contribute to cost-efficient decarbonization, by realizing synergies and interlinkages between different parts of the economy and deriving in potentially higher economic benefits and greater mitigation impact. Managing a renewable



power and an electrified transport could deliver on economies of scale, demand side management, energy storage flexibility and result in streamlined investments in both.⁵³



A coupled transition between the transport and power sectors would also represent an efficient allocation of capital resources in LAC and result in quantifiable benefits in energy security, minimize refining infrastructure and costs, and effectively reduce GHG and airborne criteria pollutants from the cities in the region, delivering in the process sizable health benefits.

Additional advantages include job opportunities, enterprise generation and technology development as many services would require novel in situ approaches. A diversified power sector, based in renewables, would also yield a resiliency benefit against anticipated changes in rainfall patterns and extended periods of drought.

Transitions of this sort, along parallel tracks, would face substantial policy, regulatory and incentive barriers that need to be addressed. For example, the rules for electricity generation, grid delivery and use were traditionally defined with fossil fuel resources in mind and in many cases still reflect a bias. The infrastructure was developed under different circumstances, without allowances for novel, intermittent, renewable energy technologies. The regulatory and policy frameworks were likewise designed with fossil fuels in mind. Transport regulations and infrastructure are the domain of internal combustion vehicles. There are also strong economic interests that would represent obstacles to otherwise desirable sector transformations.

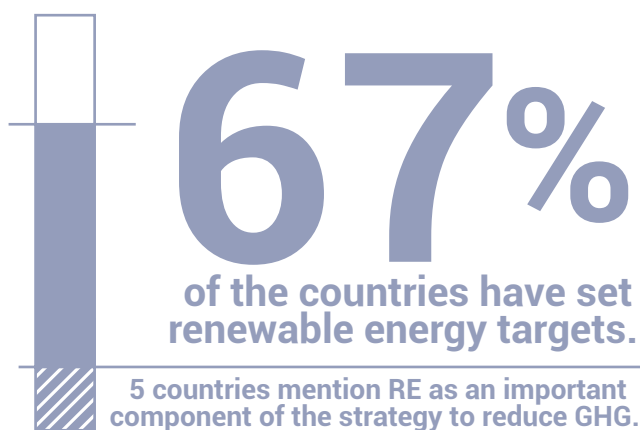
But, if such simultaneous transitions and benefits were to be achieved, there would be strong arguments, to further the evolution toward an entirely electrified economy. For example, similar transformations in the industrial and domestic sectors could also be catalyzed when the necessary cost reductions and technologies become available. An electrified economy based on plentiful and cost competitive supply of renewable-based power would deliver on climate and efficiency goals without requiring sacrifices on access and quality of services.

53. In the assessment of the transition, the report uses outputs from the Global Change Assessment Model, v 5.1 (GCAM) to provide a reference, business as usual, projection to mid-century; the LAC Greenhouse gas Abatement Cost Model GACMO, version of 6. May 2015 updated to 1. July 2019 (GACMO) tools to estimate current and future levelized costs of energy generation and cargo and passenger transport options; and FAO Statistics (FAOSTAT) and the Global Forest Watch (GFW) to provide information for land-use-related issues.

Some nations are better prepared to embark along a zero-carbon path, and in fact some are already well on track with the necessary investments, policies and private sector participation required for the transition. Further, experiences in a few countries may be regional, if not global, examples on how to proceed. Other countries have significant potential to lead and yet others can help characterize case studies for different approaches. All countries in the region have presented Nationally Determined Contributions (NDC)⁵⁴ setting priorities for mitigation and adaptation to climate change. Measures in the energy sector are present in all NDCs, which highlights the importance of the sector in the region and in the achievement of the Paris Agreement. Transport sector is commonly mentioned within the energy sector, except for 9 countries that address transport separately.

Almost no country in the region has set quantifiable targets of GHG emissions reductions for the energy sector. Ecuador is the exemption with targets of 20% to 25% reduction of GHG from the energy sector in comparison to its BAU scenario. Another exemption is Grenada, setting an emissions reduction of 30% by 2025, associated to 10% renewable energy penetration and 20% efficiency measures. The lack of quantifiable targets in the sectors makes it hard to monitor progress on NDCs. On the bright side, many countries have set numeric targets on energy efficiency and renewable energy, thus enabling measurements on GHG emission reduction and therefore an estimation of the contribution to the energy sector.⁵⁵

Most of the measures of the energy sector are related to renewable energy and energy efficiency targets. In the case of the transport sector, mentions are related to efficiency of technology, dirty fuel taxes, promotion of cleaner fuels and cleaner technologies. It is worth noting that electric vehicles are 3 times more efficient than internal combustion engines. Therefore, the



adoption of EVs could help attain faster these energy efficiency goals. Table 1 below shows which countries mention or has targets on the focus sectors of this report. Out of the 33 countries listed, 22 countries have set renewable energy targets and 5 mention that RE are an important component of the strategy to reduce GHG. The rest of the countries (6) do not even mention RE in their NDCs, and consistently, they also make no statement for electric transport.



12 countries made commitments on electric transport in their NDCs.
Uruguay is the only one with specific targets on electric vehicles.






















Panama, Ecuador and El Salvador mention electrification of transport through expansion of the tram or subway system. Four other countries explicitly mention electric transport in their NDCs while three others allude to it with terms like clean energy in transport, alternative fuel vehicles or low emission vehicles, this were also counted as mentions. Dominica's NDC commitment is to hybrid vehicles. The rest of the countries made no mention of transport at all or stated general efficiency improvements. Due to lack of specificity, this were not counted as mentions to electric transport.



54. The NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. The Paris Agreement (Article 4, paragraph 2) requires each Party to prepare, communicate and maintain successive nationally determined contributions, NDCs that it intends to achieve. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions.

55. OLADE, 2018 - <http://biblioteca.olade.org/opac-tmpl/Documentos/old0414.pdf>

Table 1. Mentions and targets on Renewable Energy and Electric transport in the NDCs of countries of the region

 Target	 Mention	 Renewable Energy	 Electric Transport
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Country			Comments
Antigua & Barbuda			<ul style="list-style-type: none"> · By 2030, achieve an energy matrix with 50 MW of electricity from renewable sources both on and off-grid in the public and private sectors. · By 2020, establish efficiency standards for the importation of all vehicles and appliances. Reference to use of vehicles with higher fuel efficiency and lower emissions, and support for hybrid, flex-fuel for electric vehicles.
Argentina			Measures will be taken in transport and energy sector to reduce emissions but does not specify how.
Bahamas			<ul style="list-style-type: none"> · Minimum of 30% renewable in the energy matrix by 2030. · Mentions fuel switching and the deployment of fuel cell technologies.
Barbados			<ul style="list-style-type: none"> · Renewable energy: contributing 65% of total peak electrical demand by 2030. · GOB is investing in alternative vehicles and fuels such as compressed natural gas, liquid petroleum gas, ethanol, natural gas, hybrid and electric and encouraging their adoption through tax incentives.
Belize			85% renewable energy by 2030 by implementing hydropower, solar, wind and biomass, and reduction of transmission and distribution losses.
Bolivia			Increased participation of renewable energy to 79% by 2030 from 39% in 2010.
Brazil			Expanding the use of renewable energy sources other than hydropower in the total energy mix to between 28% and 33% by 2030.
Chile			20% of the energetic matrix should be made up of non-conventional renewable energies by 2025.
Colombia			The scope includes the sectors of energy and transport but does not specify any particular target.
Costa Rica			<ul style="list-style-type: none"> · Achieve and maintain a 100% renewable energy matrix by 2030. · (i) Greater use of electric transportation, both public and private (ii) intercity electric train (iii) investment portfolio in sustainable transportation.
Cuba			Increase renewable energy in the power matrix with 2.144 MW of biomass, solar, wind and small hydro.
Dominica		 (hybrid)	<ul style="list-style-type: none"> · Three separate mini-grids, estimated at 500kW each, comprising 500kW of wind energy and 200kW of PV, with bio-diesel generator back-up for each, are proposed. · Reduce transport emissions in 16.9% from BAU scenario by 2030 (i) Introduce a policy that, all government vehicles, at their time of replacement, will be replaced by hybrids vehicles; (ii) Introduce market-based mechanisms to motivate the private sector to buy hybrid vehicles when replacing current vehicles.
Dominican Republic			No specific mention to renewables or transport sector. Mentions energy as one of the sectors addressed.
Ecuador			<ul style="list-style-type: none"> · Boost solar and wind energy · Development of electric tramway and subway
El Salvador			<ul style="list-style-type: none"> · (i) Boost renewable energy, (ii) development of geothermal energy conditioned to financial support (iii) development of a target for RE to achieve by 2025 that is no less than 12% of total energy generated in 2014. · Expand tram system.

Country			Comments
Grenada	●		10% RE in power sector by 2025.
Guatemala	●	●	<ul style="list-style-type: none"> · 80% RE in the power sector by 2030 from a base of 69.72%. · Develop fiscal incentive programs and subsidies schemes for the use of clean energy in private and public transport.
Guyana	●		Develop a 100% renewable power supply by 2025.
Haití	●		Increase by 47% the participation of RE in the power system.
Honduras			No specific mention to renewables or transport sector. Mentions energy as one of the sectors addressed.
Jamaica	●		Increasing the share of renewable sources of energy in its primary energy mix to 20% by 2030.
Mexico			Mentions energy as one of the sectors addressed, with transport as a sub sector.
Nicaragua	●		Reach 60% renewable energy in the power sector by 2030 from a 53.5% base.
Panama	●	●	<ul style="list-style-type: none"> · Increase by 30% non-conventional RE by 2050. · Electrification of transport by expansion of subway system.
Paraguay	●		Increase RE consumption by 60%.
Perú			Energy mentioned under water sector. No mention of RE or transport.
Saint Kitts and Nevis	●		Increase the use of renewable energy sources by 50%.
Saint Lucia	●	●	<ul style="list-style-type: none"> · 35% Renewable Energy Target by 2025 and 50% by 2030 based on a mix of geothermal, wind and solar energy sources. · Reduction of excise tax and duty for importers of fuel efficient vehicles and alternative energy vehicles.
Saint Vincent and the Grenadines	●	●	<ul style="list-style-type: none"> · (i) Country's proposed geothermal power plant (planned to be completed in 2018) will generate approximately 50% of the national annual electricity consumption needs (ii) enabling and encouraging the installation of small-scale photovoltaics (PV) in the private and public sectors. · Policies to reduce the import duty paid on low emission vehicles.
Suriname	●		Through existing efforts and with funding for implementation, Suriname is keen to continue to transition its energy sector to ensure it stays above 25% renewable by 2025.
Trinidad & Tobago	●		Mentions RE as a means to reduce emissions.
Uruguay	●	●	<ul style="list-style-type: none"> · Ring closure of the high-voltage power supply network throughout the country, to support decentralized electrical power generation from renewable sources: additional 215 km installed by 2025. · (i) Further adoption of electric vehicles in public transport: 110 buses and 550 taxis by 2025. (ii) Further adoption of utility electric vehicles: 900 units by 2025. (iii) Replacement of 5% of the fleet of light private vehicles with electric vehicles by 2025. (iv) Network of electric vehicle charging stations throughout the country and extension of the Electrical Route to the main roads across Uruguay. (v) Fast charging network: installation of fast charging stations in direct current.
Venezuela	●		Development of two large wind parks.

Source: NDC Registry <https://www4.unfccc.int/sites/NDCStaging/Pages/All.aspx>

Since the presentation of the NDCs several countries have strengthened their commitments in the renewable energy and electric transport sectors in their National Energy Plans, Decarbonization Plans and/or in other energy and environmental policy instruments (see chapter 9). The goal of the study in this respect is to support countries efforts, for the next round of NDCs, to consider the coupled benefits of addressing these two sectors conjunctively to further advance their climate goals.

The rationale for the current report is to increase awareness on opportunities to reach zero-carbon emission goals and help expand the NDC's ambitions in the region, providing examples of practical actions and data supporting the transition towards an electrified, renewable-power driven economy. The report should also be a continuation of the previous document, published in 2015 (UNEP Zero Carbon Latin America, 2015), and in anticipation of additional analytical efforts.

Data sources and methods

The report largely relies on existing information in the technical literature and industrial data. Energy sector information was obtained through ENERDATA and British Petroleum (BP) statistics. Information on land use was obtained from the Food and Agricultural Organization database (FAOSTAT) and the Global Forest Watch (GFW) created and maintained by World Resources Institute (WRI). Information on location and capacities of existing power plants was retrieved from Resource Watch (RW) also created and maintained by WRI. For purposes of the reference or BAU scenario, the Global Change Assessment Model (GCAM; GCAM 5.1.3: <http://www.globalchange.umd.edu/gcam/>) created and operated by the Joint Global Change Research Institute of the Pacific Northwest National Laboratory was used. The estimates of LCOEs, LCOTs and other costing data was calculated through the LAC version of the Greenhouse Gas Abatement Cost Model (GACMO), created and managed by the UNEP/Danish Technical Institute partnership.



CHAPTER 2

CURRENT STATUS AND PROJECTIONS OF THE POWER AND TRANSPORT SECTORS IN THE LAC REGION UNDER A BAU SCENARIO

This chapter summarizes the supply and demand for electricity from these sectors of the regional economy. It also looks at the carbon intensity of power generation and for transport and the carbon emissions by mode. Finally, it concludes with projections of future demand and carbon emissions by 2050, under a BAU scenario, as defined under the GCAM modeling framework.

 Panama City, Panama
Photo by Levi Morsy, Unsplash

2.1 Power sector

Recent trends

Demand for electricity is growing at a moderate pace, driven by demographics, gross domestic product (GDP) increase, improved access, and increases in the overall standard of living.

 **LAC's Power generation in 2018 is estimated at 1.57 PWh,⁵⁶ which represents a 7% increase since 2012.**

However, it has been relatively flat since 2016. This level of generation is equivalent to about 6% of global electricity generation (26.6 PWh),⁵⁷ for a region with 8.5% of the global population and 6.7% of the global GDP.

Table 1 brings together, through key indicators, the current trends in the power sector. Electricity has maintained its approximate share in the primary energy demand in the region. Nevertheless, the composition of the power generation matrix is changing. There has been a substantial increase in installed capacity of non-conventional renewables.⁵⁸

Table 1. Recent dynamics of change in the region's power sector

	2012	2018	Remarks
Regional GDP in Trillion (constant 2010 US\$)	5.74	6.12	Moderate increase in the value of production of goods and services.
Total Primary Energy Demand (PWh e)	10.20	10.33	Overall energy demand increasing at a much lower rate than economic output, indicating improved energy efficiency.
Total Electric Power demand (PWh)	1.46	1.57	Slight increase of electric share in total primary energy demand.
Installed Nominal Capacity Power Sector (GW)	327	405	Power matrix continues to grow in tandem with anticipated demands while providing a margin of safety in operations.
Hydropower capacity (GW)	155	185(*)	There were few large hydropower installations coming on stream but their relative contribution to the total is falling as non-conventional renewables have increased share.
Non-conventional renewables (GW) and as share of total nominal capacity.	21 6%	48 (*) 12%	Falling generation costs and a conducive policy environment have contributed to more than doubling of capacity of non-conventional renewables since 2012.
Carbon intensity of power sector (tCO ₂ /GWh)	280 (**)	243	The sector continues to reduce its low carbon footprint per MWh, from an already low base as a result of the high and increasing share of renewables in the power matrix.
Annual per capita power consumption (MWh/person)	248	251	Region maintains low per-capita power demand.
Electricity use per unit of PIB (MWh/1000 USD PPP, 2018)	320	290	Electricity intensity of economic output continues to decrease.
Energy access (% of population with access to electricity)	96.5 (***)	97.7 (***)	Very high access compared to other regions of the developing world, access continues to improve. Coverage in urban areas exceeds 99%.
Share of electricity in the energy use in transport (%)	0.0007	0.0067	Transport relies on fossil fuels with some participation of ethanol and biodiesel; there is a large relative increase in electricity use, but from a very low base.

Source: based on data from BP Stats, 2013 & 2019; Enerdata; WEC, 2018, IRENA, 2019; (*) data for 2017; World Bank, 2019; (**) data for 2014 from GACMO, 2019. (***) data for 2012 and 2016 from: <https://tradingeconomics.com/latin-america-and-caribbean-developing-only/access-to-electricity-percent-of-population-wb-data.html>; GDP data from: <https://data.worldbank.org/indicator/NY.GDP.MKTP.KD?end=2018&locations=ZJ&start=2012>; accessed August 2019

56. Data from GACMO, accessed July 29, 2019.

57. BP Statistics, 2019.

58. Non-conventional renewables groups all renewable energy sources other than hydro, and includes solar, wind geothermal, marine and biomass.

Specifically, the gains for solar and wind have been the result of lower equipment, operation and management costs (discussed in more detail in Section 4); technological and efficiency improvements, including capacity to store energy; awareness of the negative impact of fossil fuel-driven power plants on the environment; and more forceful policy commitments, in many of the countries in the region.⁵⁹ The net result has been a further reduction in the carbon intensity of the sector, making electricity generation in LAC one of the least carbon-intensive worldwide.⁶⁰

In fact, measured in terms of intensity of use in economic activity, electricity has continued a long-term trend toward improved efficiency, reaching in 2018, 290 MWh/US\$1000 PPP. This is well below the average for developing nations such as China, or the entire Africa and Asia regions. The region is efficient in its use of power and it is becoming increasingly so. Also, overall, the region continues to have a modest per capita electricity consumption (2.5 MWh/person year) but a relatively high access, with close to 98%

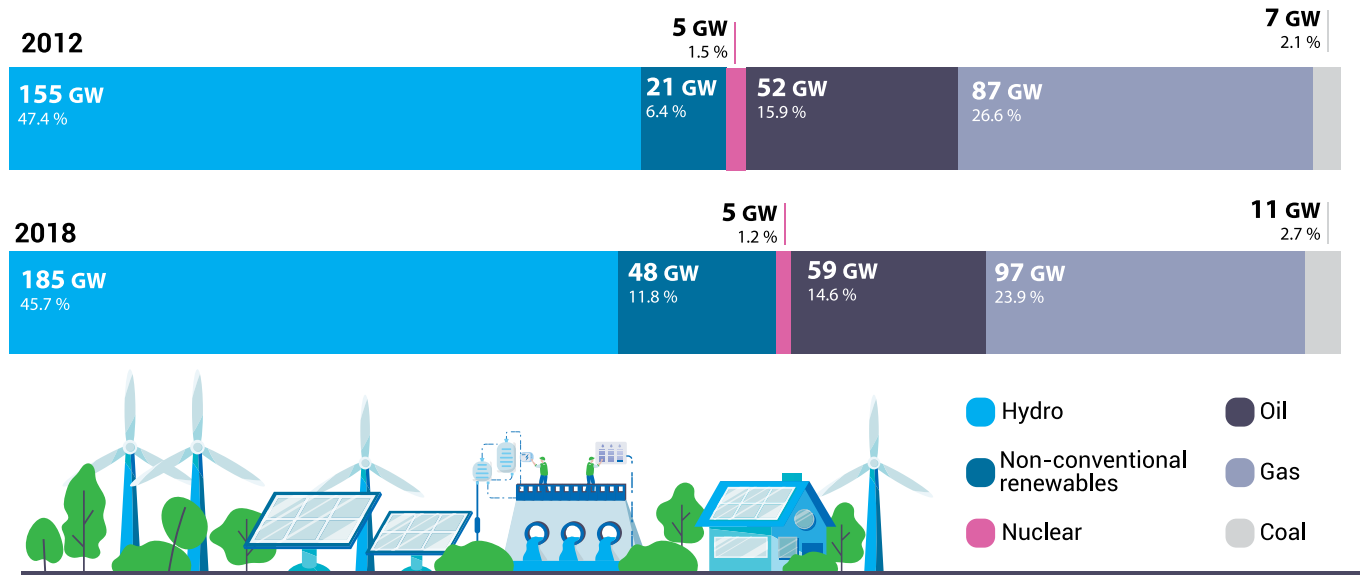
of the population connected to the grid. Additional energy efficiency efforts have a good starting point in the region. Finally, the share of electricity in energy use in transport despite vigorous growth, continues to be relatively modest.

In summary, renewable energy options are gaining in deployment and market share. The use of power per unit of economic output shows increased efficiency, the per capita use is low and energy access is higher than the world average (88.8%)⁶¹ and comparatively high with respect to most developing regions.⁶²

Sources of electricity generation and its carbon footprint

Currently, most of the installed capacity is in hydropower (46%). But, since 2012 the installed capacity for non-conventional renewables, has doubled its participation in the regional matrix to 11.8%. Renewable energy, including hydropower, accounted for almost 58% in 2018 (Figure 1).

Figure 1. Evolution in power installed capacity, 2012 to 2018



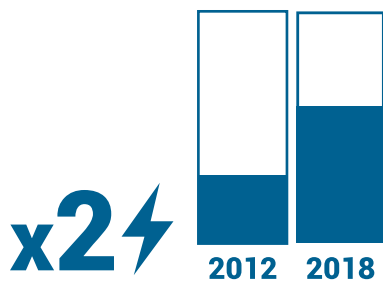
Source: from data in ENERDATA, accessed August 2019.

59. A review of policy frameworks can be consulted in UNEP Zero Carbon Latin America, 2015.

60. A few countries in other regions have lower carbon footprints, but LAC has the lowest footprint worldwide.

61. Based on data from: <https://data.worldbank.org/indicator/eg.elc.accs.zs>; accessed August 2019.

62. Access to electricity is 43% in Africa, 79% in South Asia and 87% in East Asia. (<https://www.brookings.edu/blog/africa-in-focus/2019/03/29/figure-of-the-week-electricity-access-in-africa/>;))



Since 2012, the installed capacity for non-conventional renewables, has doubled its participation in the regional matrix to 11.8%.

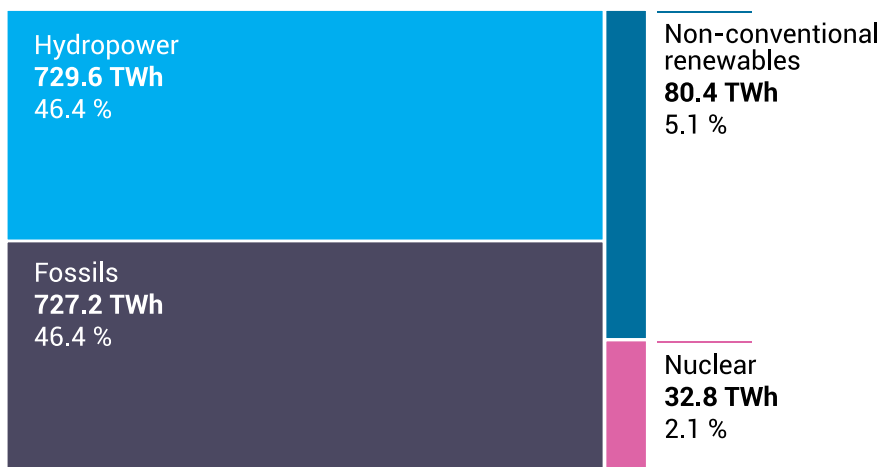
Renewable energy, including hydropower, account for almost 58% of the total in 2018.

Some countries in the region have reached or are in the process of attaining 100% renewable power and more are aligning actions and policies toward this goal. Non-conventional renewables are increasingly displacing fossil fuels in the electricity sources share. The share in total generation can be seen in Figure 2.

The new capacity structure has led to a reduction in CO₂ emissions by 15%. Figure 3 shows their recent evolution, emissions peaked in 2015. Given the momentum of renewable alternatives, this is a trend unlikely to be reversed. The energy transition has already started.

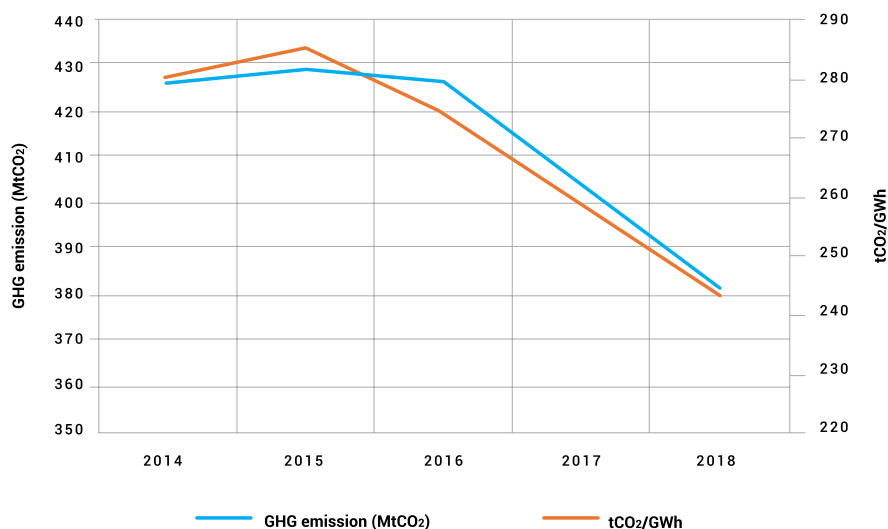
The increase in participation of renewables has clipped the carbon intensity of the sector, from an already low starting point of 285 tCO₂/GWh in 2015 to 243 tCO₂/GWh in 2018⁶³ making the region a world leader in low-carbon power generation. An efficient and low carbon matrix is a strong argument to electrify

Figure 2. Power generation, by source, 2018



Source: from data in ENERDATA, accessed August 2019

Figure 3. Evolution of GHG emissions from the power generation sector, 2014-2018



Source: from data in ENERDATA, accessed August 2019.

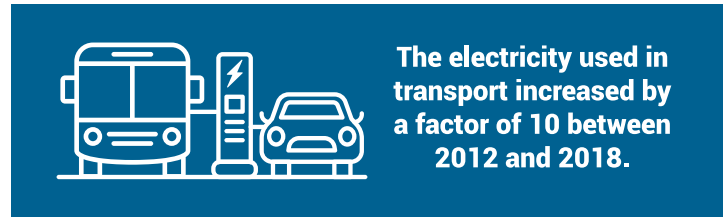
63. GACMO database accessed July, 2019

other economic activities, like transport. It offers opportunities to couple the transition of other sectors of the economy towards complete decarbonization. The region, in its power sector, has a good launching pad towards full decarbonization.

However, contrary to the overall regional situation, the Caribbean's main source for electricity continues to be fossil fuels at 82% (McIntyre A., et. al., 2016), with extremely high electricity prices and all countries being energy importers except for Trinidad and Tobago. These high electricity prices are also the result of a costly distribution network supplying multiple points, each with relatively modest demands. At the same time, substantial solar and wind resources are available, which makes an argument for the Caribbean to transition to a decarbonized power sector.

Electricity is used in various degrees in the residential and commercial sectors, in part, addressing a growing demand for space cooling, but mainly for cooking, refrigeration, lighting, and water heating, and in the industrial sector for heating, cooling and pumping; but,

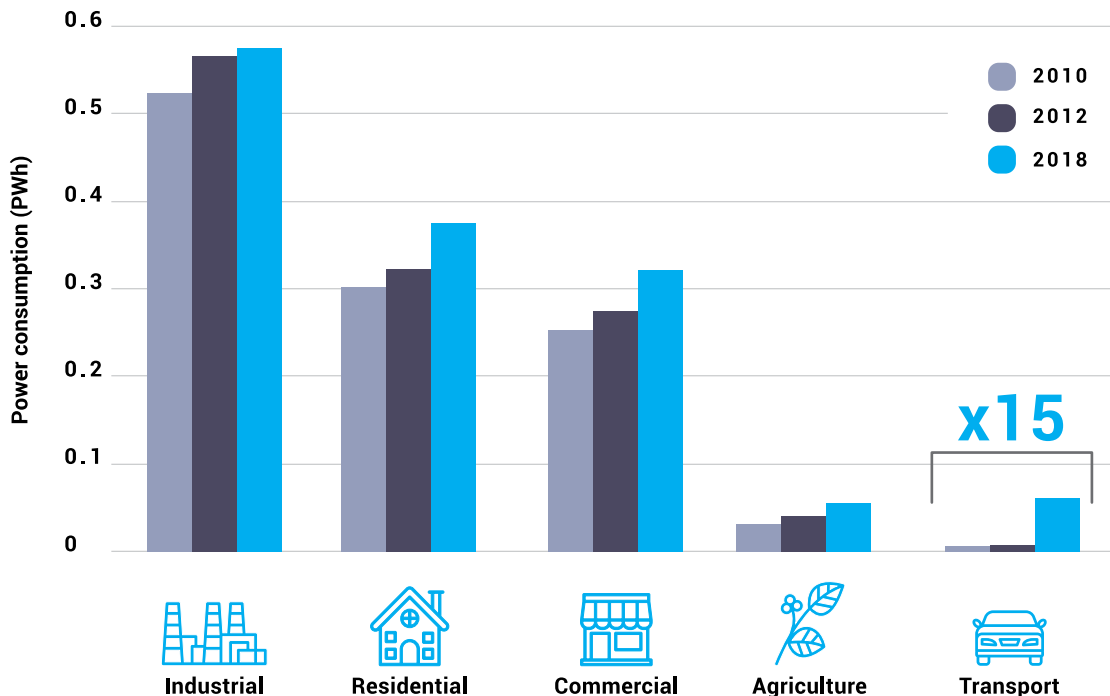
only very marginally in the transport and agriculture sectors (Figure 4). The electricity used in transport did increase by a factor of 10 between 2012 and 2018, reflecting growing deployment of subway, light-duty and passenger electric vehicles.



Country typology

Most of the region's supply and demand, as well as its carbon footprint is concentrated in a few nations with a significant share of renewables. The countries listed below account for 83% of the total power generation and constitute a target list for a country-based characterization. There is a subset of countries that is already at, or very close to, 100% renewable in their power generation mainly as a result of purposeful policies to decarbonize (Uruguay, Costa Rica).

Figure 4. Evolution of electricity use, by sector, 2010-2018



Source: GACMO accessed August, 2019; based on overall power production of 1.57 PWh, and consumption 1.31 PWh in 2018.

A second subset has a majority of renewables in its power sector, based on their historical reliance on hydropower (the Andean Nations, Brazil). There is one additional group with a heavy dependence on fossil fuels (Argentina, Mexico, Panama), with one country (Chile) already on a stated decarbonization path. Jamaica is included as a representative sample of the conditions in the Caribbean region. Table 2 summarizes the overall energy demand, power generation and carbon footprint of the power sector in these countries. Besides Uruguay and Costa Rica, Brazil, Colombia and Peru are among the sampled countries with the lowest carbon intensities. Mexico, Chile and Jamaica have the largest intensities; however, Chile has embarked in an ambitious power sector transition to renewable sources.

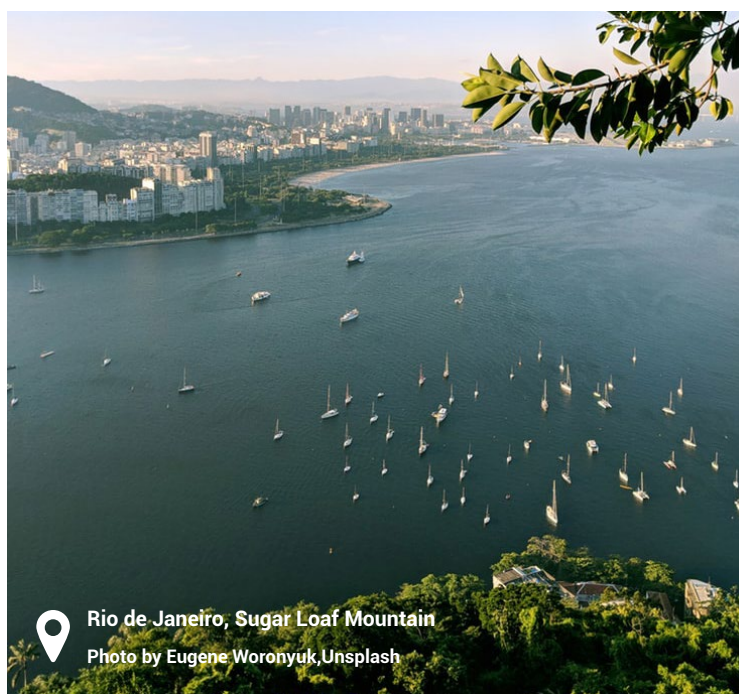


Table 2. Country primary energy demand and electricity generation, 2018

Country	Primary energy demand (TWh e)	Total power generation (TWh)	Share of electricity generation in energy demand (%)	Share of renewables in electricity generation (%)	CO ₂ emissions (Mt)	Carbon Intensity of the power sector (T CO ₂ /MWh)
Argentina	992	147	15	31	41.4	0.28
Brazil	3388	588	17	83	47.5	0.08
Chile	447	80	18	47	34.4	0.43
Colombia	449	77	17	76	10.6	0.14
Costa Rica	58	9	16	100	0	0
Jamaica	34	3	9	0	2.0	0.67
Mexico	2191	332	15	16	129.7	0.39
Panama	55	8	14	25	2.3	0.28
Peru	278	54	19	60	9.6	0.17
Uruguay	59	9	15	95	0.1	0.01
Total Region		1570				

Source:⁶⁴ ENERDATA 2019, BP Statistics 2019, Index Mundi 2019, IRENA 2018, DGE 2019.

64. Primary energy demand and total power generation based on data presented in ENERDATA, 2019 and BP Statistics, 2019, except for Uruguay and Costa Rica, power generation based on data presented in Index Mundi, (<https://www.indexmundi.com/g/g.aspx?v=81&c=bb&l=en>) accessed July, 2019 and ENERDATA. Power generation in Panama is for 2015. Share of renewables in Panama, as reported by IRENA in https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/May/IRENA_RRA_Panama_2018_En.pdf; otherwise, data on share of renewables from Global Energy Statistical Yearbook 2019, <https://yearbook.enerdata.net/renewables/renewable-in-electricity-production-share.html>; accessed in July, 2019, except Peru from DGE, 2019. Emissions are based on fuel consumption, average efficiencies of power plants as reported by USEIA (<https://eia.gov>) and emission factors used in GACMO.

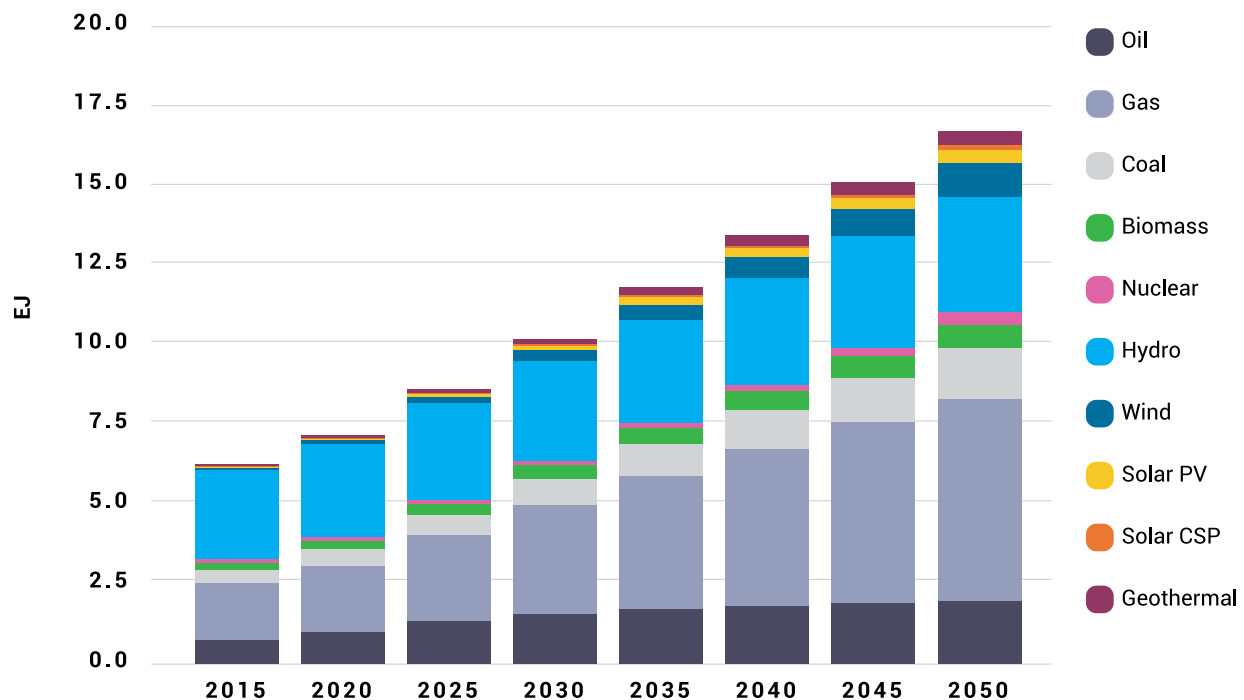
Future power demand

Growth in regional electricity demand is expected to be driven by increases in standard of living, demographics, GDP, and urbanization. For example, under the IIASA's GEA (International Institute for Applied Systems Analysis, Global Energy Assessment) projections, demand for power in the region would triple by 2050 to 18 EJ. For purposes of this analysis, the BAU scenario is based on the reference scenario from the Global Change Assessment Model.⁶⁵ The GCAM reference scenario reflects BAU conditions, in which social, economic and technological trends do not differ markedly from historical patterns and with no additional policies or measures to those already in place until 2010 (calibration year) to mitigate greenhouse gas emissions.⁶⁶ A summary description of the model

and its capabilities can be found in Calvin et al., 2018. In the GCAM 5.1.3 (Latin America and the Caribbean – LAC – model version used here), the LAC region is represented by eight model regions: Argentina, Brazil, Central America and Caribbean, Colombia, Mexico, Northern South America, Southern South America and Uruguay. GCAM outputs from these eight regions were aggregated to generate projection for the region. The 2050 projected electricity generation in these geographies under the GCAM BAU scenario is included in Annex 1.

Under the GCAM BAU scenario, the total projected regional power demand reaches 16.7 EJ by 2050, almost tripling (x2.7) 2015 electricity demand (Figure 5). Fossil sources would generate about 60% of the electricity by mid-century, with natural gas tripling the electricity delivered in 2015.

Figure 5. Projected electricity generation, by technology, under GCAM BAU,⁶⁷ 2015-2050 (net addition)



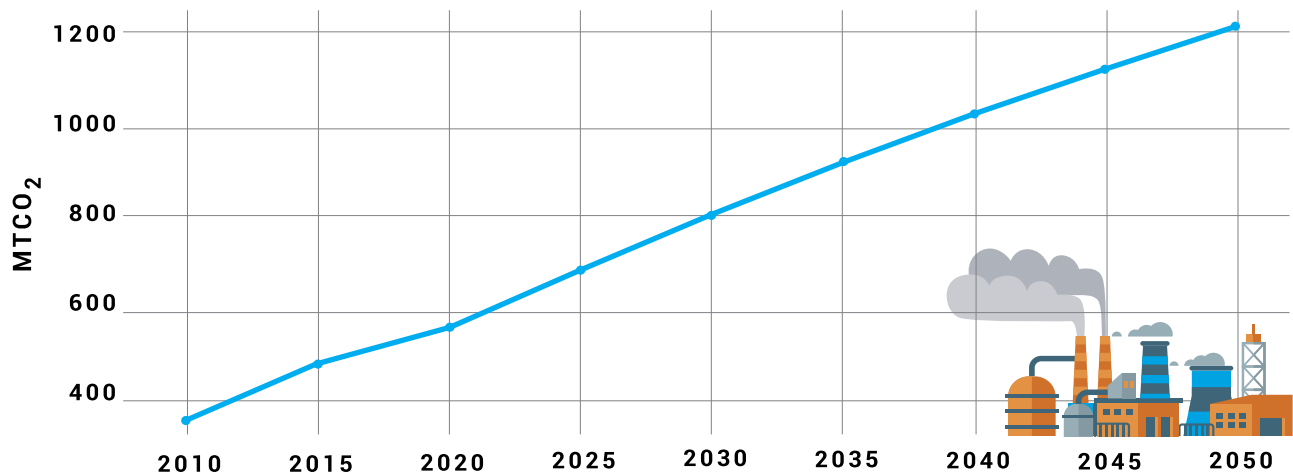
Source: As projected under GCAM BAU outputs, August 2019.

65. A description of the GCAM model (GCAM 5.1.3: <http://www.globalchange.umd.edu/gcam/>) and on-line documentation are available at: <http://jgcri.github.io/gcam-doc/>;

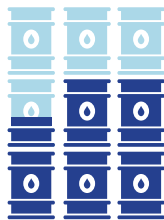
66. The reference scenario assumptions for socioeconomic conditions are consistent with the SSP2 pathway. GCAM base year for its BAU scenario is 2010. Therefore, it does not fully capture the recent changes in the composition of the generation plants in the region. However, it is indicative of a potential future where fossil-fuel based capacity continues to operate and provides details on the emissions that would be associated with such scenario. The GCAM BAU is also useful to provide insights on the implications in terms of capital outlays that could be compared with the intervention scenario.

67. The PV fraction includes utility size and distributed capacity.

Figure 6. Projected emissions from the power generation sector, under the GCAM BAU scenario, 2010-2050



Source: As projected under GCAM BAU outputs, August 2019



BAU scenario: Fossil sources generate about 60% of the electricity by 2050.

Non-conventional renewable sources and hydro would substantially increase in capacity but only represent 47% of the total capacity installed. Climate impacts on installed hydropower facility are not considered. Most of the new capacity would still be provided by natural gas.

Consequently, emissions would increase 2.4-fold from about 500 million tons of CO₂ in 2017 to 1,200 million tons by mid-century (Figure 6).⁶⁸ This is a future that cannot be afforded if the region is to meet the goals of

the Paris Agreement. The associated investments⁶⁹ to keep this level of electricity generation were also calculated using GCAM. Under the BAU scenario, the investment in generation capacity required for the entire region is estimated at US\$ 943 billion (2010)⁷⁰ (Figure 7, this is equivalent to US\$ 1083 billion (2018)).



Investment in BAU scenario: US\$ 1083 billion (2018).

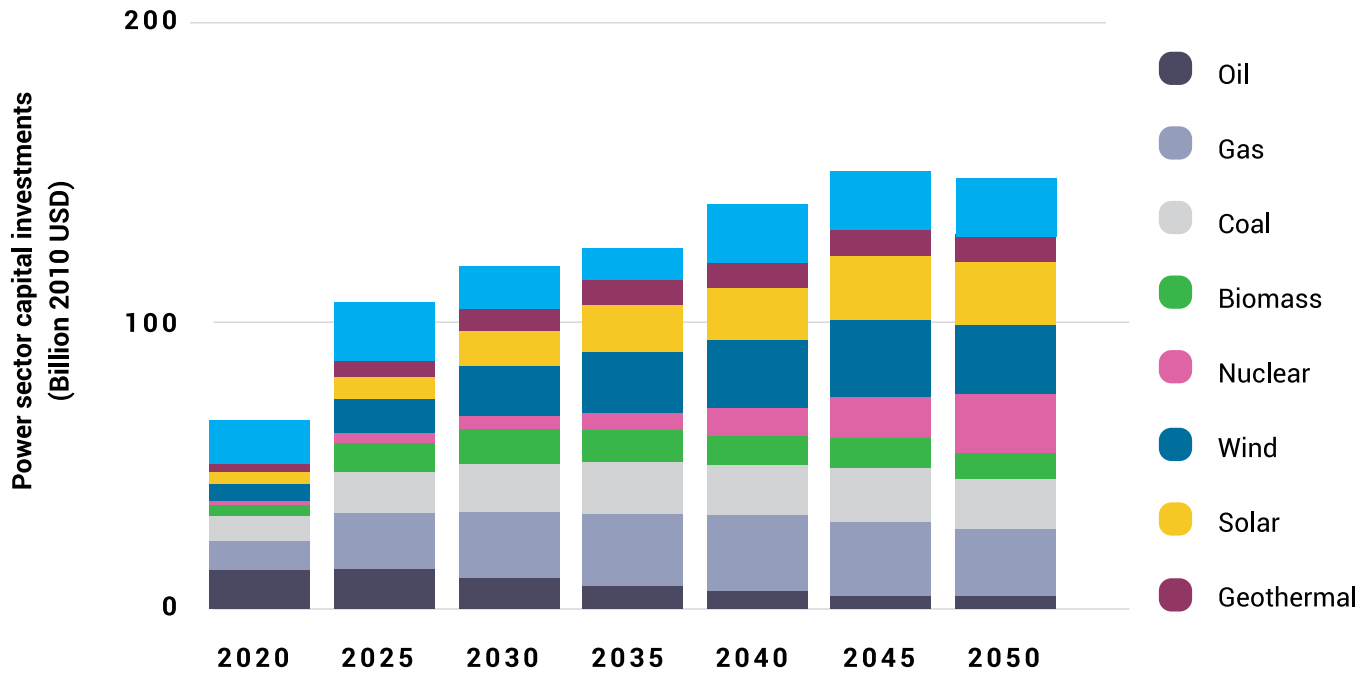
Out of this total, investments in fossil fuel power capacity would result in US\$ 365 billion 2010 (US\$ 420 billion (2018)), of which 70% corresponds to new coal and gas power investment. This would be a major outlay of capital, on a technology that faces strong competition and sunseting pressure in order to meet climate goals.

68. GCAM overestimates the 2017 emissions of the power sector by about 20% when compared with data from ENERDATA, compiled through GACMO.

69. The investment amounts only reflect investments in installed power capacity.

70. GCAM capital estimates are based in 2010 US\$. For purposes of homogeneity these estimates have been adjusted to 2018 US\$. The capital cost estimates only include the cost of generation capacity. Transmission and distribution costs were not calculated and are not included. The inference is that there is no appreciable difference in transmission costs between the two scenarios using a smart grid approach.

Figure 7. Annual capital investment in the power sector, by 5-year periods, under GCAM-BAU scenario, 2020-2025



Source: As projected under GCAM BAU outputs, August 2019

2.2 Transport sector

Recent evolution of the transport sector

Although electric transportation has evidenced a slow-paced adoption in the region, the electricity demand in the transportation sector has multiplied by 10-fold in the last 6 years. The decarbonization of the transportation sector has moved more towards improving energy efficiency and carbon emissions standards. However, it remains the sector of the economy with the highest fossil-energy use and, therefore, leading in terms of fossil-fuel related emissions (15% of all regional GHG emissions in 2018).⁷¹ Factors contributing to the increase in the use of energy include a fast motorization rate; an expanding urban population coupled with poor urban planning processes; more movement of cargo

for domestic and export markets; and improving living standards. The regional transport sector includes a large fleet of road transport vehicles, where cargo and passenger, participate in approximate equal parts in energy use and GHG emissions. It also includes a significant railroad fleet, concentrated in a few countries (Brazil, Chile, Colombia, Mexico), as well as marine (fluvial) and air transport components.⁷² Transport is a complex sector of the economy attending to varied demand for services, with fleets that respond to different drivers.⁷³ Efforts to increase electric mobility in each segment will require different technologies, approaches, and policy tools and will face different economics. The dynamics of change of the sector at large and its impact on the carbon footprint are summarized in Table 3. The table includes energy use and carbon footprint of the current fleet, except for aviation.

71. Compilation in GACMO, accessed August 2019, using data from ENERDATA

72. The overall road transport fleet, cargo and passenger fleet in the region for the countries of interest is summarized in the annex 5.

73. The development and maintenance of road, rail and waterway infrastructure is also very important to the efficiency of the sector.



Table 3. Recent dynamics of change in the transport sector and implications for its carbon footprint

Indicator	2012	2018	Driver	Impact on emissions from transport sector
Energy use in transport (EJ)	8.77	9.08	Economic growth, urbanization	Continuing demand for transport services, high motorization rates, expansion of cargo has increased carbon footprint.
Urbanization (% of total population in urban areas (*))	78.6	80.7	Availability of services and job opportunities in urban areas.	Continuing high rate of urbanization concentrates the carbon footprint from passenger and light cargo fleets. It has also resulted in congestion. But, offers opportunities for wholesale changes in metropolitan areas.
Motorization rates (vehicles per 1000 inhabitants (**)) (automobiles)	275 (Mex) 250 (Bra) 314 (Arg) 130 (Pan)	297 (Mex) 294 (Bra) 316 (Arg) 208 (Pan) ⁷⁴	Growth of middle class, high rates or urbanization.	Growing motorization rates are increasing per capita emissions of transport sector. Resulting congestion reduces fuel efficiency and increases emissions per passenger kilometer.
Estimated modal share of public transport services (% passenger trips)	Between 30 to 40% depending on each urban area.	Stagnant	High Institutional and governance transaction costs.	High, but stagnant participation of surface public transport systems in passenger transport is limiting potential impact of BRTs and other systems on efficiency of use of public space and on reduction of emissions per passenger.
Estimated age of cargo fleet (years)	13 to over 20 years (see Table 6)	13 to over 20 years (see Table 6)	Atomization of fleet ownership and high cost of equipment discourages technology upgrades in the absence of benefits from emission reductions	Obsolescence of rolling stock in cargo transport and lax regulations maintain high rates of emissions per ton kilometer.
Electricity use in rail transport (%)	Low	Low	Grid coverage is limited.	High participation of diesel engines in rail transport.
GHG emissions by transport sector (MTCO ₂)	665	604	Improved energy efficiency in fleet.	Increases in rate of motorization are being compensated by improvements in energy efficiency of fleets, high fuel costs.

Source: Data from GACMO and Enerdata, unless indicated. (*) <https://population.un.org/wup/Download/>; accessed August 2019: 2010 and 2018 data. (**) data for Mexico Brazil, and Argentina in 2010 (Daniela Roque and Masoumi H., 2015).

74. Provincia de Panama: 1992-2005



Passenger transport

Light-duty vehicles

While the rate of ownership is still well below that of countries in Europe and the U.S., the fleet of automobiles in the region is growing by six million units per year (Lustic, N., 2019). The growing fleet is adding to already congested public spaces in urban areas; contributing to increases in the pollution load in urban airsheds; and, to an increase in GHG emissions per passenger km.⁷⁵

The rise in motorization has been continuous, prompting the adoption of measures by city administrators to strengthen or add restrictions to passenger traffic. These include curtailing access during peak traffic periods; designation of car-free zones; increases in parking fees and others. Still, evidence indicates that the congestion issue has not improved in a significant manner in most urban areas. As a result, the automobile fleet continues to produce most of the carbon footprint in urban areas, while delivering a minority of the passenger kilometers.



Public transport

The composition of transport modes in many urban areas in the region compare very favorably with use of public passenger transport use in cities in Northern Europe and elsewhere, mainly due to the use of public transport. In terms of passenger-kilometers, public transport has the highest share of all modes. The region has one of the largest bus fleets and the highest per-capita bus use in the world (UN Environment Programme, 2018).

Data in table 4 illustrates that the largest share of CO₂ emissions is linked to light-duty vehicles whereas public transport carries many more passenger kilometers. In cities like Buenos Aires, Mexico City and Lima, the majority of passenger travel is done by public transport, yet these cities experience severe traffic congestion. Clearly, an emphasis on public zero emission vehicles and non-motorized transport would not only reduce emissions from urban areas, both of global and local importance, but would also alleviate congestion and contribute to improvements in productivity and health indicators.

75. While electrification of transport in urban areas has the potential to displace emissions of GHG and airborne criteria pollutants, it will not per-se impact congestion and the resulting losses in productivity and quality of life of passengers. To address congestion, other complementary measures are required favoring increased use of public and non-motorized transport.

Table 4. Share of emission and passenger kilometer loads

Country	Annual Motorization rate (%) (2010-2020)	Automobile's share of GHG emissions in passenger transport (%)	Share of passenger kilometers in representative urban areas (%)		
			City		
Argentina	3.4	93	Buenos Aires	22 ⁷⁶	50
Brazil	4.2	92	Sao Paulo	46 ⁷⁷	37
Chile	5.2	83	Santiago	28 ⁷⁸	30
Colombia	7.9	77	Eleven cities	24 ⁷⁹	47 ⁸⁰
Costa Rica	5.3	66		n/a	n/a
Mexico	3.0	91	Mexico D.F.	36 ⁸¹	58
Panama	7.6	n/a	Panama City	n/a	n/a
Peru	9.5	71	Lima and Callao	22 ⁸²	54
Uruguay	4.5	n/a	Montevideo	26 ⁸³	36

 Automobiles and light vehicles

 Public transport (Buses, metro, light rail)⁸⁴

Source: data on motorization rates as reported in UN Environment Programme, 2018; emissions estimated on the basis of fleet composition, other sources as indicated in the footnotes.

Bus Rapid Transit System



The region is the world's leader in Bus Rapid Transit (BRT) systems.⁸⁵

There are now BRTs in 54 cities in Latin America.⁸⁶ These include 99 BRT routes operating with an extension surpassing 1300 kilometers in 10 countries including Argentina, Brazil, Chile, Colombia, Mexico and Peru (see table 5). According to Global BRT data, Latin America's BRT system transports almost 21 million people per day, accounting for 62% of passengers moved by BRT worldwide.⁸⁷ At least three

BRTs are now including or about to commission electric buses (Santiago, Bogota and Curitiba) in their core or feeder routes. Santiago has launched the first 100% electric-fleet BRT⁸⁸ with 389 electric buses in total and Colombia has just acquired 379 electric buses for the TransMilenio. These cities have the largest electric bus fleets in the world after China. There are also 21 additional BRT systems in construction and 10 in expansion in the region.⁸⁹ The region has also been a pioneer in the development of the institutions, operational protocols and infrastructure for bus rapid transit systems, which could be further expanded or replicated in other cities to increase the overall impact on mobility and emissions.

76. Centro Tecnológico del Transporte de Argentina (2013).

77. Only motorized transport (2017): <https://g1.globo.com/sp/sao-paulo/noticia/2019/07/03/anda-sp-super-rush-da-hora-do-almoco-concentra-o-maior-numero-deslocamentos-diz-pesquisa.ghtml>

78. (2012) <https://www.mtt.gob.cl/archivos/10194>;

79. <http://imaginabogota.com/academia/movilidad-en-bogota-bien-en-distribucion-de-modos-nos-falta-mucho-en-satisfaccion/>;

80. Figure just for Bogota.

81. 2017: <http://giitral.iingen.unam.mx/Estudios/EOD-Estadisticas-03.html>

82. WRI internal communication

83. WRI internal communication

84. Estimates of share of passenger-kilometers provided by WRI in private

communication. The balance left after accounting for automobiles, which includes shared rides and taxis, and public transport is provided by non-motorized transport.

85. BRTs or Bus Rapid Transit Systems is a bus-based transport system with dedicated transit lanes designed to improve the occupancy of public space and deliver improvements in mobility of passenger transport in cities.







86. <https://brtdata.org/>; consulted August 2019

87. <https://brtdata.org/>

88. <https://www.electrive.com/2019/10/16/chile-launches-latin-americas-first-electric-bus-corridor/>

89. (<https://brtdata.org/>); consulted August 2019

Table 5. Overall characteristics of BRT systems in the region

 BRT	 Number of routes	 Length (km) [corridor]	 Daily demand (Million passengers per day) [corridor]	 Average cost (US\$ million per km) [corridor]	 Total fleet (number of vehicles)
Argentina	9	59.80	1.73	-	-
Brazil	27	420.71	2.73	39.38	3966
Chile	9	81.15	0.33	-	-
Colombia	26	229.82	3.34	20.09	2006
Ecuador	6	116.80	1.05	-	582
El Salvador	1	6.40	0.27	6.60	67
Guatemala	2	24.00	0.21	-	130
Mexico	14	307.70	1.97	23.24	647
Peru	1	26.00	0.70	-	487
Venezuela	4	42.20	0.24	-	45
Total	99	1314.58	12.4	89.31	3966

Source: BRT data base, consulted, August 1st, 2019.

Cargo transport

Cargo transport is vital to the economy of LAC, enabling commerce and access to services. Cargo in the region is moved through trucks, rail, vessels and airplanes. The infrastructure involves highways, railways, cargo depots, ports and exchange nodes with many operators and distributors.

Trucks

About 70% of cargo transport in the region is carried by trucks (Barbero J.L., 2017). There is a continuous growth in the fleet of trucks of all sizes, and the kilometers travelled by road, in direct response to increases in economic activity and the demand for exports of food, fiber, metals and minerals from the international and domestic markets. Segments of the fleet present different organization and equipment characteristics and different fuel and emission profiles, making a detailed assessment challenging. Still, some characterizations can be made from a few studies (IDB, 2017, IIRSA, 2015). Most of the rolling stock of the region is in four countries (Argentina, Brazil, Mexico and Colombia) and is linked to the transport of agricultural commodities, minerals and manufactured products. Contributing to the high emissions profile of the truck fleet is its relative old age and low fuel efficiency (Table 6).



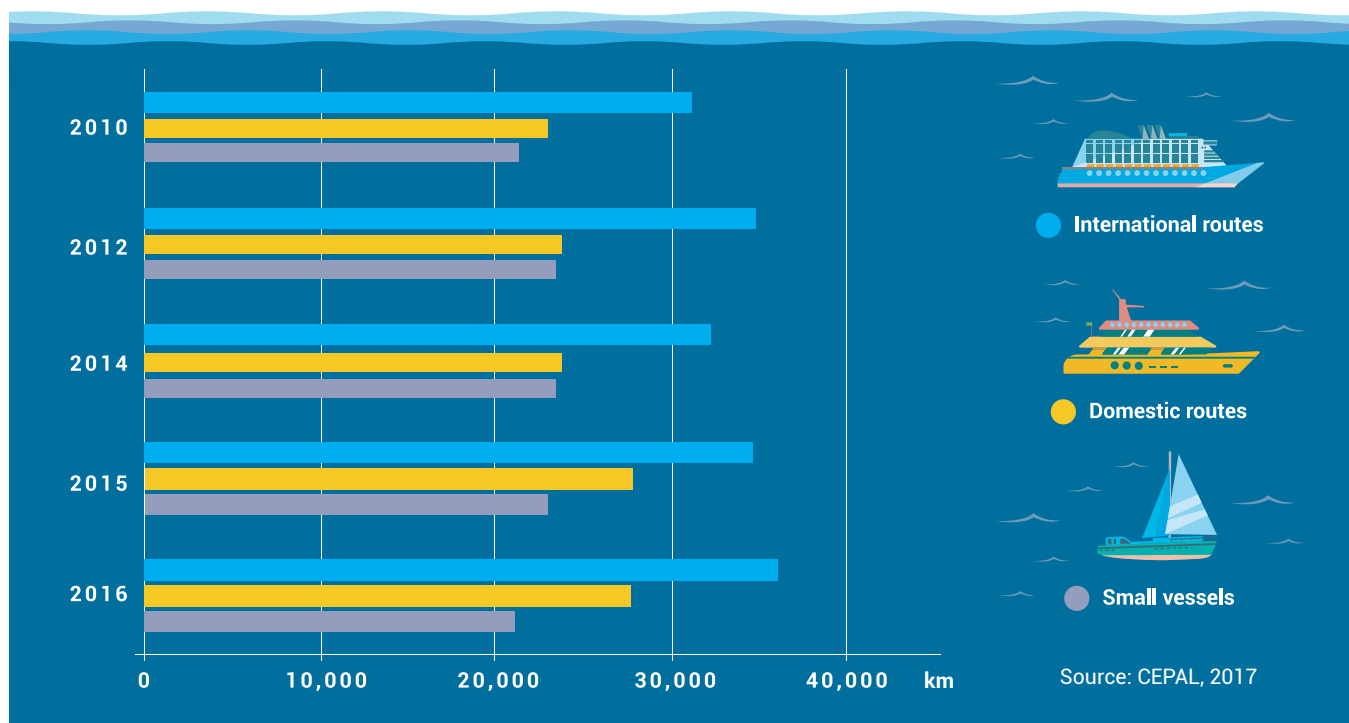
Table 6. Estimate of age and distance travelled per year for trucks fleet, by subregions, 2017

Region	Fleet Age (years)	Annual distance travelled (km)	Fuel Efficiency
Central America	Over 20	40,000	Low
Andean Nations	20	60,000	Medium
Southern Cone	13	80,000	High
Brazil	12	80,000	High
United States	Under 7	105,000	High

Source: IIRSA 2017 and author's estimates.

Fluvial and marine vessels

The region has a rich endowment of fluvial transport routes (concentrated in South America) as well as important maritime routes, anchored by the location of the Panama Canal and the export oriented economic activities in the region. For example, some countries in the region have very high densities of fluvial network comparable to countries in Europe.⁹⁰ In Brazil fluvial transport accounts for about the same distance travelled as for international transport (Figure 8). In Central America and the Caribbean, ocean transport is the principal mode of commercial trade.⁹¹

Figure 8. Fluvial transport in Brazil. Annual distance travelled (km), by type of vessel, 2010-2016.

90. Colombia, Peru, Argentina and Brazil have extensive, yet underutilized fluvial networks (see CEPAL, 2017 for a review of fluvial infrastructure in the region).

91. Estimate from <http://thecentralamericangroup.com> consulted, September 2019.

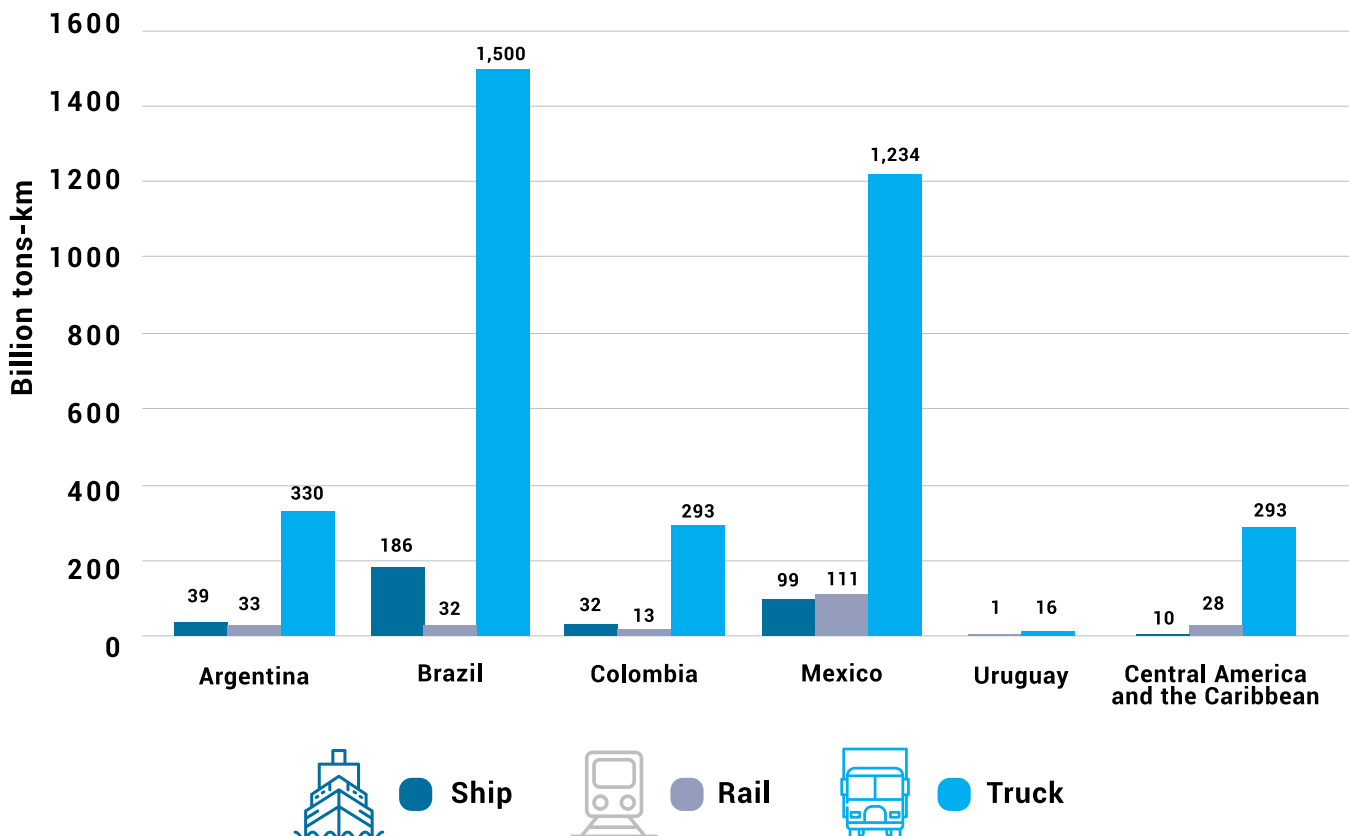
Recently, some countries in the region, including Colombia and Brazil have announced ambitious programs to better utilize fluvial transport in domestic cargo and passenger movements. Other countries, such as Ecuador and Peru are advancing in the modernization of the institutional frameworks for the sector.

In terms of carbon efficiency, marine and fluvial transport rank first compared to other modes (Figure 5). Regrettably, the cargo and passenger volume on these modes are relatively small, ranking third in terms of tonnage moved and fourth in terms of economic activity (CEPAL, 2017). There is insufficient information on total fluvial and marine fleets and their total share of cargo and passenger transport in the region. For the purposes of this report, statistics on the use of marine diesel have been used as a proxy to estimate the share of marine and fluvial transport in the overall carbon footprint of the transport sector.

Rail

Many of the indicators for rail cargo and passenger transport show inefficiency, low levels of safety, overstaffing and, in general, low productivity related to the age and poor maintenance of track and rolling stock. This is compounded with a loss of tracks under service in the region (Domenech and Montalvo, 2010). The average age of the region's locomotive fleet is estimated to exceed 40 years with some having been in active service for over 50 years (Frost and Sullivan cited by Rail Pro 2016). Railways are losing share in cargo and passenger transport, yet they are a more cost and carbon efficient alternative to trucks. There is significant potential to strengthen the rail system in the region to fully contribute to the demand for passengers and cargo in the future. An estimate of the total cargo movement for some countries is shown in Figure 9. Trucks are the predominant mode in cargo.

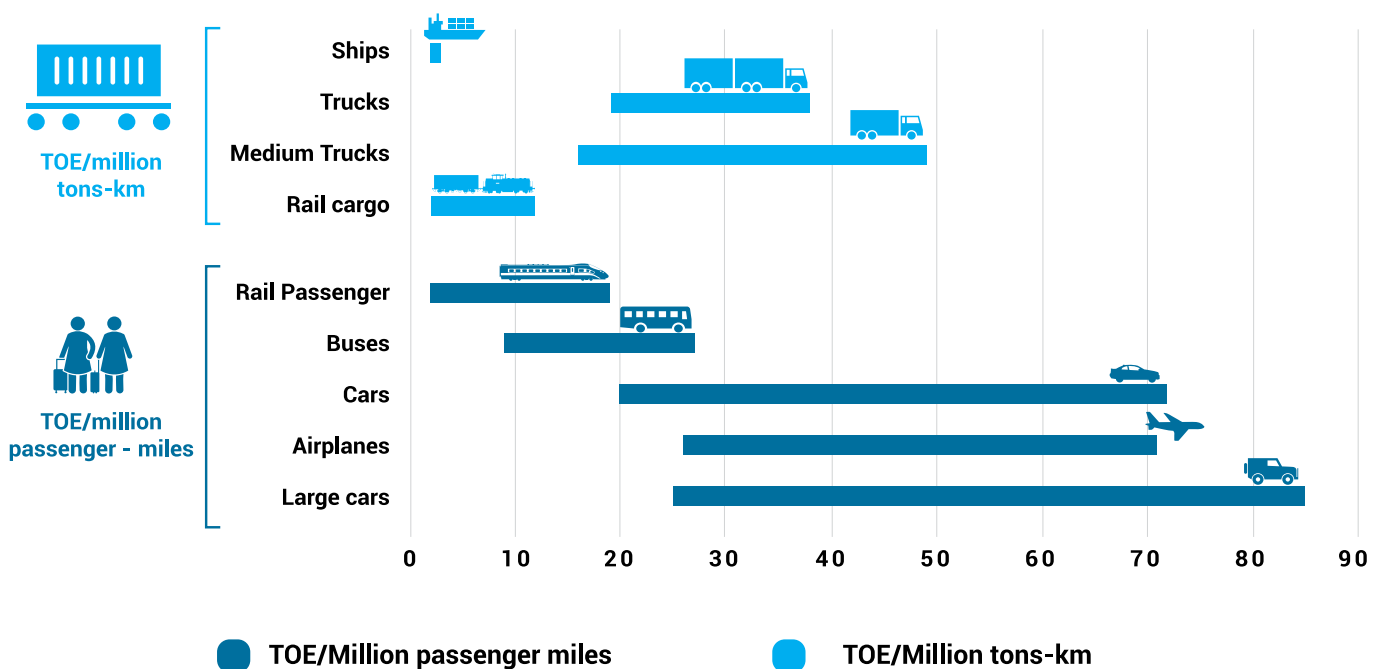
Figure 9. Estimated cargo transported (in billion tons-kilometer), in selected LAC countries, by mode, 2015.



Source: Data from GCAM for 2015



Figure 10. Energy efficiency of passenger and cargo transport modes, 2019.

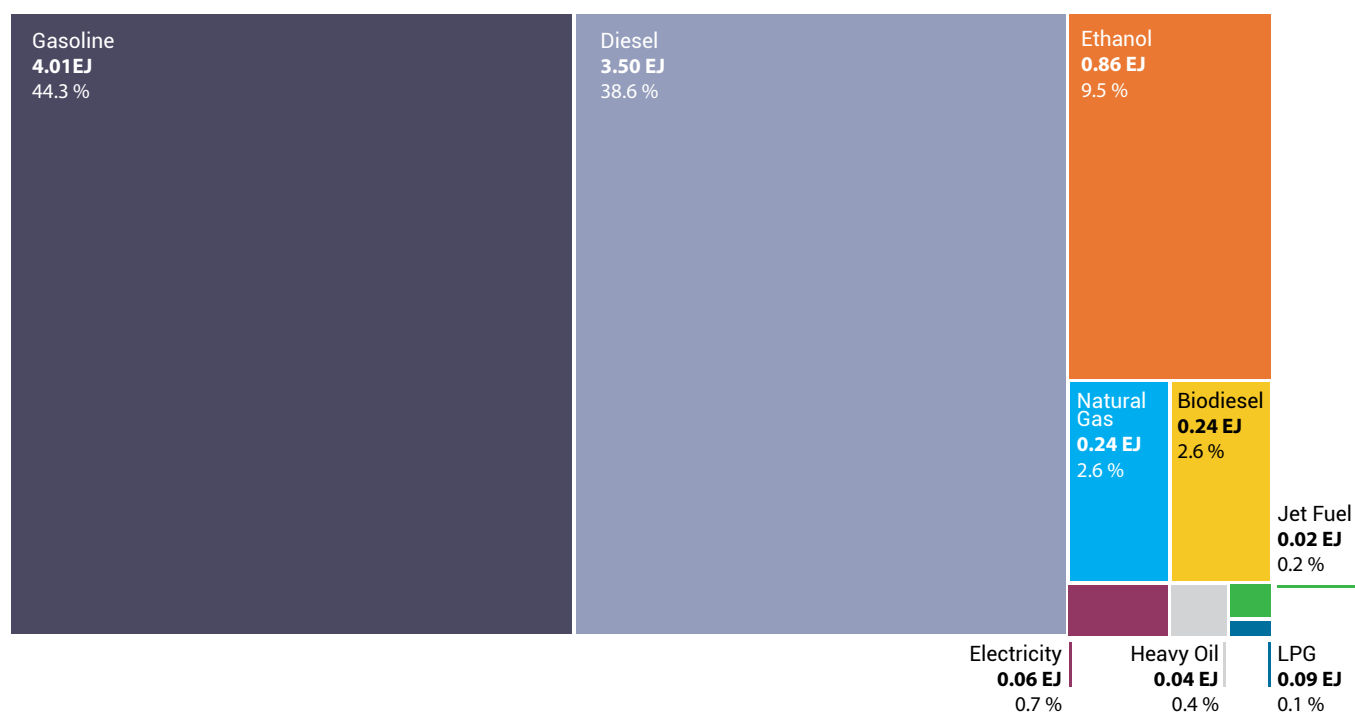


Source: IEA, 2019

Energy efficiency and carbon footprint

Rail and ships are considerably more energy efficient per unit of weight transported and today have the lowest carbon footprints of all modes for the movement of passengers and cargo per unit of weight moved and distance travelled (Figure 10). Maximizing both would be the most rational approach, even if all modes move to electricity under a renewable energy matrix. Diesel fuel and gasoline continue to be the fuels most used in transport, accounting for 83% of the total in terms

of energy use. The use of fuels in the transport sector by type is presented in Figure 11. Electricity is now showing up in the statistics available. There is a growing body of experience with electrification in passenger and cargo fleets and some limited manufacture of electric vehicles. The current carbon footprint for the target countries for cargo and passengers per mode of transport is presented in Table 7. While buses carry a large number of passenger kilometers and trucks most of the cargo, light vehicles have a similar carbon footprint. Rail and shipping are relevant only in a few countries.

Figure 11. Fuels used in the transport sector, by product, 2018 (Total: 9 EJ).

Source: Compiled from Enerdata through GACMO. Emissions from manufacture of the fuels are not included. Emissions from electricity estimated assuming a 50% renewable power matrix and three times efficiency in delivery of work. Some coal is used in rail operations but the tonnage is marginal.

Table 7. Estimated carbon footprint (MT CO₂) in the transport sector by country and by mode, 2018.

Country	Road passenger vehicles					Total
	Automobiles and other light vehicles	Heavy vehicles	Rail	Vessels	Other	
Argentina	18.5	19.5	-	1.1	5.1	44.2
Brazil	60.1	110.1	4.0	0.9	4.9	180.6
Chile	9.9	13.7	0.2	0.5	0.2	24.5
Colombia	15.9	15.1	-	0.1	1.3	32.4
Costa Rica	2.7	2.8	-	-	-	5.5
Jamaica	1.4	0.3	-	-	-	1.7
Mexico	88.8	38.6	2.4	3.0	3.4	136.2
Panama	2.6	-	-	-	2.1	4.7
Peru	5.1	13.3	-	-	2.8	21.2
Uruguay	1.8	1.8	-	-	-	3.6

Source: Enerdata compiled through GACMO on the use of fuels. Assumes all light vehicles use gasoline and all buses and trucks use diesel. It considers that the use of ethanol and biodiesel does not result in any direct emissions. Some data not available.

Future demand

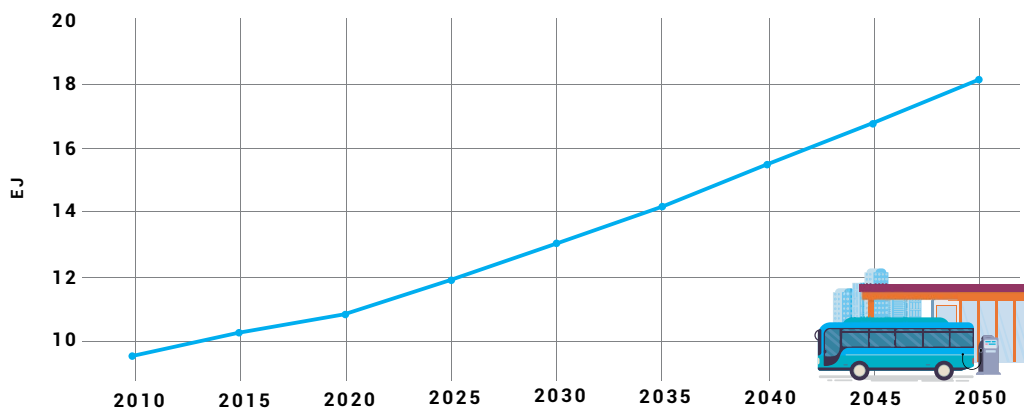
The IIASA projections place annual energy use by transport growing to 14 EJ by 2050.⁹² The GCAM BAU scenario projects a duplication of the energy demand reaching 18 EJ by 2050 (Figure 12).⁹³

The projected service demand for the transport of passengers under the GCAM BAU scenario is presented in Figure 13, in million passenger-kilometers. Most demand continues to be associated with light duty vehicles. Participation of buses is maintained roughly constant.



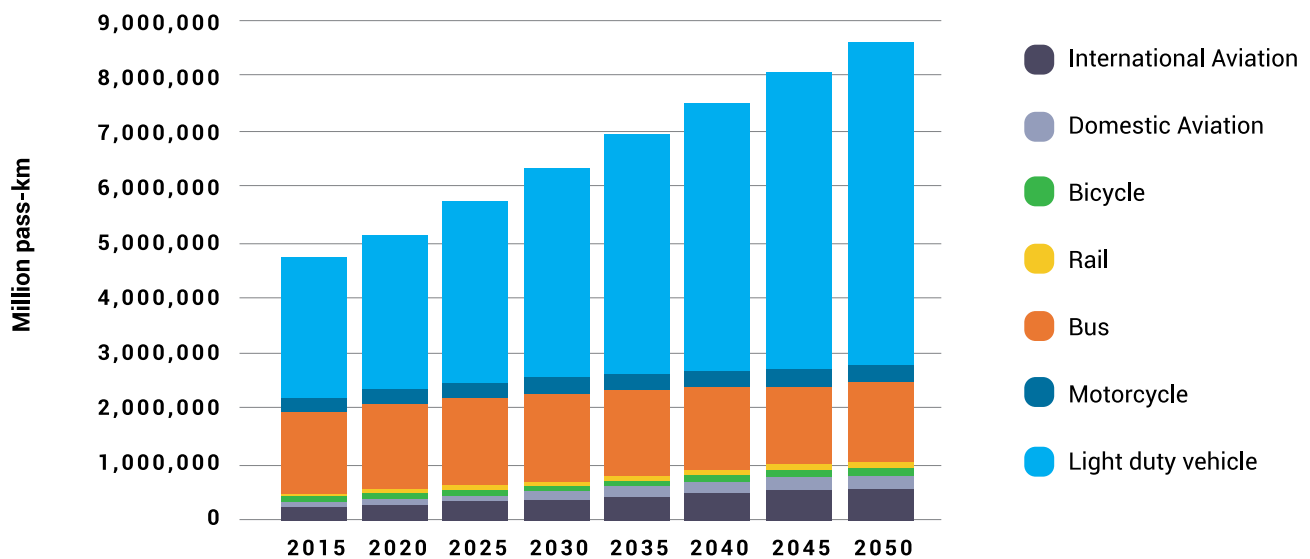
BAU scenario projects a duplication of the energy demand reaching 18 EJ with 1200 MT CO₂ by 2050.

Figure 12. Projected energy demand of the transport sector, under GCAM BAU scenario, 2010-2050.



Source: As projected under GCAM BAU outputs, August 2019

Figure 13. Projected passenger demand, transport service by mode in LAC, under GCAM-BAU scenario, 2015-2050.



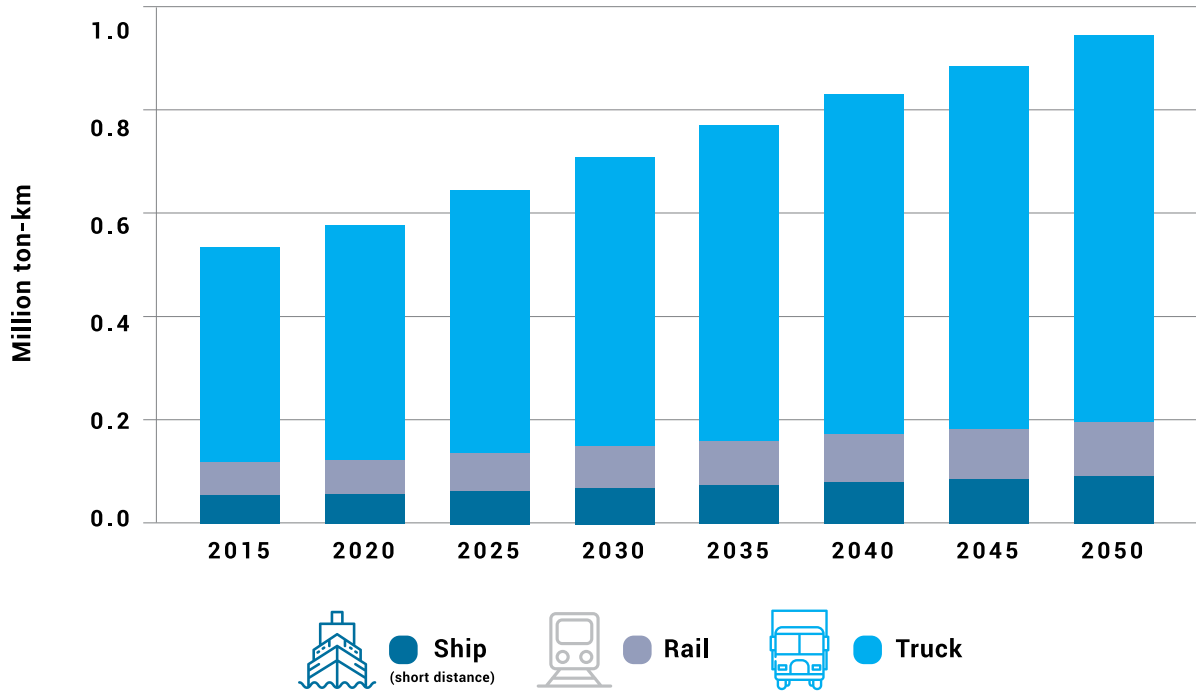
Source: As projected under GCAM BAU outputs, August 2019

92. This is the projected increase under the GCAM BAU scenario.

93. Both the energy use in power generation and in transport are above. Data on the current situation is derived from ENERDATA.

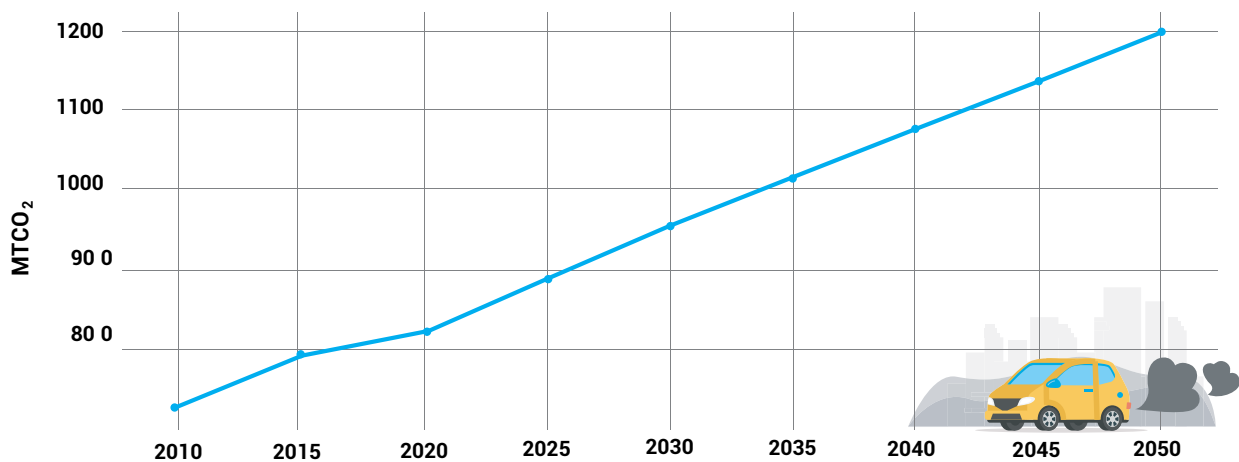
Projected growth of cargo services, under the GCAM BAU scenario is shown in Figure 14. Under the reference scenario 90% of all new cargo will continue to move by truck. The emissions linked to this future scenario are shown in Figure 15, as calculated through GCAM. The projection calls for emissions to increase to 1200 MT CO₂, a 50% increase from current levels.

Figure 14. Projected cargo demand, transport service by mode, under GCAM-BAU scenario, 2015-2050.



Source: As projected under GCAM BAU outputs, August 2019.

Figure 15. Projected associated CO₂ emissions from the transport sector, under GCAM BAU scenario, 2010-2050.



Source: As projected under GCAM BAU outputs, August 2019.



In contrast to the power sector, in the case of the transport sector, there is no projection of capital investment (CAPEX) to cover future transport demand since existing refinery infrastructure is enough to cover the projected increase of demand. Therefore, this report assumes a zero CAPEX for transport under the BAU scenario. The current trends of passenger car electrification and the increased uptake for alternative energies such as LNG and hydrogen for commercial vehicles will certainly impact the refinery market.

Eliminating emissions from the transport sector would require an enormous effort. Also, any displacement of fossil fuels by electricity will add to the demand by the power sector. The electrification of transport is also expected to reduce the overall energy requirements given the much higher efficiency of electric motors. Also, anticipated improvements in the costs of electricity and the potential for synergies with the power sector could aid the transformation of the sector. These aspects are discussed in Chapters 3 to 7.

CHAPTER 3

THE EVOLVING ECONOMICS OF RENEWABLE ENERGY IN THE REGION



Panama City, Panama
Photo by Termosolar Panamá







This section reviews the conditions to support an accelerated decarbonization of the power sector. It looks at the endowment of renewable resources in the region and explores their significance for the transition. It also summarizes current and estimated projection generation costs with renewables (measured in terms of Levelized Costs of Electricity (LCOEs)) based on actual and projected data and technology trends. For comparison purposes, it presents current and projected costs of generation with fossil fuels in the region.

3.1 Resource endowment

Latin America and the Caribbean region has a substantial renewable energy resource already documented by various studies (ECOFYS, 2009; Paredes, J., 2017, A. Luecke, 2011). By one estimate (Vergara, W., 2013), its resource base has the potential to provide 22 times the electricity needs of the global economy. Examples of this resource endowment include areas with high solar irradiance like the

Atacama Desert in Chile and Peru, the North East of Brazil, and the Sonora/Chihuahua Desert in Mexico. Areas with strong wind regimes include the Isthmus of Tehuantepec in Mexico, the Guajira Peninsula in Colombia, the south of Argentina and Chile, and the Atlantic coast of South America. A large marine energy field has been documented off the southern pacific coast. Geothermal fields continue to be assessed over the Andes, the Central American Cordillera and other areas of interest.⁹⁴

Figure 1. Examples of endowment of renewable energy sources in the region.

- 
Solar energy
 - Atacama Desert.
Potential generation: 2700 GW (with 10% of area under use)
 - Sonora Desert.
Potential generation: 4,940 GW (with 10% of area under use)
- 
Hydropower energy
 - All countries particularly the Andes and the Amazon basin.
Potential generation: 675 GW
- 
Marine energy
 - Southern Pacific Coast
Potential generation: 200- 240 GW
- 
Geothermal energy
 - Andes Cordillera and Central American Cordillera
Potential generation: 44 GW
- 
Off-shore wind energy
 - The entire region has 50,000 km of coastline
Potential generation : 1,300 GW (Brazil)
- 
Wind energy
 - High southern latitudes
Intensity: 600-1300 W/m²
 - Southern Atlantic Coast
Intensity: 100-450 W/m²
 - Brazil coastal and northeastern areas
Potential generation: 500 GW
 - Guajira Peninsula
Intensity 10 GW
 - Isthm of Tehuantepec
Potential generation: 30 GW
 - Southern Atlantic Coast
Intensity 100-450 W/m²

Source: Author's estimates.



Latin America and the Caribbean renewable energy resource has the potential to provide 22 times the electricity needs of the global economy.

94. For example through IRENA's Andes Geothermal Initiative: <https://www.irena.org/newsroom/articles/2015/Sep/A-Look-at-IRENAs-Geothermal-Initiative-in-the-Andes>

The annual electricity generation potential of some of these areas is of a comparable size, to annual oil extraction in oil-rich nations. For example, in Chile's Atacama region, the potential for solar power when using 10% of the area with commercially available conversion efficiencies of PV systems would produce about eight months' worth electricity to equal the potential generation from the annual production of oil from Saudi Arabia (Table 1, see details in Annex 3). After nine months, the same production potential would remain, while the oil reserves of Saudi Arabia would have been reduced with a leftover footprint of a higher CO₂ concentration in the atmosphere. The potential of Atacama for power generation is just starting to be exploited. The government and private sector have already started planning for a much larger utilization of this resource.

Similar estimates indicate that the solar energy potential in 10% of the Sonora/Chihuahua area could equal the annual production of Iran in one month. Also, the onshore potential for wind energy in Brazil is about the same in electricity equivalence to its annual production of oil. The renewable energy fields in the region are of global scale and could potentially make a global difference, as well as play a major local role.

Table 1. Comparison between electric potential of proven oil reserves and renewable energy potential in Latin America

Oil Producing Country	Annual oil production (MMBBL)	Equivalent electricity generation potential (PWh)	Renewable Energy Area	Months of generation of 10% of area with PV technology to equal use of equivalent annual oil production.
Saudi Arabia	4.53	3.85	Atacama	8
Iran	1.63	1.1	Sonora Chihuahua	1
Brazil	1.27	1.0	On shore wind in Brazil	14

Source: Author's estimates; assume 10% of area, PV efficiency of 20% wind energy production at 20% of potential. Uses average efficiency of power thermal plants at 50%. For wind in Brazil, it uses a 500 GW potential.



3.2 Evolution of capacity by country and cost structure of renewable resources

Installed capacity by country

The total installed renewable capacity added for the 2012-2018 period was 52 GW (about half in new hydropower). All countries in the analysis added renewable capacity, reflecting the favorable environment for the deployment of renewables, improved competitiveness, and supportive policy framework. Most of the added generation was installed in six countries, Brazil 30 GW, Mexico and Chile, each 4 GW, and, Colombia, Peru and Uruguay, each about 2 GW (Figure 2). The rapid development of renewable energy in the region is facilitating gains

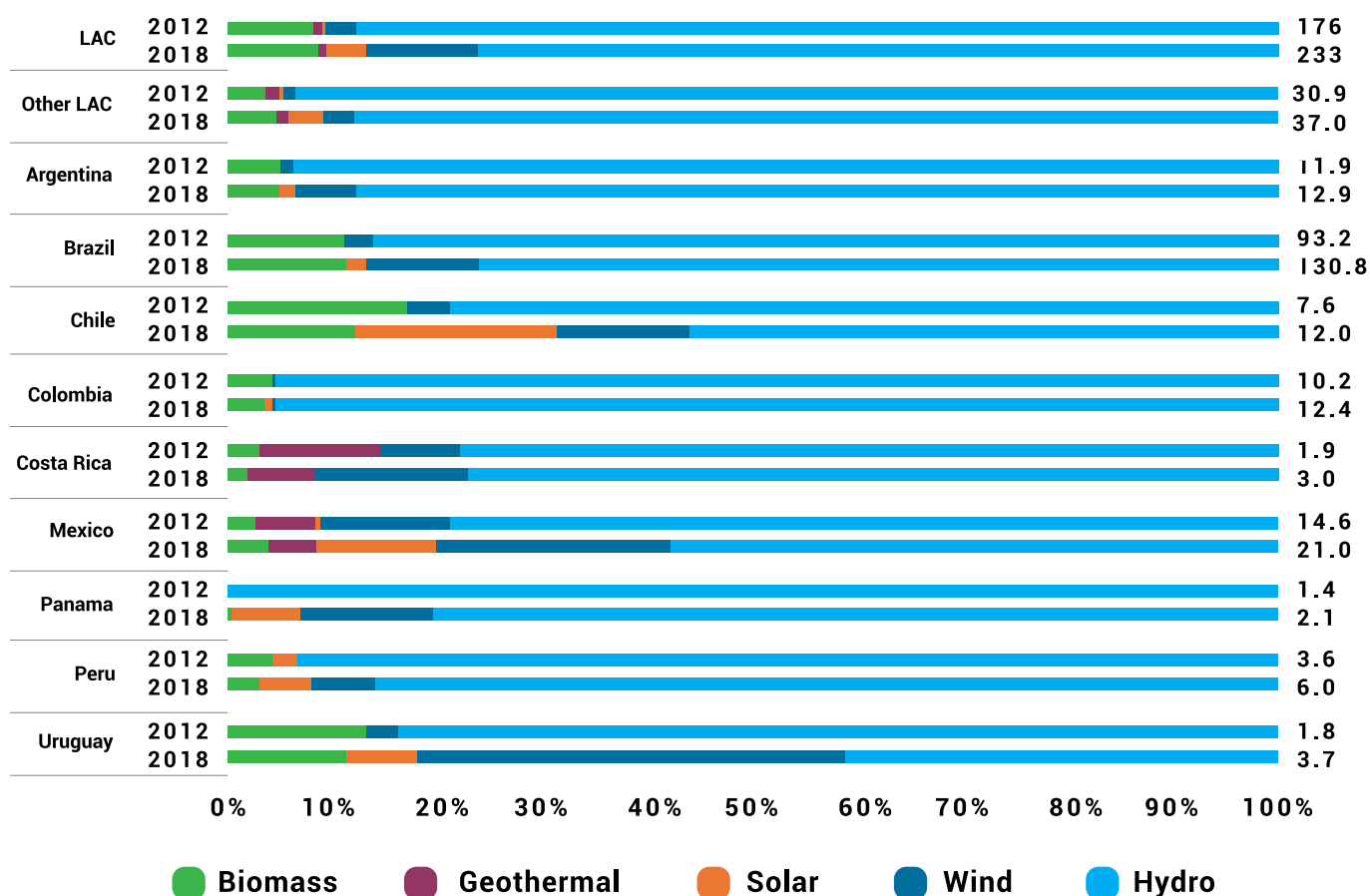
in knowledge and practical experience that will be helpful in reducing operation and maintenance costs. For the same period, non-conventional renewables have doubled its participation in the power matrix (Table 1 Chapter 2).



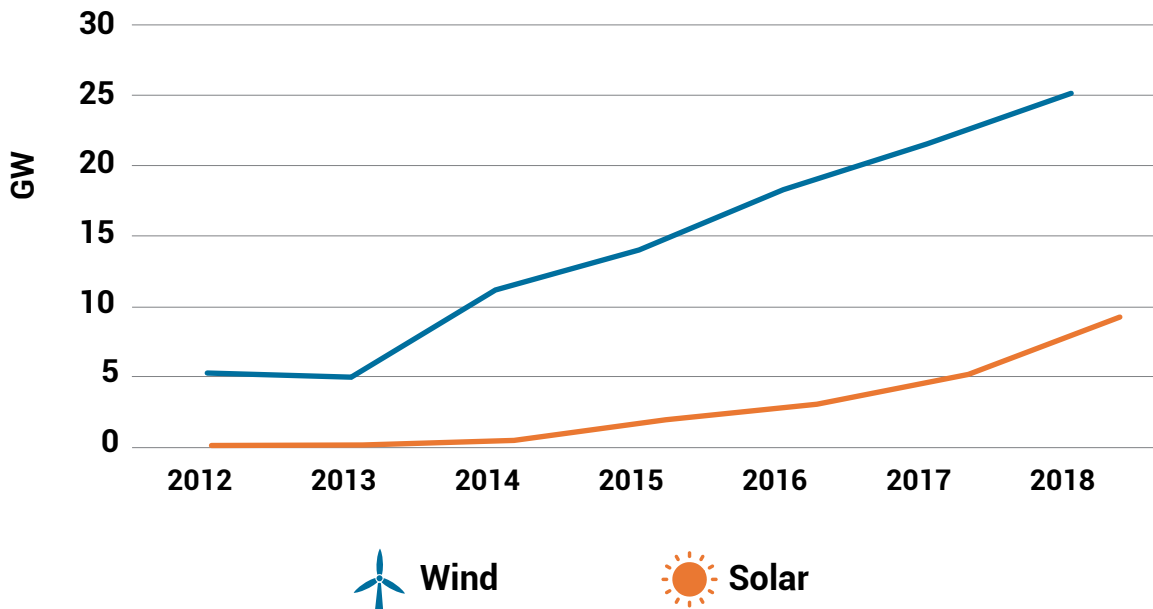
Installed capacity for wind energy increased by nearly 400%, and for solar PV increased 29,000% (Figure 3).

Currently, wind and solar PV installations exceed 50GW, which is almost a third of the total generation capacity installed to power Brazil. The fast deployment was driven by the significant decrease on the cost of renewables (see Figure 5, 6 & 7 below).

Figure 2. Evolution of share of nominal capacity in renewable energy, in LAC (2012-2018)



Source: Based on information from ENERDATA compiled in GACMO accessed July 31st, 2019. For hydro and geothermal 2017 data was used for some countries where 2018 data was unavailable. . Other LAC refers to all the countries of the region not listed individually.

Figure 3. Evolution of wind and solar PV installed capacity in the region, 2012-2018

Source: Enerdata.

Capacity under construction or contracted

The pipeline of renewable energy projects under construction or contracted is quite significant and in many countries is higher than the renewable energy capacity already in operation. This is further indication of the momentum that renewables have gained in the region. Furthermore, as the demand for electricity has remained flat in the last few years, the new installed capacity is most likely to displace thermal units (coal, natural gas and fuel oil) than to add net capacities to the system. Examples of capacity under construction in some countries in the region and the impact this will have on the existing power matrix are shown in Figure 4. In some cases, the capacity is under construction or contracted surpasses the operational capacity by a good margin.

In the longer term, the projections for power demand call for net increases where renewables can be expected to play a growing role. The scenario of additional demand for electricity is strengthened when considering the potential for electrification of other sectors of the economy that are fossil fuel-driven today, such as transport and industry.



Photo by Science in HD, Unsplash

Figure 4. Examples of wind and solar PV capacity under construction and contracted (GW) in some Latin America countries

Wind

Country	Operational	Under Construction	Contracted	Upcoming capacity as % of operational
Mexico	4.68	1.08	1.15	48
Chile	1.52	1.01	n/a	67
Colombia	0.01	n/a	1	10,000
Brazil	14.40	3.64	0.96	32
Argentina	0.75	n/a	0.10	13
Rest of South America	2.16	n/a	1.16	54

Solar

Country	Operational	Under Construction	Contracted	Upcoming capacity as % of operational
Mexico	2.43	1.85	1.50	138
Chile	2.27	0.59	n/a	26
Colombia	0.08	n/a	0.3	375
Brazil	2.23	1.03	0.44	123
Argentina	0.19	0.46	2.47	489
Rest of South America	0.74	n/a	0.24	32

Source: Industry data as of September 2019.

3.3 Cost evolution of non-conventional renewables

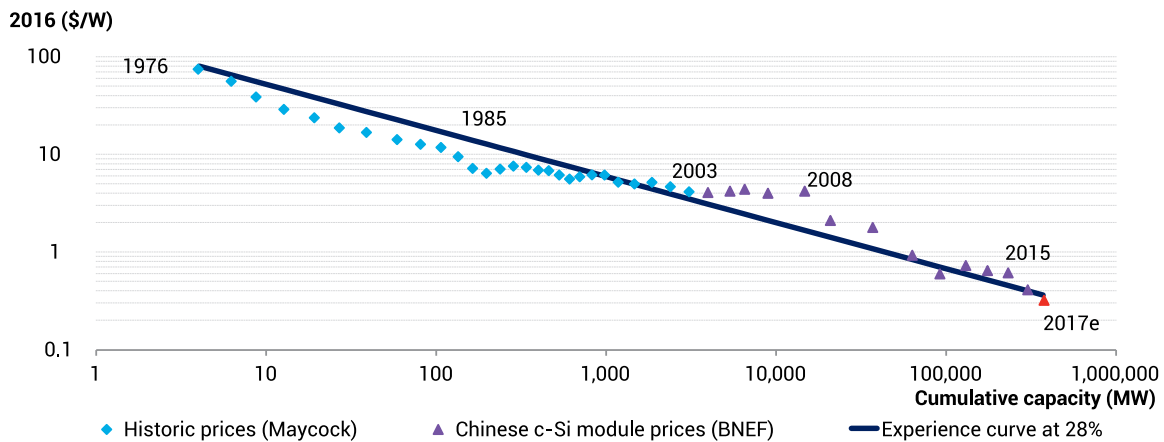
Trends in technology costs

A recent analysis (BloombergNEF, 2019) of PV modules and wind turbine prices has found that since 2010, costs have fallen by 85% and 45% respectively (Figure 5 & 6). At the same time, rotor diameters of wind turbines have seen significant increases reaching an average size of 129 meters in 2019. The nominal capacity for wind turbines has grown from 30 kW average in the 80th to 5 MW for the present year.⁹⁵ Off-shore turbines have reached a nominal capacity of 12 MW. On the other hand, the efficiency of solar panels has increased only 7 percentage points, up to 23% since 1992. In 2017, a group of US scientists designed a solar cell capable of converting solar radiation to electricity with a 44.5% efficiency but the product is not commercially available given the prohibitive costs of scale-up.⁹⁶

PV modules and wind turbine prices have fallen since 2010.

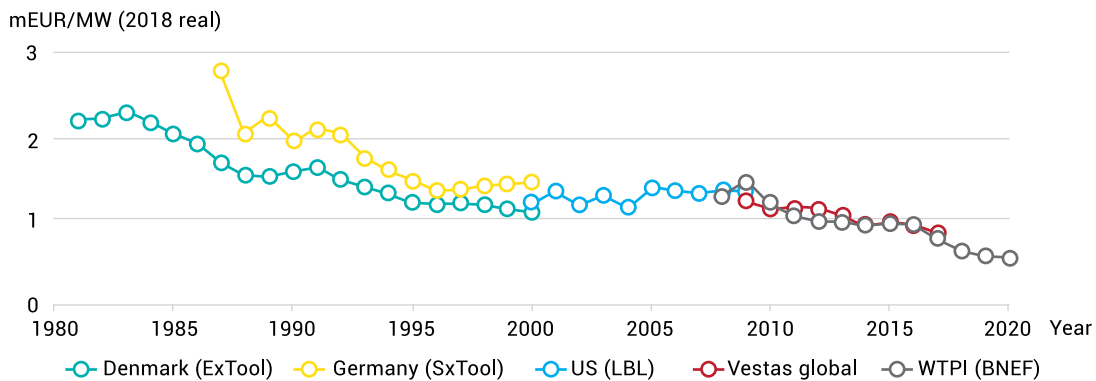
85% | 45%

Figure 5. Trend in cost of PV modules per Watt



Source: Maycock, Bloomberg New Energy Finance

Figure 6. Trend in cost of wind turbines (M Euros/MW)



Source: BloombergNEF, Lawrence Berkeley National Laboratory (LBL), Ex Tool study (Neij et al. 2003), Vestas annual reports

95. <https://www.statista.com/statistics/263901/changes-in-the-size-of-wind-turbines/>

96. <https://www.nanalyze.com/2019/04/most-efficient-solar-cell/>

Cost of generation using non-conventional renewables

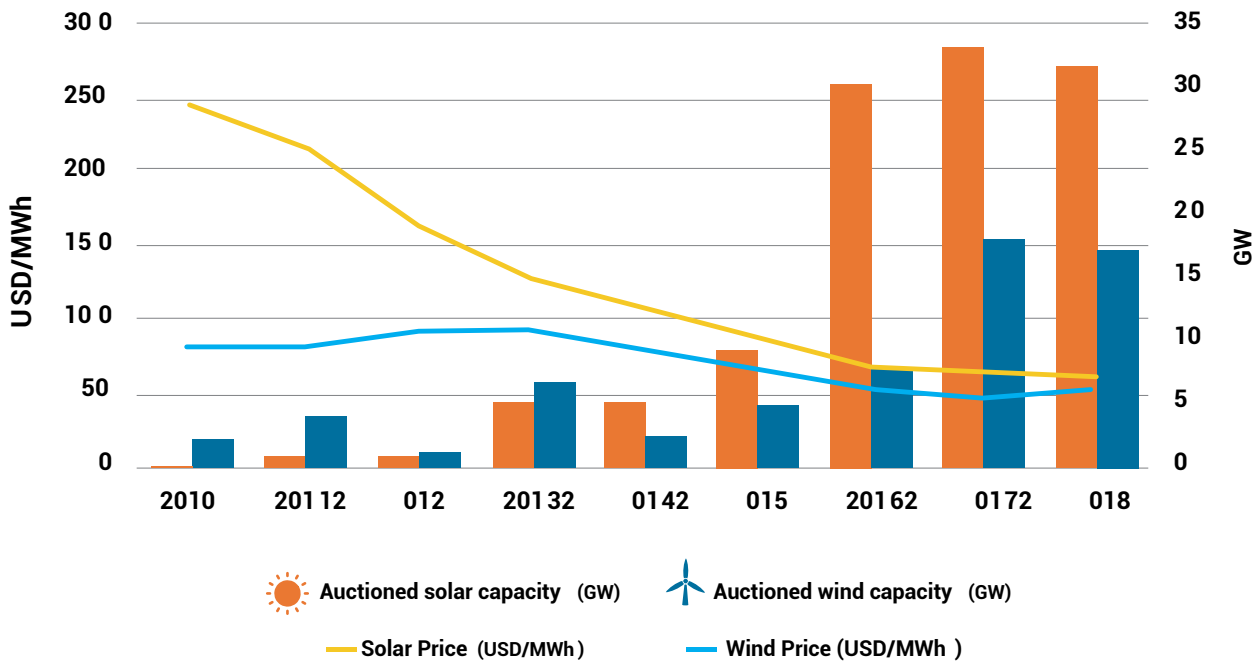
Reductions in the cost of generation for wind and solar projects have continued. A recent analysis by IRENA (IRENA, 2019) indicates that auctioned prices have fallen (between 2010 and 2018) by 75% and 25% respectively for solar and wind powered installations (Figure 7). The fast deployment of wind and solar PV energy installations was driven by the significant decrease in costs of main components (wind turbines

and PV modules) and technology improvements, which, consecutively, has led to tremendous decline in cost of power generation (LCOE) through these two technologies. Recent auctions for wind and solar PV energy installations in the region confirm the long-term trend of improved economic competitiveness.



Auctioned prices have fallen, between 2013 and 2019, by more than 80% for both technologies in LAC (Figure 8 and 9).

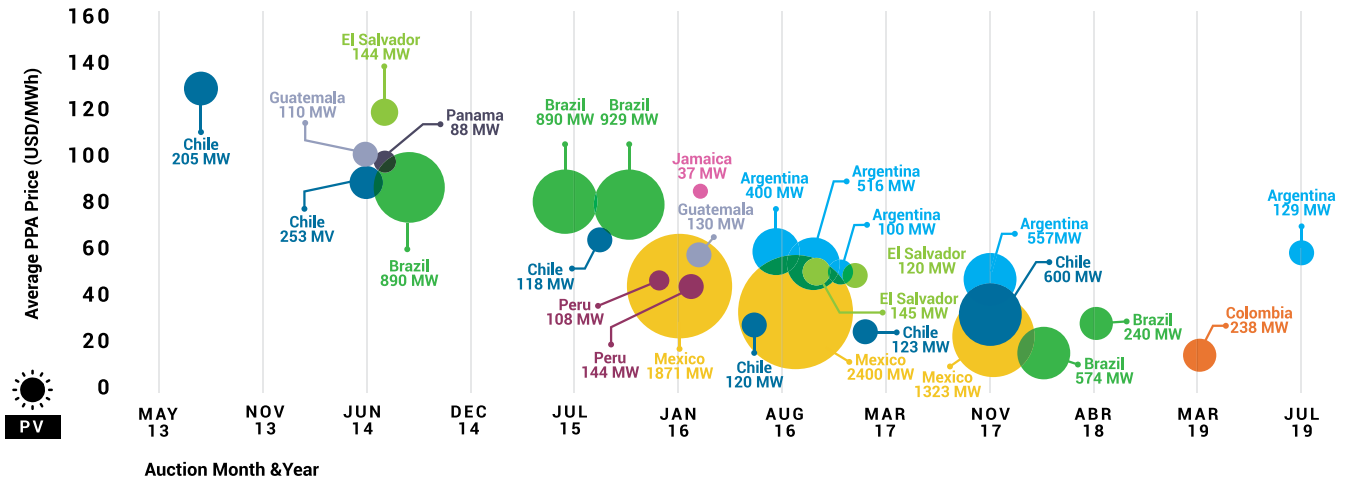
Figure 7. Global trends in average auctioned prices for solar and wind powered plants, 2010-2018



Source: IRENA, 2019

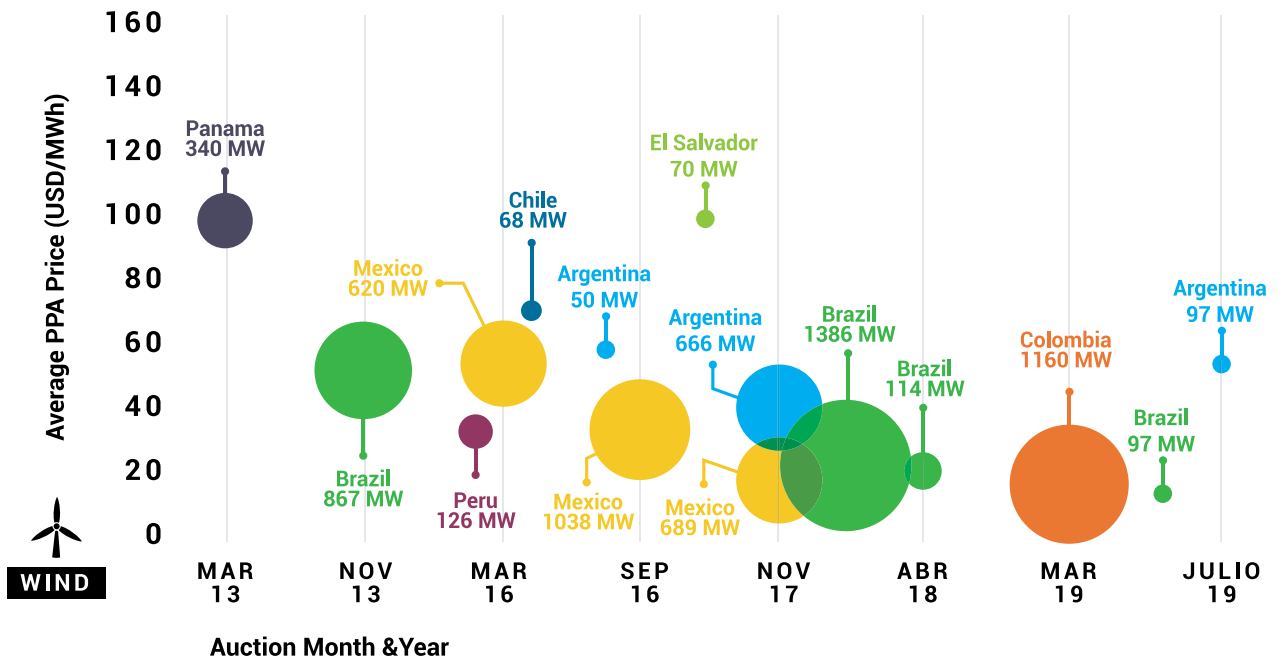


Figure 8. Evolution of auction prices for solar PV projects in LAC, 2013-2019



Source: Based on data from Nagendran S., 2017 and industry data.

Figure 9. Evolution of auction prices for wind projects in LAC, 2013-2019



Source: Based on industry data.

While the reduction in prices is smaller for wind installations, it follows the same tendency and has resulted in lower costs than for PV units. The actual market prices are considerably lower than projections made just a few years ago (i.e., IRENA, 2016). The current PPAs are at a level of least-cost fossil fuel alternatives, without the need for economic incentives. Prices are such that companies are deciding to build the projects without any subsidy or PPA associated.⁹⁷

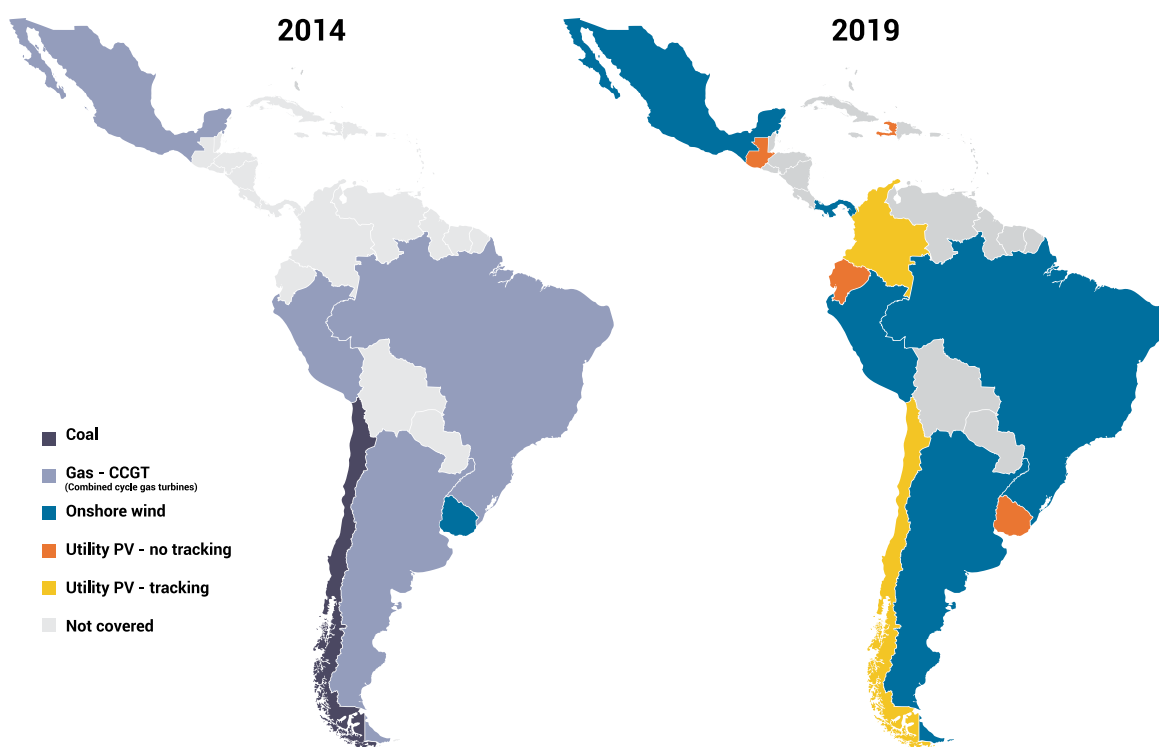
The LCOE for solar PV and wind power reached cost parity with hydrocarbons-based generation in some LAC countries.



New wind and solar PV plants are cheaper than new coal and gas plants in some countries in LAC, making the renewable energy pathway a no regret option.

These technologies are winning the race to be the cheapest sources of new generation. In many countries, such as Peru, Mexico, Uruguay, Argentina and Brazil, wind energy is below LCOEs for fossil fuels. In the case of solar PV, Chile has one of the lowest LCOEs in the world meanwhile in Peru, Chile, Colombia and Mexico solar is already cost competitive with fossil fuels. Figure 10 shows that on purely economic grounds it will be increasingly difficult to justify investments for power generation using fossil fuels in some countries. Solar plus storage facilities and concentrated solar power (CSP) prices are not included in the graph as there are just a few facilities under construction or being commissioned in the region (for example, the CSP plant in Cerro Dominador, Chile). However, technology developments and cost effectiveness of storage options (further described in section 4) also bode well for their future as fully dispatchable units.

Figure 10. Most competitive source of new utility-scale generation in 2014 and 2019



Source: CFLI, 2019. This map shows the technology with the lowest benchmark LCOE in each market, excluding subsidies or tax credits.

97. <https://renewablesnow.com/news/brazils-neoenergia-okays-construction-of-5665-mw-wind-complex-669828/>



Other sources of renewable energy have also shared in the rapid increase in installed capacity. Additional capacity in geothermal and biomass was added (67 MW and 528 MW between, 2012 and 2017 respectively). A trend in generation costs for these options is more difficult to discern, given the influence of local conditions in the overall cost structure. Gradually, the increased market share of the new resources will start pulling down electricity prices, with a beneficial effect on the entire economy and representing a strong argument for the electrification of other sectors, including transport and industry. Those market players that move first will accumulate experience and assets, gaining a foothold on the future economy.

3.4 Projected costs of generation in the region

Based on the results of recent auctions and trends, an update of the estimated LCOE has been made, including fossil fuel options using current (2018) prices in the international market for fossil fuels and FOB prices for natural gas in Brazil and Mexico and FOB for low sulfur coal in Colombia. Solar and wind options have been updated with recently released

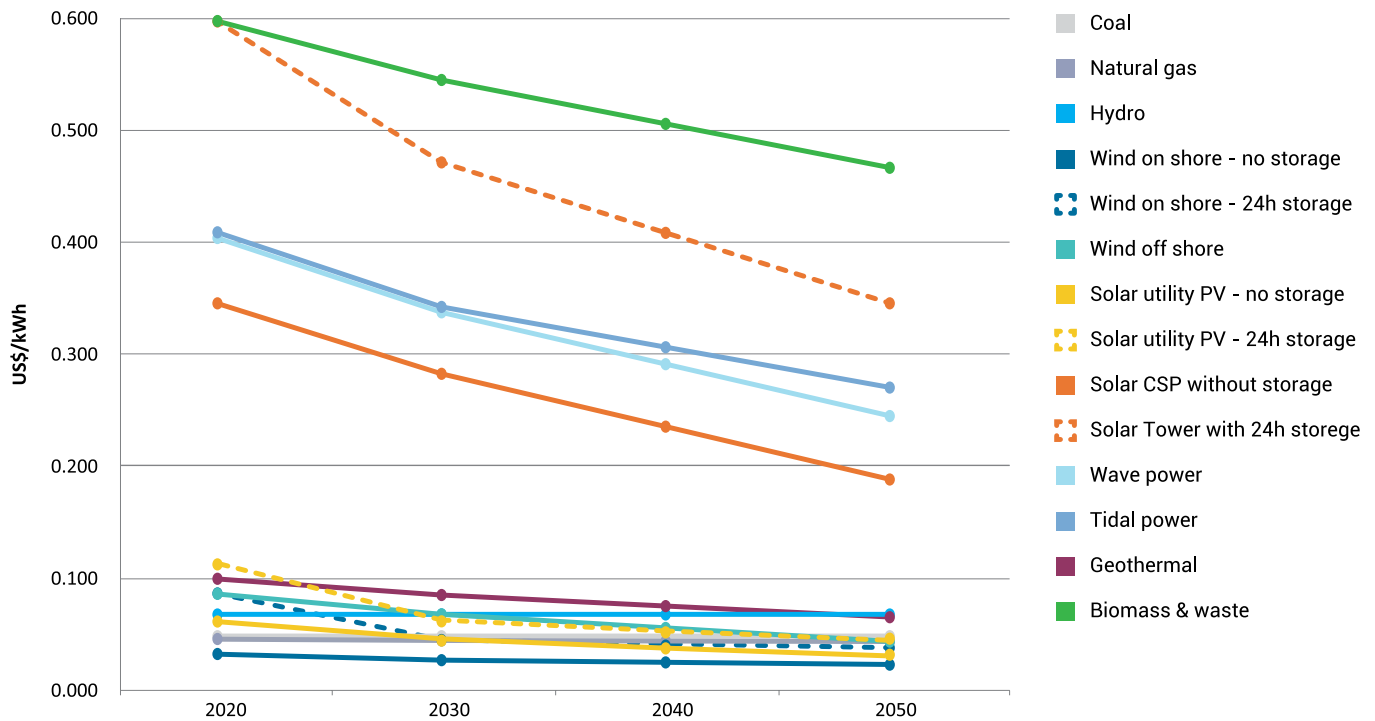
information on projected costs for turbines and PV modules (BNEF, 2019, NREL, 2019).⁹⁸ Options for PV plus storage and wind plus storage have been added reflecting recent developments, including the AURA III project just commissioned in Mexico (Sanchez-Molina, 2019) and the proposed PV plus storage project Espejo de Tarapaca in Chile (PVtech, 2019).⁹⁹ Estimates for marine options (wave and tidal) have been updated based on information compiled by the UK Marine Resources Board and adjusted to reflect the state of development in Chile. The projected cost of fossil fuel options has been adjusted to reflect the expectation of future fuel prices, including a downward pressure exerted by increased competition of renewables in power generation. The results are presented in Figure 11.

Onshore wind is already well below the costs of generation with coal and petroleum derivatives, and even with natural gas. Furthermore, it is expected to further gain in competitiveness as experience and improvements in efficiency are factored in. Accordingly, and taking advantage of its significant endowments, onshore wind is likely to play a major role in the energy transition in the region. Solar PV is not far behind and will likely continue the fast pace of

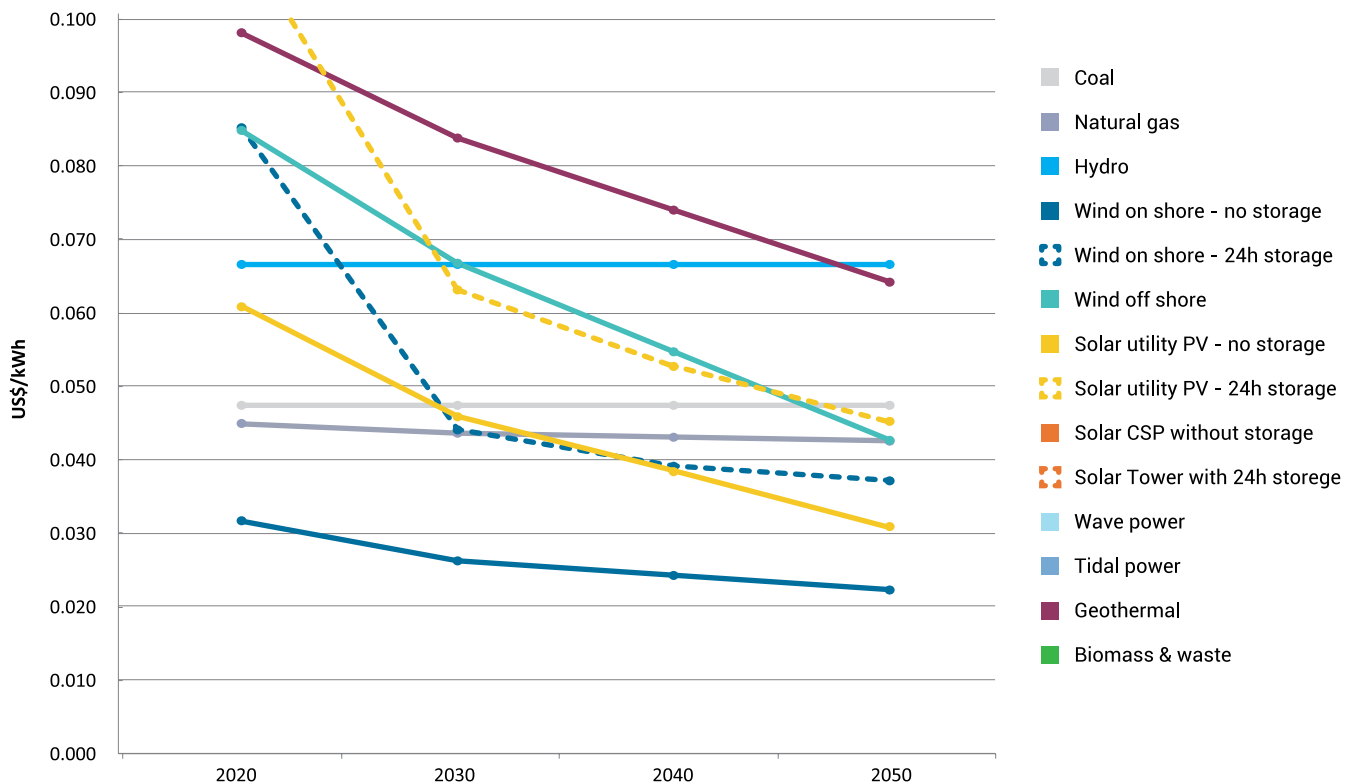
98. <https://atb.nrel.gov/electricity/2019/index.html?t=ow>

99. The costs of storing power in Latin America are reviewed later in the report

Figure 11. Projected LCOEs, by source of energy, 2017-2050



Zoom in of the LCOEs lower range (0 to 0.1)



Source: Author's estimates using GACMO.

reductions in investment costs. Both wind and solar represent logical investments for capacity expansion just on purely financial grounds.

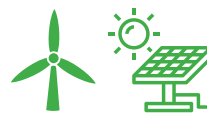
The results indicate that on purely economic grounds it will be increasingly difficult to justify investments for power generation using fossil fuels. Coal is no longer competitive in many situations and there are no sound reasons that new coal plants should be installed in the region. Also, the arguments in favor of new investments in natural gas are questionable. Natural gas is being outperformed by wind and challenged by solar power. Investments in natural gas will not be competitive in the future (see Figure 11). Locking in natural gas infrastructure at this time may result in capital losses once these units cease to be competitive.¹⁰⁰

LCOEs presented in Figure 11 are an average for the region. According to the analysis by Bloomberg, many countries such as Peru, Mexico, Uruguay, Argentina and Brazil, wind energy is below LCOEs for fossil fuels. In the case of solar, Chile has one of the lowest LCOEs

in the world meanwhile in Peru, Chile, Colombia and Mexico solar is already cost competitive with fossil fuels (Figure 10). Increased competitiveness of options including storage offer an additional challenge to the arguments for continuing operation of fossil-based generation on ease of ramping to attend peak demands. Cost reductions are also anticipated for marine energy, which while not competitive at the present may play an important role in the future. According to the results shown below, the future of power generation in the region is likely to be in the hands of renewables.

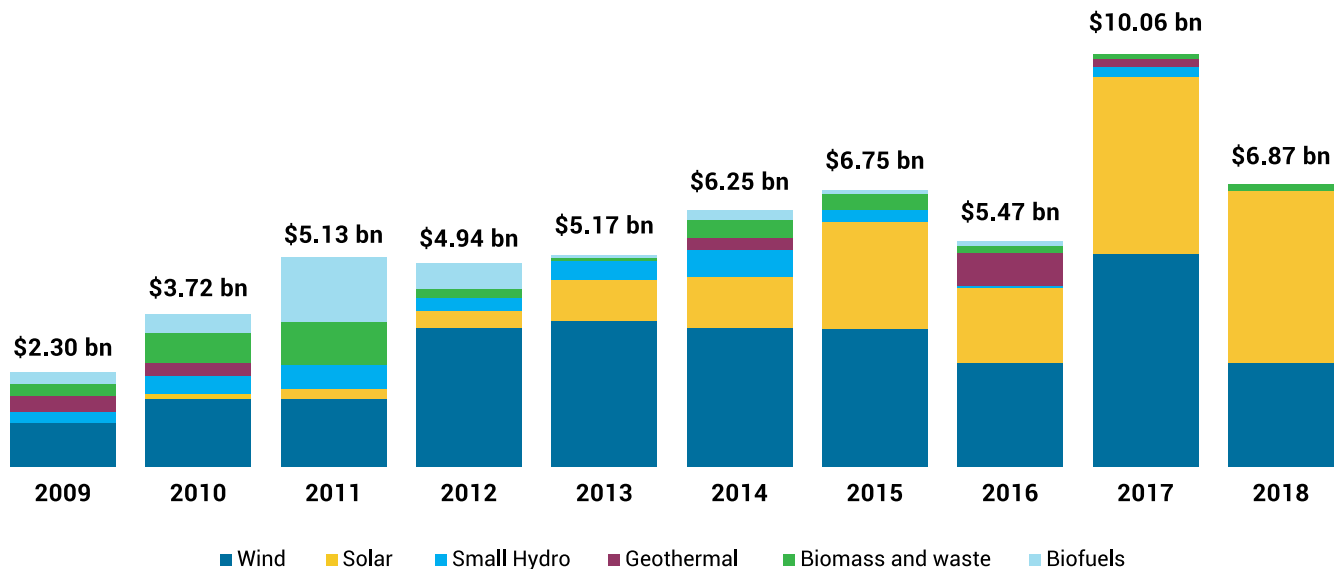
3.5 Investments trends in the region

In the last 5 years, the non-conventional renewable energy sector in Latin America and the Caribbean received more than USD\$35 billion in investment (44% of global direct foreign investment flows).



90% was destined to Solar PV and wind projects; USD\$14 billion and USD\$17 billion, respectively (Figure 12).

Figure 12. Annual investment in renewable energy in LAC by recipient sector and deal signing year, 2009-2018



Source: Climatescope, 2019.

100. The numbers in figure 8 also consider marginal improvements in efficiency from natural gas power plants but no change in overall efficiency from coal power plants.

Non-conventional renewable energy investment tends to blossom in countries with well-constructed enabling environments, which means clear and consistent renewable energy policies, including well-structured auctions. As is the case in Mexico, Brazil, Chile and Argentina, which received 70% of the region total investment flows (Table 2). Other countries are beginning to attract foreign direct investment towards the solar PV and wind markets in 2018 are Colombia, El Salvador and Dominican Republic, since they have built legal and regulatory frameworks that give certainty to private investment. Furthermore, three Latin America and Caribbean nations – Brazil, Mexico and Chile – ranked leaders in the 2018 Top 10 recipient countries for solar PV and wind investment worldwide (Figure 13).

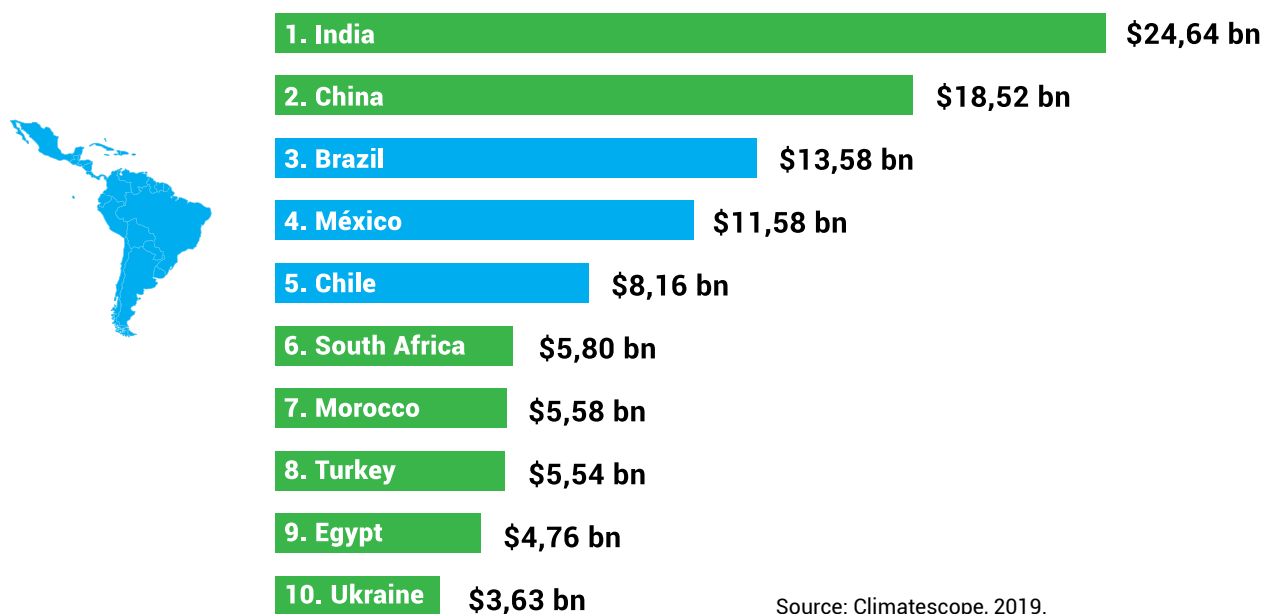
This is consistent with the Clean Energy Investment Climatescope 2019 Ranking where Chile, Brazil, Argentina and Peru are in the Top 10 most attractive countries for clean energy investments out of 104 nations.

Table 2. Top 10 investment recipient countries in Latin America and the Caribbean, 5-year cumulative investment (USD Billion)

Country	5- year Investment (USD Billion)
Mexico	8.45
Brazil	8.4
Chile	6.36
Argentina	2.11
Honduras	0.88
Uruguay	0.85
Peru	0.66
Dominican Republic	0.36
Panama	0.31
Costa Rica	0.24
El Salvador	0.18
Colombia	0.14

Source: Climatescope, 2019.

Figure 13. Top 10 investment recipient countries in the world, cumulative investment, 2009-2018



Source: Climatescope, 2019.

Figure 14. Most attractive emerging markets for clean energy investment in LAC 2019

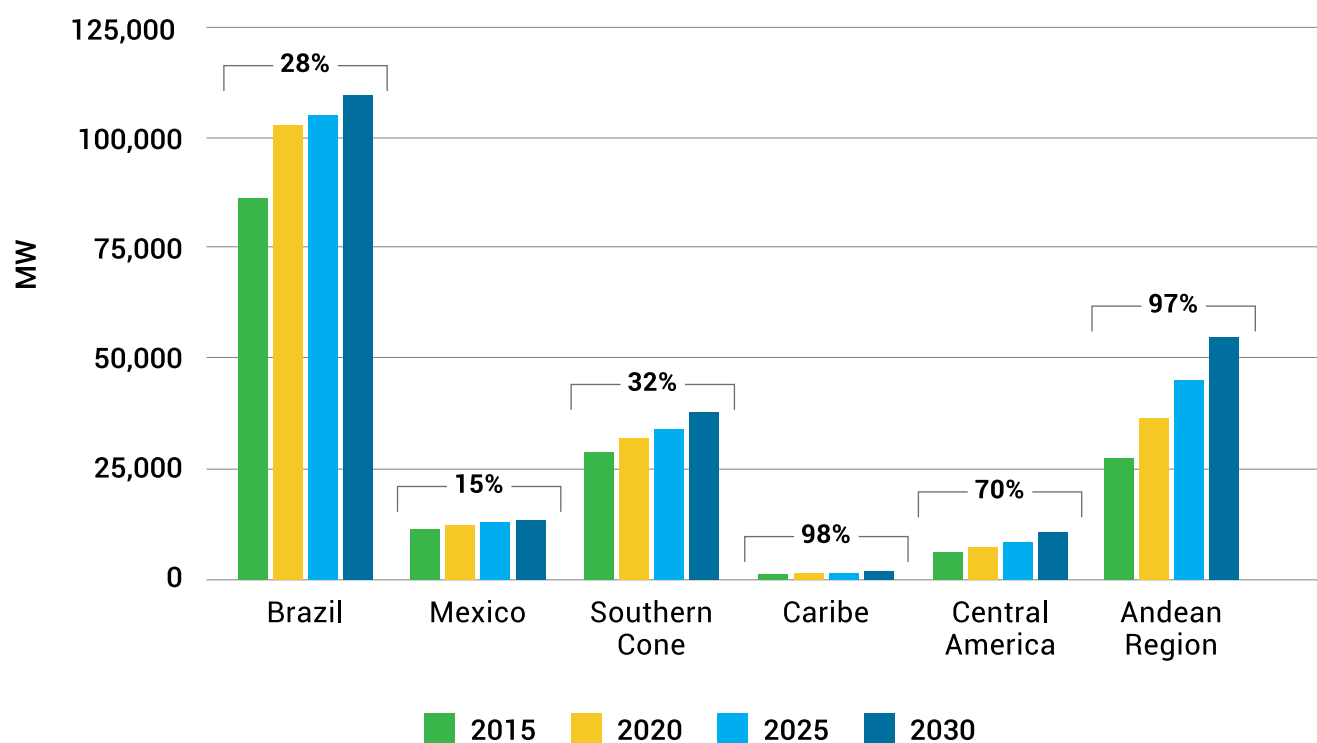
Source: Climatescope, 2019.

Three more countries, Colombia, Panama and Uruguay made it to the Top 20 (Figure 14). The fact that 7 countries in the region have been named as attractive markets for clean energy investments is indicative of the opportunities in Latin America and the Caribbean to achieve the decarbonization of the power sector.

3.6 Tipping point for decision making in Latin America and the Caribbean power market

While acknowledging the challenges and differences between national circumstances, political, economic and technical feasibility of solar energy, wind energy and power storage have considerably improved in

Latin America and the Caribbean over the past few years. However, national plans of countries in Latin America and the Caribbean still projects expansions of their generation capacity in the power sector by 2030 with technologies that have negative socio-economic and environmental impacts. Figure 15 shows a significant increase of hydropower generation capacity planned in Brazil and the Andean Region, and to a lesser extent in the southern cone. The development of these projects should take into consideration the changes on the duration and intensity of rainfall patterns and drought periods affecting firm capacity of hydropower, which already have shown repercussion in the power system, as well as the environmental and social impacts that bear the implementation of such projects.

Figure 15. Projected cumulative hydroelectric capacity installations (MW) per subregion, 2015 – 2030

Source: OLADE, 2018.

An even higher concern is the projected expansion of the thermal plants in the region. Figure 16 shows that almost all subregions plan to expand their generation capacity in the future by including natural gas (in a larger extent), diesel fuel or carbon in their energy matrix with Mexico leading this path. Natural gas, which has abundant reserves in the region, has been proposed by some in the industry¹⁰¹ as a cleaner option to coal and petroleum derivatives.

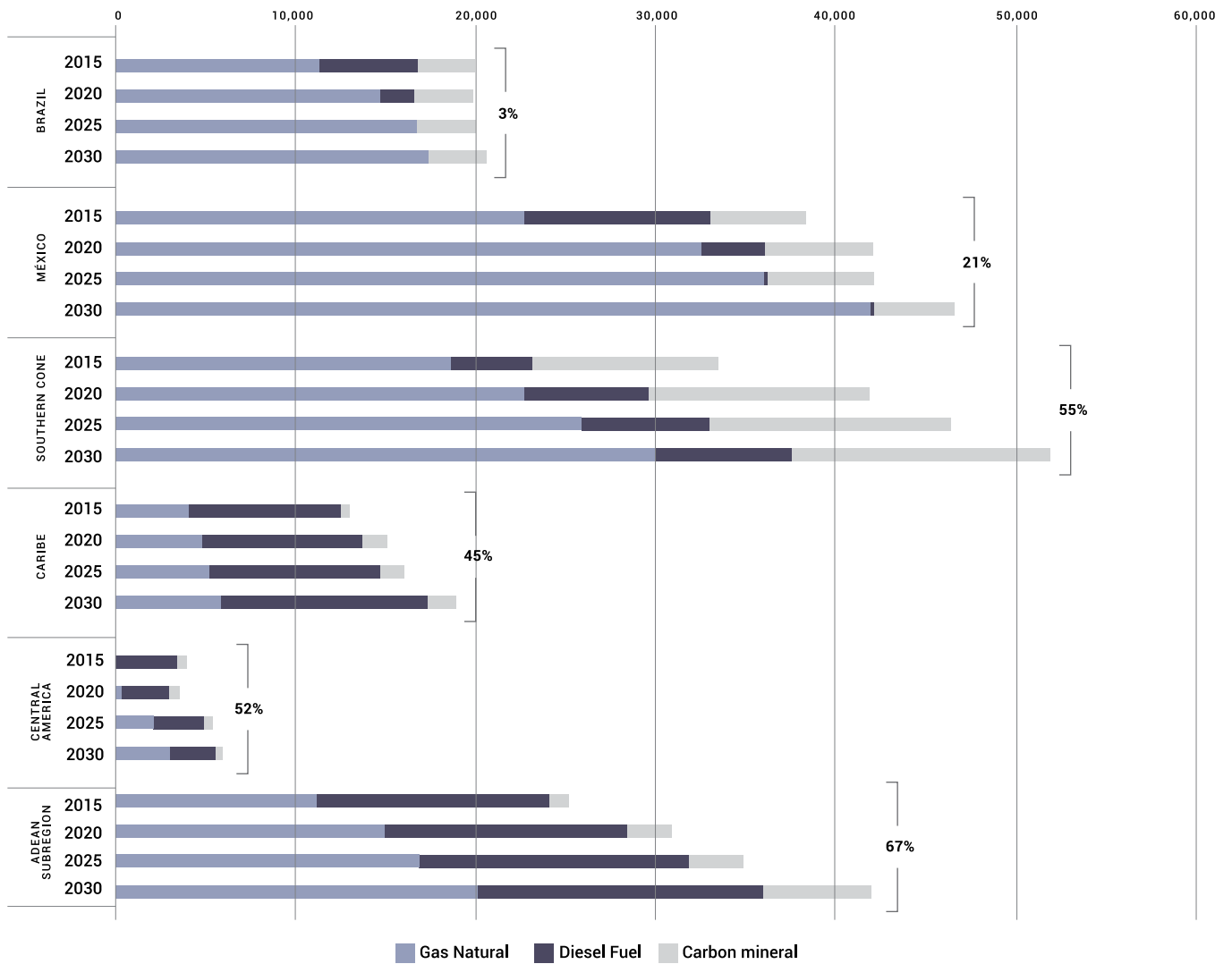
Data on the carbon footprint of the complete cycle of gas exploration, production, transport and end use cycle do not support this assertion. Based on the warming potential of CO₂ and CH₄ it can be shown that 3.3% by weight of fugitive emissions from gas would make it equal the emissions of CO₂ by coal (Annex 2). There is evidence that fugitive emissions in at least some countries in the region, surpass this threshold. These new thermal power plants inclusions are highly

discouraged if the region is to meet its NDCs and work towards a cleaner environment. Furthermore, the LCOEs of non-conventional renewable energies are reaching or have reached cost parity with fossil fuel-based generation technologies, thus making thermal plants less profitable in the future and with high risk of becoming stranded assets.

The region is currently in a crossroad to make strategic decisions that will define the future of its power system. The path taken today will create a technology lock-in for many years ahead. For that reason, it is crucial that the nations start including the highest share possible of renewables in their power matrix, which is the most cost-effective option for the regional economy given the aforementioned decrease in their LCOEs, discouraging technologies that contribute to climate change and that pose future economic uncertainties.

101. <https://www.igu.org/natural-gas-cleanest-fossil-fuel>

Figure 16. Projected cumulative thermal capacity installations (MW) per subregion, 2015-2030



Source: OLADE, 2018

CHAPTER 4

TRANSMISSION AND DISTRIBUTION

The chapter:

- a) Includes a summary of actors playing a role in, and key elements of the physical structure of, the generation transmission and distribution system.
- b) Examines the role of demand management, distributed and off-grid generation in the system.
- c) Reviews the potential of different storage options including hydropower as a large storage regional facility.
- d) Reviews the complementarity of different renewable resources and the current status and prospects for regional integration.



The transmission and distribution infrastructure are critical elements of the transition process. This section reviews the generation and transmission infrastructure available in the region and the transmission and distribution requirements to support a fully renewable power matrix. The overall premise is that regional deployment of the abundant renewable resource endowments would be able to meet overall demand, attending all domestic needs, and allowing for optimal use of generation assets, resources and storage but will require of an efficient, modern grid.¹⁰² Despite the common features of availability of renewable resources in the region, each country must consider their own characteristics and circumstances in order to determine priorities to advance the energy transformation and assure national energy objectives are achieved.

A supporting transmission and distribution infrastructure should be able to integrate large shares of variable resources with the baseload capacities provided by the existing hydropower, available geothermal facilities and other sources that could operate as baseloads. It should also be able to accommodate local stresses caused for example, by unexpected variations in rainfall or large demand surges. Regional connectivity will facilitate improvements in the transmission and distribution networks. A supporting smart grid¹⁰³ should be able to enhance stability and reliability, with ready access

to distributed generation systems while reducing overall costs,¹⁰⁴ enabling net metering¹⁰⁵ and the participation of power storage facilities and the end user. Therefore, the grid must be able to respond to more dynamic demand and supply conditions. Local off-grid systems serving the appropriate areas could strengthen the overall provision of power and provide robust demand/supply management for isolated communities. Likewise, digitization of transmission and distribution systems will facilitate entry of small and medium scale generation capacity and support optimal development of grid networks.

4.1 Structure of transmission and distribution

Most countries in the region have open, unbundled, markets operating over national grids with many private sector participants in generation and in distribution. Other countries have majority state assets, but are, in most cases, open to private investment. The domestic markets are normally regulated through an independent entity.

There is already a degree of integration in sub-regional markets with some companies involved in trans-national transactions in generation and transmission. The business of generation and distribution is well known and practiced. There is also ample experience with generation and distribution of hydropower.

102. Notwithstanding the common agenda of greater inter-connection and the advantages of a regional market for power, each country's conditions and priorities will in the end define the pace and scope of integration.

103. **Smart grids**, integrate the action of all users in the power network using computer-based remote control and automation. This two-way interaction is what makes the grid "smart". Smart grids allow for more efficient tariffs, that transmit efficient signal prices to the consumers and help to adequate demand to the production. It also allows the demand to provide ancillary services to the system.

104. The advantages of integration in a fully renewable power system have been reviewed by Aghahosseini A., et al, 2019.

105. **Net metering** refers to a system in which energy generators are connected to a public-utility power grid and surplus power is transferred onto the grid, allowing customers to offset the cost of power drawn from the utility.

While non-conventional renewable energy generation (wind, solar and others) is a relatively new, albeit high-growth business, an increasing number of utility-size renewable energy facilities have entered operation and are part of the distribution system. Some characteristics of the generation and distribution market in the target countries are included in Table 1.

Table 1. Some characteristics of the generation and distribution market in the region

Country	Market regime	Generators	Operators Distributors	Access (%)	Grid
Argentina	Open, unbundled, in a competitive, mostly liberalized market.	75% of generation capacity in private hands.	<i>Compañía Nacional de Transporte Energético en Alta Tensión</i> (Transener) is the lead operator of the national transmission grid. In the distribution sector, three private companies operate.	100	Two main interconnected systems, SADI for most of the country, SIP for the Patagonian region.
Brazil	Open, unbundled, with majority State's participation	Large government-owned companies account for 69% of generation. Remaining assets are in private sector.	ONS, a non-profit private entity operates the system. 40 transmission concessions; 64% of distribution assets are in private hands.	99	National, integrated, grid with international links to Paraguay, Argentina and Uruguay.
Chile	Open, unbundled	26 companies that participate in generation. Three main economic clusters control the sector: Endesa group, AES Gener and Tractebel (Colbún).	25 private distributors	100	4 electricity systems (SIC, SING, AYSEN and MAGALLANES) undergoing a process of grid integration serve most demand.
Colombia	Open, unbundled. Dispatch done on basis of least marginal cost.	10 main generators, all under private market regime. EPM, EMGESA and ISAGEN account for 80% of generation.	43 private distributors and carriers.	99.6	Country is interconnected with minor pockets of isolated demand. New 300 MW link to Ecuador being developed. Close to 70% of demand met through hydro.
Costa Rica	Mixed. Open to generation and distribution. No wholesale market.	State owned ICE is largest generator. Private companies have 23% of installed capacity and 15% of generation.	State owned (ICE).	99.6	Member of SIEPAC. Already at or near 100% renewables in electricity generation.
Mexico	In transition. CFE is now independent competing in market.	Open to market. Private companies can now generate power under results of long-term auctions.	State owned distribution infrastructure open to private installations.	100	Links to the United States, Limited links to Guatemala (200 MW) and Belize.
Jamaica	Mixed regime with monopoly on distribution. Open to private generation.	Privately owned with some state participation.	Privately owned with some state participation.	99.5	Island grid.
Panama	Mixed. Open for Generation and distribution with state participation.	Most capacity is in private hands with state participation in some cases.	State owned company in charge of transmission. Three private distributors all with partial public ownership (ENSA, EDE Metro Oeste, EDE Chiriquí)	100	National, Integrated, grid with international links to the rest of Central America (Member of SIEPAC).
Perú	Open, unbundled, in urban areas. Served by State in rural areas.	38 generators. EDEGEL, ELECTROPERU, are the largest.	22 private distributors and carriers.	96.4	National, integrated grid.
Uruguay	Generation is open to private participation.	State continues to operate transmission and distribution with open access.	UTE is the national distributor but large consumers can access the wholesale market directly.	100	National integrated grid with access to Argentina and Brazil.

Source: Data compiled by the authors, information on energy access from: <https://data.worldbank.org/indicator/eg.elc.accs.zs>; accessed August 12, 2019.

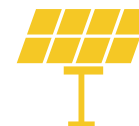
Generation companies work, in most cases, under very competitive market conditions. Some generators have global size assets and state-of-the-art management tools in hydropower generation and are a growing practice with other renewables. These are collectively a source of global expertise on the subject. There are also some large state-owned companies. For example, in Mexico CFE owns and manages 56 GW. Likewise, experience with management and maintenance of grids is extensive. In general access to the grid is very high (over 99% for countries in the analysis, based on total population) and electricity prices are low by world standards.¹⁰⁶

Distributed generation¹⁰⁷

Traditionally, distributed systems were thought of as solutions for isolated demand nodes, areas where linkage to the grid was not practical on account of economic or environmental issues. But, as the degree of access to power in the region has steadily increased, the role of distributed power has changed and is now seen as a mechanism that provides multiple benefits to the power system, such as: (i) reduction in technical losses in the transmission and distribution grid; (ii) flattening the peak demand curve; (iii) minimize the need for investment in new transmission capacity; (iv) mitigation of power price volatility; (v) increased security of supply and; (vi) mitigation of emissions. Besides, decentralized generation and the interconnection between regions or countries would help alleviate the variability of renewables by providing a complementarity between different energy sources. One rationale for implementing renewable distributed generation (DG) is to reduce the cost of electricity in areas that depend on expensive imported fossil fuels, such as in island countries in the Caribbean.

Renewable DG, mainly distributed solar PV, is starting to gain a larger share of Latin America and the Caribbean's renewable market.

Almost 2GW of distributed solar PV has been installed in the region by the first half of 2019.



870_{MW} Brazil ¹⁰⁸	817_{GW} Mexico ¹⁰⁹	119_{MW} Dominican Republic ¹¹⁰	27_{MW} Chile ¹¹¹
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Distributed solar PV systems reached grid parity under these four countries' DG regulations, thus having a disruptive growth in PV system installations – more than doubling installed capacity. High electricity prices for non-subsidized residential, industrial and commercial power consumers and abrupt cost drops in solar PV systems are the main drivers.

Emerging markets for DG in Latin America are starting to flourish, including Honduras, Colombia and Argentina. The last two have recently enacted DG laws. A growing number of Latin America and Caribbean countries are issuing net-metering/net-billing laws and incentive packages to promote DG deployment.

At the end of 2010, only two countries in Latin America had pledged net-metering/net-billing laws to promote decentralized generation from renewable energy sources. In contrast, in 2019, at least 15 have done so (Figure 1). Net-metering/net-billing is the instrument of excellence to boost self-consumption. Generally, the surplus energy injected into the grid under a net metering scheme is paid at retail prices through a monetary accounting system

106. With some exceptions, like for example in many Caribbean Islands where local conditions of generation and transport and limited competition have kept electricity prices high.

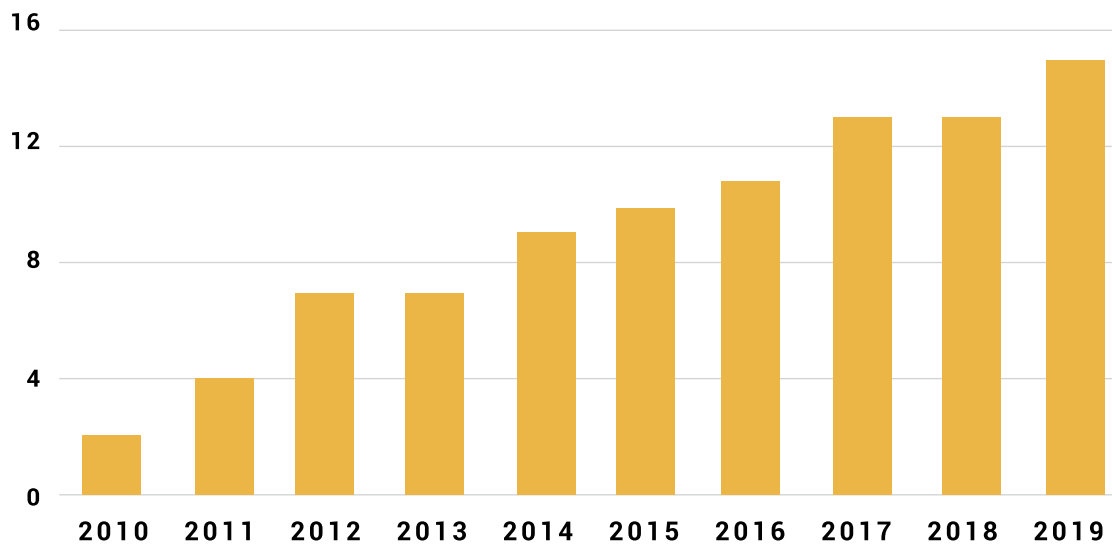
107. Distributed generation (DG) is generally defined as that connected to a distribution network, rather than to high voltage transmission network. The use of distributed power can produce electricity close to end users without reliance on extensive transmission systems and in many cases could offer electricity at competitive costs with reliability and security of supply.

108. <https://www.aneel.gov.br/>

109. https://www.gob.mx/cms/uploads/attachment/file/483322/Estadisticas_GD_2019-1.pdf

110. <https://www.cne.gob.do/medicion-neta/>

111. <https://acera.cl/wp-content/uploads/2019/11/2019-10-Bolet%C3%ADn-estad%C3%ADsticas-ACERA.pdf>

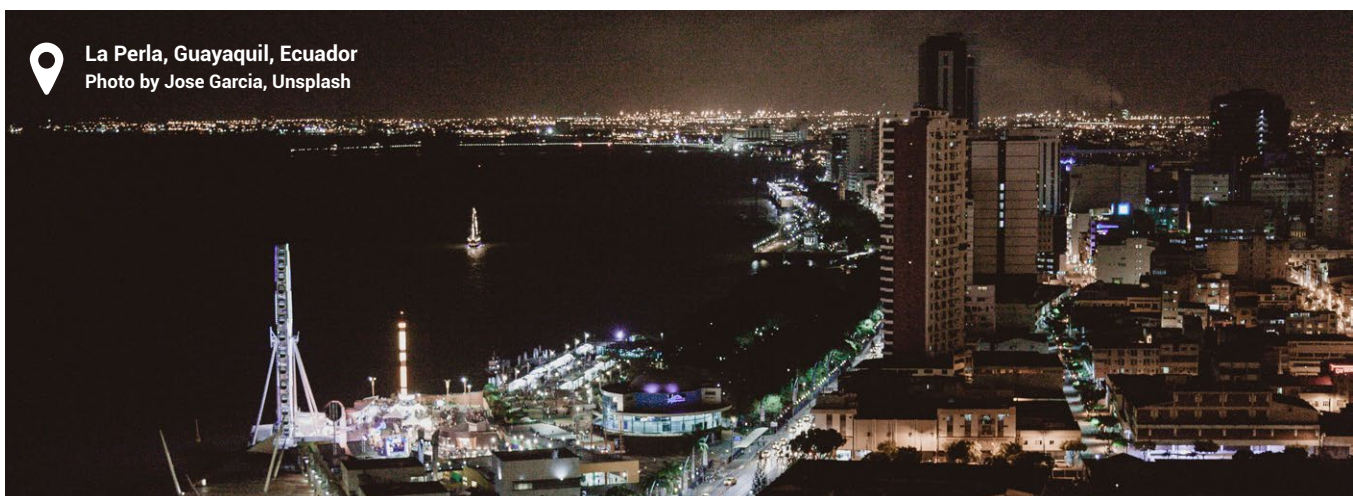
Figure 1. Number of countries in Latin America with net metering/net billing laws issued, 2010-2019

Source: Author's estimate with policy information from countries.

in the electricity bill or is returned as energy credits to offset future consumption. On the other hand, under a net billing scheme the energy surplus is given the wholesale monetary value. Mexico, as one of the most developed solar DG markets in the regions, counts with both mechanisms through which DG users can sell energy to the grid. Furthermore, a third mechanism called 'total sale' is available for independent power producers to sell all the energy generated by a distributed source (not for self-consumption) to the grid at wholesale prices. This report will use the terms net billing and net metering indistinctly as payment for surplus energy injected to the grid (See table 2). DG is allowing the end user to become a participant

in the demand/supply market. However, to realize its potential, regulators and grid operators would need to review market mechanisms and current tariff structures to accommodate DG characteristics and ensure an efficient allocation of costs avoiding potential cross-subsidization between customers.

Furthermore, another key element to consider in DG regulations is to incorporate simplified authorization procedures, such as, in the case of Mexico, a simplified interconnection procedure, the exemption of power generation permit, and standardization of contracts model for suppliers. One of the most common challenges this market faces is the lack of availability of



affordable and long-term consumer financing options (solar leases/loans). This is driven by the common perception, among commercial banks, that 1) the distributed solar PV credit market is negligible; 2) the technology and installation risks are high. Some countries, together with their national development banks and commercial bank associations, have established Distributed Solar Generation Finance Programs. Such is the case of Mexico (CSOLAR)¹¹² and Argentina (Renewable Energy Distributed Generation Fund - FODIS) that will offer financing on terms and conditions appropriate to the new solar asset. These solar-customized public financial schemes will facilitate the flow of long-term debt from commercial banks to the distributed solar PV market.

Table 2. Supporting tools for distributed power in the region

Country	Net Metering/accounting system available with energy (E) or monetary accumulation (M)	Maximum installed capacity allowed (kW)
Argentina	E & M	Not defined
Brazil	E	5000
Chile	M	2000
Colombia	M	15% of substation capacity
Costa Rica	E & M	15% of yearly demand
Jamaica	M	100
Mexico	E & M	500
Panama	M	500
Peru	Not defined	Not defined
Uruguay	E	100

Source: Based on data presented by Mejdalani A., et. al, 2018



The renewable DG sector is a strategic market to foster innovation and promote new business and job creation (Chapter 8). Such is the case of the Mexican solar DG market that has been estimated at US\$ 7 billion for 2024.



Up to 2019, US\$1 billion has been already invested with the creation of over 9,000 jobs.¹¹³

112. <https://csolarmexico.com/>

113. ASOLMEX, 2019

DG can be supported by local storage capability, enabling demand nodes to be grid-independent in practice.¹¹⁴ DG is not necessarily restricted to small installations. Economies of scale could make the difference in terms of overall viability of DG systems in a fully integrated market. For example, in the U.S., of the 83.7 MW of wind-tied distributed systems operating in 2017, 78 MW came from distributed wind projects using turbines greater than 1 MW (PNNL, 2018). Nevertheless, distributed power in LAC region is still largely based on solar PV installations. In the case of wind, DG installations remain small (i.e. 0.02% of total installed capacity for the Mexican market). However, wind and other renewable energy sources such as geothermal could eventually flourish. Some of those niches are presented in Table 3.

Table 3. Niches for distributed generation in highly integrated national systems

Application	Locations	Advantages
Isolated or hard to reach loads.	End of point for transmission grids. Island systems.	Lower transmission costs or only option available.
Concentrated demand with access to local solar or wind resources.	Mining facilities, port areas, large commercial establishments.	Lower costs of generation and transmission of a local system
Highly variable loads with ready access to storage capacities.	Electric transport fleet terminals, port facilities and intermodal electric transit points.	Storage provides the ease of access and peak loads too onerous for the grid system.
Seasonal food processing or agro-industrial centers with access to local solar or wind resources.	Rural areas with limited transmission systems.	Lower overall generation costs
Residential, commercial and industrial power consumers.	Individual households, commercial buildings and industries.	Could be financially attractive in areas with high solar radiation and high electricity costs. Economically competitive DG solar PV systems.
Integrated solutions	EV charging infrastructure	Clean energy and lower generation costs.

Source: Author's compilation

114. This has created anxiety in distributors and carriers, as they could face declining use of the grid and force a different business structure or end up charging more for their services from a smaller consumer base.



As more players enter the market for provision of services, the electricity system will shift towards decentralization, becoming a system of systems, where the traditional vertically integrated energy scheme will need to adapt to integrate a great number of distributed energy resources. Prosumers,¹¹⁵ electric vehicles, demand-response and many more technologies and agents making use of the grid and providing ancillary services, like storage, generation, flexibility and perhaps even balancing are slowly but steadily becoming a reality. This new meshed system will open opportunities for traditional utilities to provide services for which they already have the know-how and the technical capabilities. Furthermore, grid operators, notably, distribution network operators will play a crucial role in managing, balancing and coordinating all the new energy flows and economic transactions that will be generated to make that system possible.

The development of policies and tariffs that make the system viable for all agents should be in the agenda of legislators and regulators in order to provide a fair transition for all parties involved and the society as a

whole, taking into account the economic sustainability of the grid, energy poverty, energy security and the environment. These would include, the set-up of a supportive policy framework; provisions/regulations for access to the grid, including net metering and associated accounting systems, and allowances for installed capacity for self-generation.

Off grid systems

Even in a region with relatively high access to the grid, completely off-grid systems, can be justified in areas where transmission costs are very high or where there is still no connection to the transmission system. Distributed systems are niches for their use. For example, isolated areas (islands without a national grid, or isolated mountains or forest and indigenous communities), necessitate, by definition, the use of off grid supply. There are also cases in which reaching local demand through expansion of the grid is not advisable because of economic costs and/or environmental and social impacts. While the total demand represented by these systems is marginal to the overall regional needs, off-grid

¹¹⁵ Prosumers are energy users who consumes, produces, stores and shares energy with other grid users.

systems can provide solutions addressing important social needs of isolated communities. The share of power generated by off grid systems in the region has always been small and has been falling as access to the grid has increased.

Demand Management

The balance of supply and demand is becoming more complex with the emergence of sizable amounts of variable and intermittent sources of energy, distributed generation, utility-size energy storage and coupling of the power demand of the transport sector. There are now advanced management systems capable of integrating dynamic demand in the overall load. Smart metering is an example. Demand management strategies will need to align with these new elements assisted by new management tools. Also, users will have a more dynamic role to play in the future demand and supply balance of the grid. This level of complexity will require of control technology and the deployment of adequate business models¹¹⁶ for utilities and other power suppliers. The participation of large shares of variable renewable

energy sources, together with an increased demand of an electric transport sector, requires active demand management to ensure the integration of these resources and flexibility of response. Fortunately, there are now systems and software available to support effective management and optimization of costs. Flexible, intelligent demand management is an important element in the decarbonization process. It can help with the adjustments required by distribution networks and encourage innovation. Some elements to consider in effective demand management and management strategies are summarized in Table 4.

Transmission costs

Transmission costs are an important component of total electricity costs. These would typically cover the cost of the transmission infrastructure, losses and administration costs. As the grid has grown in complexity and coverage, reaching even small demands in remote locations, the overall costs of transmission and distribution have escalated. In the U.S. costs were estimated at US\$ 0.041/kWh in 2018 but are projected to increase to US\$ 0.051/kWh by

Table 4. Elements to consider in effective demand management and examples of management strategies in a more dynamic grid

Supply/Generation system	Added complexity	Management strategy (smart grid provisions)
Distributed energy resources (DER): distributed solar, wind, storage.	Requirements in planning coordination and information systems.	Distribution planning tools. Cost effective price signals. Smart metering.
Intermittent (variable) supply from solar/wind/others.	Mismatches between generation and demand.	Grid modernization and integration investments. Coupling of hydro power or other baseload providers with variable sources in dispatch systems.
Transport or other sector loads as new sectors of the economy electrify.	Large additional demand from disperse users and nodal (fleet) points, may strain grid.	Cost effective price signals and provisions for Vehicle to Grid systems and valley filling. Management programs for spillover demand to residential and industrial sectors.
Utility size storage.	Planning, market and information requirements to incorporate expansion in storage capacity at multiple nodes.	Contractual demand response programs. Forward capacity market provisions allowing storage to participate.

Source: Author's elaboration.

116. https://www.acatech.de/wp-content/uploads/2017/11/ESYS_Position_Paper_Coupling_the_different_energy_sectors.pdf

2050 (USEIA, 2019). In Latin America transmission costs have been reported at 10% of the costs of generation in Peru and at US\$ 0.070/kWh in Mexico (CRE, 2019). CAF has estimated a tag of US\$ 4.6 billion investment required to establish the most critical links (CAF, 2012).

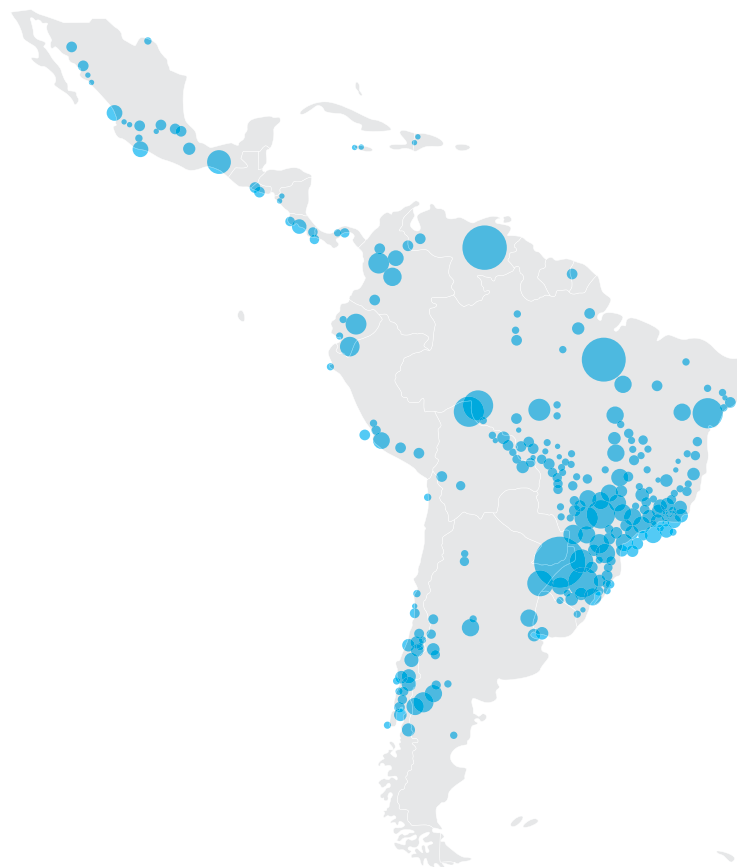
The deployment of modern transmission infrastructure, like HVDC will reduce losses over longer transmission distances and contribute to a reduction in transmission costs in integrated systems. Behind-the-meter systems and distributed generation may reduce transmission costs at a local level. Adoption of new management systems and digitalization with technologies like artificial intelligence, big data or block chain will also facilitate the transition and have the potential to reduce overall distribution costs. The transmission and distribution costs are not expected to vary greatly between the BAU and intervention scenarios.

4.2 Power storage

Hydro-based storage capabilities

Countries in the region have a large energy storage capacity represented by multi annual and other large-scale reservoirs. The energy storage potential of all the large reservoirs in the region when filled at capacity is estimated to be at about 0.2 TWh (Annex 4). Many of these reservoirs operate for domestic markets. The big exception are the complexes of Yacireta-Itaipu-Salto Grande which link Paraguay, Argentina, Brazil and Uruguay, not just through interconnections but through binational power plants. Figure 2 presents the location of all hydropower units in the region that are 1 GW or higher. Hydropower storage has increased its relevance in a climate with more intense periods of rainfall and longer periods of drought. Table 5 summarizes the significant role

Figure 2. Location and relative nominal potential of hydropower reservoirs



Source: Global Energy Observatory, Google, KTH Royal Institute of Technology in Stockholm, Enipedia, World Resources Institute. 2019. Global Power Plant Database v1.2.0. Published on Resource Watch (<http://resourcewatch.org/>) and Google Earth Engine (<https://earthengine.google.com/>). Accessed through Resource Watch, (July 2019). www.resourcewatch.org.

Table 5. Role of hydropower in domestic markets

	Nominal Hydropower capacity (GW)	Peak Power Demand (GW)	Base Power Demand (GW)	Nominal Hydropower as share of peak demand (%)	Hydropower delivered to the grid as share of total (%)
Argentina	10.1	21.7	12.9	46	23
Brazil	109.2	83.5	51.0	131	63
Chile	6.7	10.4	7.4	64	30
Colombia	11.0	9.3	6.3	118	67
Costa Rica	2.4	1.6	0.9	177	73
Jamaica	small	0.6	n.a	small	3
Mexico	12.6	37.9	30.5	33	12
Panama	1.8	1.6	1.0	112	70
Peru	4.9	6.5	n.a	75	58
Uruguay	1.5	1.6	1.0	94	52

Source: Nominal hydropower capacity from Enerdata. Peak and base demands from daily load curves provided through OLADE, except for Mexico, Chile, Peru and Jamaica.¹¹⁷

that hydropower capacity plays in domestic markets today. In many cases, the installed hydropower is near or surpasses peak demand. In practice, this only happens during seasons of intense rain and for short periods of time, when the reservoirs are at capacity. The data in table 5 illustrate a system that operates largely on the back of hydropower generation to meet baseloads and provide a margin of safety.

While heavy reliance on hydropower reduces LCOE and carbon emissions, it can also increase vulnerability to climate change impacts. There is a lack of consensus between the available Global Circulation Models (GCMs) on whether the region at large will experience drier or wetter conditions under a warmer climate, during this century, and therefore

a net impact on hydro storage cannot be predicted (W Vergara and S. Scholz, 2011). Nevertheless, most models indicate a concentration of rainfall and a lengthening of periods under drought conditions. An analysis performed by UNEP and OLADE (2017) points to net changes in streamflow for the region affecting hydropower generation vulnerability to changes in climate and water resources, with a potentially large impact on overall runoff in the region. Thus, countries with a high reliance on hydropower would strengthen their resilience to extreme weather conditions by diversifying their power matrix through deployment of other renewable sources of energy. The issue of vulnerability of power systems to climate impacts is discussed at length by Ebinger, J. and Vergara W, 2011 and is further addressed in Chapter 7.

117. Mexico data from CENACE (<https://www.cenace.gob.mx/GraficaDemanda.aspx>) accessed September 2019. Data for Chile from CNE (Comision Nacional de Energia: <https://www.cne.cl/estadisticas/electricidad/>) Maluenda B and J. Moreno (2018) for baseload. (https://www.researchgate.net/publication/328103071_New_Market_Interactions_in_the_Chilean_Electricity_System_with_high_Integration_of_Variable_Renewable_Energy). Data for Peru from Ferrari, U. (2018) (<http://www.sectorelectricidad.com/21534/peru-mercado-electrico-peruano-y-participacion-de-las-tecnologias-con-rer/>). Data for Jamaica from: <https://www.nrel.gov/docs/fy15osti/63945.pdf>



Hydropower-based systems would see an increase in flexibility and efficiency if their capacity could operate beyond national borders, during periods of intense rainfall. Countries with complementary rainfall patterns, for example those located in the inter-convergence tropical zone (Costa Rica, Panama, Colombia, Ecuador and parts of Peru and Brazil) may find opportunities to dispatch or be dispatched stored hydropower from countries outside the area at appropriate times. This is a key argument for interconnection of national systems.



Existing hydropower has an important role in facilitating market entry of wind and solar plants given the proven complementarity of natural resources. This complementarity can be used to establish hybrid energy sources like wind-hydro or wind-solar-hydro in a single power station.

While hydropower is an asset that facilitates the transition, no new large hydro units are expected to be deployed given the increasing environmental and social concerns and the fact that the best locations for hydropower are already in use.

Other large storage systems

There are other options to manage peak load or store intermittent outputs at times of low demand:

- a) At the utility level, lower costs in storage in large batteries have the potential to make them viable for both charge and discharge from the grid and ramp up and down at speeds that traditional generators can't duplicate. Utility-size, high capacity systems are already in the market in the range of tens of MWh and others are under development with ratings of several GWh.
- b) Molten salts are already in use in concentrated solar power (CSP) units with ratings of tens of GWh, as is the case for the plant under construction in Cerro Dominador, Chile.
- c) PV plus storage systems are under development, with one already installed in Mexico with a generation capacity of 32 MW that includes a lithium-ion battery storage system with a capacity of 10.5 MW/7.0 MWh.¹¹⁸
- d) There are other power storage alternatives (see for example EESI, 2019, IRENA, 2017, for a comprehensive list of alternative systems) in operation. For example, Argentina has had pumped-storage hydropower between reservoirs, since the 1980s. But, other systems like compressed air or flow batteries have no or relatively limited operational experience in the region.

118. In Mexico, General Electric has announced plans to develop five battery-based energy storage projects that will help integrate solar and wind projects into the grid. And in the Dominican Republic, two 10MW arrays of batteries, were installed in 2017 (WEforum, 2018). <https://www.pv-magazine.com/2019/05/02/regions-first-utility-scale-solar-plus-storage-project-comes-online-in-mexico/>

The combination of renewables and battery storage technologies in the region is of interest to utilities (Moreno R., 2018) in view of the potential for shifting power between different dispatch periods (temporal energy arbitrage); bringing storage to bear during periods of peak demand (congestion relief); and providing additional capacity through storage (investment deferral). Additional cost reductions could make large scale energy storage very competitive.¹¹⁹

Storage technologies can complement and strengthen a matrix relying on renewable resources, helping guarantee its zero-carbon character. The very large installed hydropower capacity in the region and potential for diverse storage systems can play a role in providing flexibility to power supply. To realize their potential, regulators and grid operators would need to create market mechanisms that accommodate batteries' unique abilities.

Electricity corridors

Efficient, long-distance movement of electricity requires of cost competitive systems that would minimize transmission losses. High Voltage Direct Current (HVDC) systems can meet these requirements. Specifically, and for purposes of this report, HVDC systems are highlighted for:

- a) Enabling the participation of offshore wind systems, or marine energy resources at lower costs over longer distances.
- b) Making possible the asynchronous linkage of renewable resources to the grid.
- c) Reducing the capital, operational and maintenance costs of transmission over longer distances.

HVDC systems would be required for large scale integration in the mainland of the region. Systems are already deployed in the region with accumulated management and operational experience.



The longest HVDC system in the world is installed between Porto Velho and Araraquara in Brazil over 2400 km, with capacity to accommodate 7.1 GW. Several HVDCs are under planning or implementation in the region. These include the HVDC Kimal-Lo Aguirre in Chile with a 1500 km extension and 600 kV capacity.¹²⁰ HVDC systems will not be competitive in the Caribbean given the short distances and low energy consumptions of the islands. Nevertheless, overhead or submarine connections between islands could be considered if there is complementarity of renewable resources and it makes economic sense. Furthermore, special attention should be paid to the maintenance of transmission and distribution lines in this subregion in order to reduce losses and improve the system.

119. At a retail level, one emerging option consists of electric battery systems connected to converters as an option that can be used for single households (or behind the meter) and is already being deployed in electric vehicles.

120. This system makes up part of an aggressive power system integration effort and is being considered in part on account on the potential for future large capacity renewable facilities in the country.

Complementarity between hydro, wind, and solar resources in the region

The concept of complementarity between renewable energy resources is based on the seasonal variation in the intensity of these resources and the shorter-term intermittencies associated with wind, solar and marine resources. Clearly, the matching of these resources is very dependent on the specific locations. Several studies have looked at the potential complementarity of rainfall patterns and solar and wind regimes in areas in the region.¹²¹ These and other reports have found various degrees of complementarity that, in general, back the notion that some integration between areas with corresponding availability of resources would strengthen the stability and reliance of power supply. There is now enough information to reach some general conclusions at a regional and sub regional level.

- At a regional level, there are significant potential opportunities to use complementary available resources in (solar, wind and hydro) energy hotspots that justify a higher degree of integration in the region.
- Brazil plays an oversized role regarding the facilitation of resource complementarity and potential for integration since it “presents the strongest capacity to complement and be complemented” through the access to hotspots and the supply to demand nodes.
- Hydropower resources from some Andean nations show a strong complementarity with wind regimes.
- Colombia has conditions for forceful deployment of available wind resources to complement hydro generation capacity and as insurance against variations in rainfall patterns.
- Uruguay has already illustrated the benefits of integration by effectively linking wind availability with domestic and regional (Brazil) hydropower resources in their power matrix.



Sierra de los Caracoles wind farm, Uruguay

- The experience in Costa Rica illustrates how investments in geothermal contribute to increase firm base load capacity of hydropower to address variations in demand. The blending of hydro and geothermal resources, typical of several countries in the region, can be managed to maintain a zero-carbon emission system and be more representative of conditions in the region.

121. These include wind and hydro in Colombia (Vergara et al, 2011). Similar assessments have been made for wind, solar and hydro for electricity generation in Uruguay (Chaer R., et al, 2014; E. Cornalino, 2016), Argentina (), for Central America () and for the region at large (Nascimento G., et. al, 2017). A landmark study on the subject was also conducted for the Western United States (Ackert T., and C. Pete, 2012).



4.3 Grid integration

There is a large renewable resource endowment in the region and a high complementarity of wind, solar and hydro. However, can these systems operate in a coordinated manner? The power market in the region is largely self-contained with national grids used mostly for domestic markets, attending local demand, even where regional links are established. There are, however, several interconnected systems in the region and country-to-country links that form the basis for a larger integration effort. The most relevant for purposes of this analysis, include:

- a) SIEPAC (Central American Electrical Interconnection System). This is an interconnection of the power grids of six nations in Central America. It consists of an 1800 km 230 kV transmission line between Guatemala and Panama with a capacity of 300 MW. Last year it reported sale and purchase of 1.5 GWh (BNAmericas, July 5th, 2019).
- b) Argentina-Brazil HDVC interconnection. It consists of a 490 km 500 kV transmission line connecting northern Argentina and southern Brazil. It has a capacity of 2200 MW, and has operated since 2002. This link has proven useful to dampen the consequences of prolonged droughts in Brazil.
- c) Bi-national hydropower plants. Yacireta, Itaipu and Salto Grande are hydropower plants serving more than one nation, including a long HDVC transmission line to reach demand nodes a distance from the units. Brazil, Argentina and Uruguay are linked in the system.

- d) Colombia's connection to Ecuador through a link with 330 MW capacity at 230 kV.
- e) Argentina's connection to Chile, through a link are linked with 720 MW capacity at 345 kV.
- f) Peru's transmission connection to Chile, which is under discussion and could potentially enable the joint use of abundant solar resources from the Atacama.

Most of these systems have been in operation for decades and represent a valuable management and operational experience, even if the overall capacity of transmission is relatively modest. Additional links have been proposed that include:

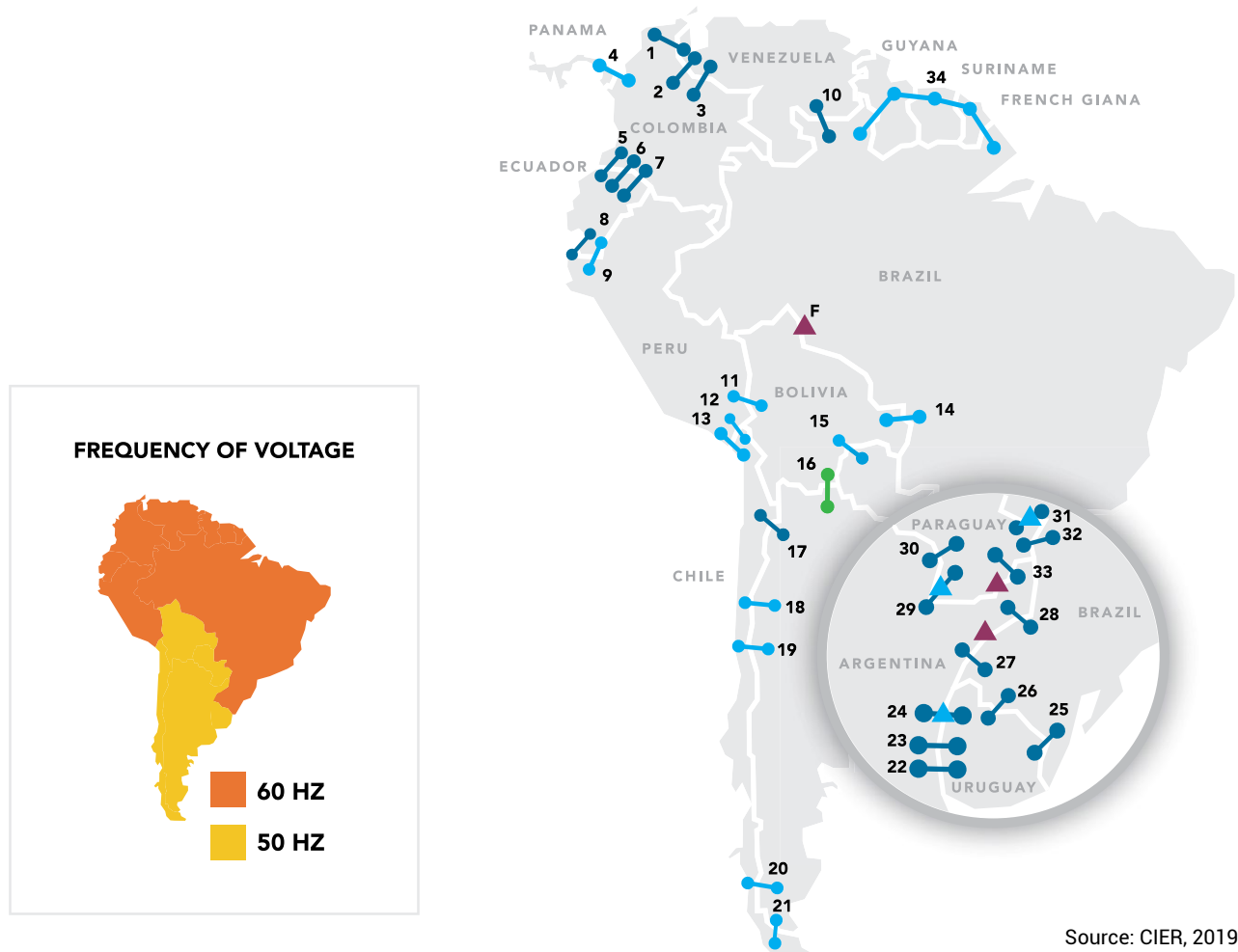
- a) SIEPAC II, a second high-voltage line connecting Panama to Guatemala has been proposed allowing a higher level of dispatch. The cost has been estimated at \$370 million. BID Invest is supporting the analysis required.
- b) SINEA is a proposed link between Colombia, Ecuador, Peru and Chile (Andean Power Corridor).
- c) SIEPAC-Colombia, a link that is also under analysis and would connect Colombia and Panama and therefore the SIEPAC system.
- d) Proposals to strengthen the links between Argentina and Chile and between Brazil, Argentina and Uruguay.
- e) The main interconnections in the region with the location of large reservoirs, and existing HVDC systems in operation or planning, for the countries of interest (as shown in Figures 3 and 4).

Figure 3. Regional electricity links in Central America, 2019



Source: CIER, 2019

Figure 4. Regional electricity links in South America, 2019



Source: CIER, 2019



It is apparent that linking the Central American and the Andean markets and establishing a link between Argentina and the Andes would link most markets without the need for intervention in the Amazon region.

The region has the potential to strengthen interconnection of power grids with benefits in terms of better supply demand conditions, especially when counting with large participation of intermittent sources as envisioned under the intervention scenario. It would also provide better utilization of its large hydropower storage capacity and thus potentially lower overall generation costs. It expands the market available to efficient generators.

4.4 Characteristics and benefits of a smart integrated grid in the region

A smart regional grid designed to cater to a 100% renewable power system, and a higher level of integration with demand, would need to:

a) Accept large shares of intermittent or variable renewable energy sources, dampening fluctuations and taking advantage of existing complementarities between hotspots.

b) Provide a link between major reservoirs in different climatic zones (areas with complementary pluviometry) allowing effective share of baseload at a regional scale.

c) Allow the integrated operation of storage systems and demand management systems.

d) Enable the operation of distributed power in nodes connected to the grid for stability and reliance.

e) Provide efficient, low loss, competitive, transmission systems over long distances and with enough capacity.

f) Permit the integration and demand and supply management of an extensive fleet of plug-in electric vehicles.

g) Enable a high-level of market transparency.

The structural and resource elements to support a smart regional grid are present in Latin America. The market operates in a relatively efficient manner, under a competitive environment. Also, the region already possesses already key elements of an integrated grid, a substantial hydropower storage capacity, large hotspots of intense renewable sources and conditions of complementarity between hydro, solar and wind. There are still gaps and elements missing, and policy instruments that could be used to accelerate the transition toward a smart, regional grid.

CHAPTER 5

TECHNOLOGY AND ECONOMIC TRENDS OF ELECTRIC TRANSPORT

This section reviews current technology trends in electric drives, storage facilities for vehicles and charging stations of relevance to the region. An assessment on impacts on energy use by electrification of transport and updates of projections for financial costs of passenger and cargo movement, are also included.

Reductions in energy storage costs, especially in lithium-ion batteries, make it possible to consider faster market entry of electric vehicles. Also, increases in energy density of electric batteries has enabled improvements in vehicle autonomy, which has been a constraint for adoption of electric vehicles. Figure 1 summarizes the recent trend in cost reductions and the anticipated trend to mid-century for costs of lithium-ion battery packs for electric vehicles by 2019, battery prices fall nearly 50% in 3 years, spurring electrification. Given the participation of energy storage in the total cost, it is now widely anticipated that electric vehicles will reach cost parity with internal combustion engines in just a few years.¹²²

Besides energy storage, there are other aspects of technology that are changing fast with applications for light, medium and heavy-duty vehicles. These include:

a) Deployment of dual battery systems that could reduce overall battery costs for scale up applications. Fully loaded, large passenger or cargo vehicles require batteries for long driving range (large storage) and for acceleration (high power). Using a dual battery system comprised of batteries with large storage and of electrical capacitors have been shown to meet

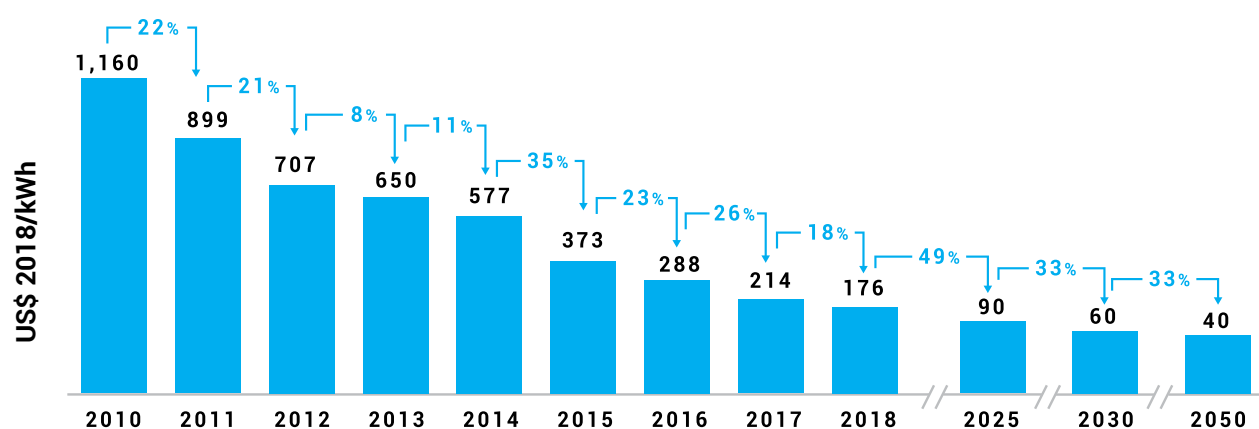
instant power requirements during acceleration and deliver cost savings (J. Liu et al, 2017).

b) Deployment of high-performance charging infrastructure with high voltages suitable for heavy vehicles (1000 volts or higher). Heavy-duty vehicles require of large capacity, high voltage charging stations to reduce idle time. It is critical to plan for energy storage at charging stations for buses or trucks requiring a rapid turnover.

c) New high-performance battery systems; for example: sodium-ion (Na-ion) batteries similar to lithium-ion (Li-ion) batteries but potentially cheaper; new battery chemistries as well as improvements in cathodes and anodes such as the use of new materials; solid-state batteries that permit the use of innovative, high-voltage high-capacity materials, enabling denser, lighter batteries

d) Development of electric highways would allow modified electric vehicles to charge while driving through an electric rail in the road. Electric highways have already been installed or are being tested in Sweden¹²³ and in Germany.¹²⁴ The concept is being applied to high density cargo roads. In Latin America it could offer a solution for intermodal transfer hubs. It could be applied to BRT routes.

Figure 1. Historical and projected costs for lithium-ion packs for electric vehicles, 2010-2050 (US\$ 2018/kWh)



Source BNEF, 2019; Bloomberg, 2019 and author's estimates.

122. <https://www.bloomberg.com/opinion/articles/2019-04-12/electric-vehicle-battery-shrinks-and-so-does-the-total-cost>

123. <https://www.forbes.com/sites/sebastianblanco/2018/04/30/sweden-opens-up-electric-highway-called-eroadarlanda/#3cd75f3346ce>

124. <https://www.bloomberg.com/news/articles/2019-05-13/germany-s-first-electric-highway-charges-trucks-as-they-drive>

e) Demand management of transport fleets. Peak power demand from a bus or truck on a fast charger is likely to be hundreds of times higher than the demand from an individual dwelling and may become a burden for power systems. Thus, heavy duty vehicles will need demand management and storage solutions. Moreover, all EVs will have the potential to become one more active player in the demand and supply balance of power systems

f) Mobility as a service. Electric vehicles could become an essential element of a shared, automated and electric future mobility.¹²⁵ Trends shows a shift-away from privately-owned vehicles into usage of on-demand car services. This movement is fueled by several mobility service providers such as ride-hailing services, bike, scooter and car sharing programs, on-demand pop-up buses, and pooling services. Additionally, large car companies are expanding their businesses to include mobility services. This means offering services associated to transport with a focus on the passenger and not the machinery.

5.1 Passenger vehicles

Cars

The fast pace of motorization is unsustainable and likely to slow down in the future as a result of congestion and productivity concerns even if high rates of electrification are achieved. There is evidence of a reduction in automobile sales worldwide¹²⁶ and of growth of passenger miles by automotive slowing down in the United States (National Household Travel Service, 2019). This report argues that future fleet projections in the region will not reflect continued increases in light passenger vehicles but rather than public transport systems will gain in passenger share.¹²⁷ This argument is consistent with the fact that a car is parked 95% of the time, and that an increase in public transport usage or ride-sharing



services can help increase efficiency of vehicles and optimize space in cities. Furthermore, trends show that younger generations are less interested in owning vehicles as a result of the rising shared mobility options.

Buses

The large number of buses in the region, concentrated in urban areas and its high utilization rate per capita offer an important market for the development of an electric-bus and ancillary industry tailored to the regional needs. Common actions are identified among countries for the promotion of electric mobility. One of them is the electrification of public transport systems. Policy makers continue to push toward zero emissions public transport. Improving economics, while complying key performance indicators (KPIs), and growing concern about health and environmental impacts of emissions from ICE buses in cities are the main drivers. Momentum for electric buses is beginning to be built regionally.

125. <https://3rev.ucdavis.edu>

126. Car sales have been stagnant or falling during the period 2016-2019 (<https://www.statista.com/statistics/200002/international-car-sales-since-1990/>;

127. Concerns over mobility, congestion and impacts on productivity are independent of type of fuel used in transport. These concerns would be addressed through policies, regulations and investment in infrastructure that promote better use of public space. The Bus Rapid Transport systems constitute a Latin American developed solution but some others being tested in the region include, congestion pricing, automobile-free zones or periods and promotion of non-motorized transport. Also, in urban areas, it has been argued that most small vehicles are on the road for a limited amount of time over a given period and thus are not necessarily an efficient use of capital.



The total cost of ownership (TCO) of electric buses is reaching cost parity with ICE buses in some cities of the LAC region. This is mainly due to the development of new business models through tendering process for public bus system that are boosting electric buses adoption, such as in Santiago de Chile and Bogota.

The investment decision making under this business models was based on the TCO rather than the purchase price. In this sense, the TCO of electric buses was lower than that of ICE buses, mainly due to a 70% reduction in operating expenses.

The bus characteristics and requirements in the region are different of those under development elsewhere (capacity, climate control, route lengths). Age of bus fleets in Latin America is very diverse; in some cases, reaching up to more than 20 years of operation. For this reason, large number of buses will be tendered throughout the region in the short and medium term. This opens a window of opportunity to increase e-buses deployment. In addition, cities with higher emissions standards (EURO VI) are more easily able to transit to zero emissions public transportation, since purchase price gap between electric buses and ICE buses is reduced.

The region has been a pioneer in the development of the institutions, operational protocols and infrastructure for bus rapid transit systems. The growing number of BRT systems also represent a unique opportunity to develop technological and market solutions suited to address the electrification of this increasing demand.

5.2 Cargo transport

Trucks

As in the case of buses, electrification of road cargo, faces the lack of charging infrastructure. Delivery applications can be served through warehouse and depot facilities, but long-haul applications will require a different approach. Large capacity charging stations will be required along cargo corridors combined with improved capacity and storage batteries.¹²⁸ Electric trucks in the region will become a viable freight and logistics tool provided that supporting infrastructure and supporting regulations are available. As discussed earlier, another alternative for long-haul or heavy-duty transport is the set-up of electric highways.¹²⁹ Alternative fuel options are being consider worldwide, such as hydrogen. Green hydrogen is produced from electrolysis of water using renewable energy and is completely CO₂-emissions free. The use of hydrogen is at an infancy stage and its production is very expensive (2.50 to 6.80 US\$/kg). Nevertheless, the costs are expected to decline faster than projected.¹³⁰

In 2019, the electrification of other transport segments, such as official fleets, delivery and cargo fleets, as well as public sanitation, has become more evident. Mostly, consisting of pilot projects to evaluate the performance of the technology for later scale up. The road cargo transport offers opportunities for electrification at the point of use, which is particularly attractive for cities (about 70% of cargo transport in the region is carried by trucks). Electric small size trucks will provide an opportunity for cargo applications, as “last mile” delivery and small logistics, particularly in urban areas. In this segment, the TCOs are starting to reach attractive values compared to those of small ICE trucks and thus same business models are beginning to evolve in the region.

128. A growing number of experiences and commercial announcements of electric cargo vehicles (Amburg, 2019) has been made. For example, commercial use of electric forklifts, hostlers, and small cargo vans is already a reality. Electric trucks are already in use for garbage collection in Brazil and food delivery in Brazil (<http://www.byd.com/en/news/2019-09-29/BYD-Delivers-to-Rio-de-Janeiro-the-Largest-Fleet-of-Electric-Waste-Trucks-Outside-of-China>) and as delivery vehicles to be built in Mexico (<https://mexiconewsdaily.com/news/slim-bimbo-bakery-to-build-electric-vehicle/>). The electric fleet in the region is already around several thousand vehicles. There are also heavy-duty trucks on the road under testing and commercial demonstration protocols. Most applications to date have been in urban applications but not yet for long distance hauls. Industry expects large trucks and long-distance cargo haulers could be road-tested by 2021.

129. An example is the Siemen's e-highway. <https://new.siemens.com/global/en/products/mobility/road-solutions/electromobility/ehighway.html>

130. <https://www.bloomberg.com/news/articles/2019-08-21/cost-of-hydrogen-from-renewables-to-plummet-next-decade-bnef>





5.3 Marine vehicles

Currently, electric ships are usually using a diesel-electric hybrid system, which is mostly used by offshore and cruise vessels. Nevertheless, all-electric barges and container ships are being commissioned in Europe and Asia. All electric ferries are also being built in Canada and Norway. In the region, there is still a lot of work to be done to set up electric fluvial or maritime transport, but the potential is significant. Fluvial transport offers a natural first step, where refueling depots could add electric charging facilities. Also, seaports can house charging and storage facilities. The Panama Canal could become an electric transit facility. Some of the specific requirements and opportunities associated with heavy duty vehicles are presented in Table 1.¹³¹

5.4 Charging facilities

The systems and technology of electric charging is evolving as fast as is the deployment of electric fleets. However, access to efficient and cost-effective charging may constitute an obstacle to faster electrification of the sector in the region. There are now faster and higher capacity charging systems that can cater from light to heavy-duty fleets. There are also developments in wireless charging, inductive charging, vehicle to grid (V2G) systems and storage systems linked to fleet charging stations as well as software developments in charging networks and management systems, interoperability, e-roaming, payment and ancillary systems. Despite the above, there has been an increase in the deployment of this type of infrastructure. This charging infrastructure

Table 1. Technology and market niches for heavy duty electric vehicles in Latin America

Market niches	Fleet	Considerations
BRT systems	 Buses	Large dedicated market already available. Estimated total fleet is about 4000 units. Vehicle technology is already available. Terminals can house storage and charging facilities. Electric highways can be incorporated into BRT routes. Opportunity charging
Urban service and cargo delivery fleets	 Medium sized trucks	Growing commercial experience, but atomized market. Charging infrastructure similar for buses and lighter vehicles but can be complemented with warehouse and depot facilities.
Inter-urban transport hubs	 Long-haul Trucks	Significant market with large energy requirements. Set up of infrastructure will require of major investments, inter-regional agreements on standards and logistics.
Port facilities	 Marine cargo and passengers, coastal and fluvial transport.	Port terminal and facilities can house required charging infrastructure. Market is large but needs of additional analysis.

Source. Author's elaboration.

131. Electric shuttle buses, school and passenger buses are now available at multiple locations in the region. In Latin America, there are buses in circulation in Brazil, Chile, Colombia, Ecuador and others. For example, by the end of 2019, Chile would have nearly 400 electric buses in operation, with an expected 500 more to follow next year. It aims to have a fully electric public transport system by 2040. Costa Rica has also committed to an all-electric bus fleet by 2040 and Bogota has announced the addition of about 600 electric buses to the Transmilenio system, placing it as the BRT with the largest electric fleet in the world.

has been developed mostly by strategic investors, such as oil and gas and utility companies and automakers. Mexico stands out in absolute terms, as the country with the highest number of public cargo centers in the region. While Barbados, stands out as the country with the largest coverage of recharge infrastructure by population density or number of registered electric vehicles. On the other hand, in 2019, Mexico launched the longest electric vehicle corridor (also known as the “electro corridor”) in

Latin America and the Caribbean with a distance of 620km. Uruguay was the first country in the region to install its electro corridor, followed by Brazil. For its part, Chile, as well as other countries and cities, are deploying charging infrastructure with the purpose of extending the autonomy radios of electric vehicles (Figure 2). In the region, it seems logical to give some priority to the design and implementation of systems that would serve multi passenger vehicles. At a private level, stations serving multi-dwelling systems,

Figure 2. Electric corridors for electric vehicles in LAC, 2019



Source: MOVE, 2019.

may be appropriate in urban areas of Latin American, where apartment buildings predominate. Whether fast-charging or slow-charging networks are deployed, it will depend on the local power and transmission systems, as well as on available incentives. For mass electrification of transport to succeed there is a need for a massive effort to build suitable capacity charging networks and develop measures to facilitate smart charging, through cost effective price signals and vehicle to grid provisions, for example, to minimize load disruptions in the grid. The current trends in the development of fast and high capacity stations with a summary of next steps needed is summarized in Table 2.

Table 2. Summary of technology trends and needs for charging stations in the region

System needs	Current Status	Next Steps
Inter-operability of charging systems	Several charging architectures, speeds and voltages have entered the market.	Market entry would benefit from the adoption of standards for light and heavy-duty vehicles at a regional level, facilitating integration and economies of scale. Need to expand charging infrastructure under appropriate standards of connectivity and interoperability.
Charging networks	Limited interconnection, billing and management services.	Need to build on current experiences to provide wider coverage and array of services.
Charging systems for heavy duty vehicles.	Limited depot chargers and opportunity chargers for heavy duty vehicles.	High power charging systems that are purpose-built for heavy-duty applications and use standardized technology for interoperability. Standards for demand management that avoid grid disruptions. For example, adoption of dynamic tariffs.
Demand management and storage systems at fleet stations depots and ports	Few demand management systems for fleets.	Standards and protocols to manage demand by large fleets and storage of power.
Wireless charging	Early stage of development.	Adoption on short distance heavy use corridors.

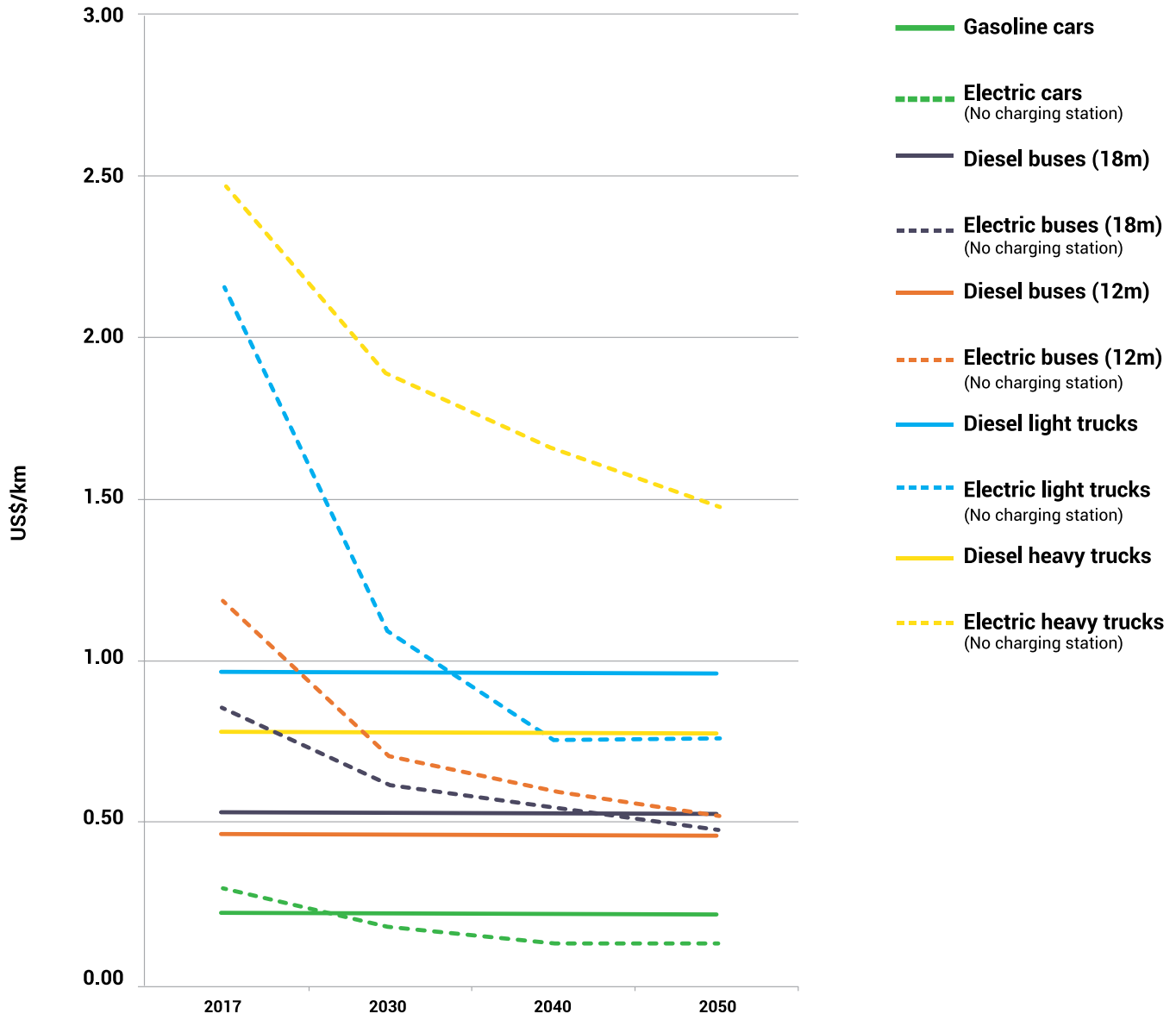
Source. Author's elaboration.

5.5 Projected costs of electric transport in the region

Future costs of electric transport, released in the previous report, have been revised on the basis of recent developments. These include, the availability of high capacity charging stations, reductions in the cost of electric vehicles, options for heavy duty and marine vehicles, and, reductions in the cost of storage. New data on the maintenance cost of electric trucks has also been incorporated. Assumptions for internal combustion vehicles have also been revised to account for new projections in the price of liquid fossil fuels and expectations of improvements in fuel efficiency. A summary of the assumptions used in the analysis is described in Annex 10.

The new results measured in terms of Levelized Costs of Transport (LCOTs)¹³² are presented in Figure 3. The results confirm an expectation of increased competitiveness for all segments of the fleet, with electric cars and buses becoming the cheapest alternative before 2025. It is worth noting that LCOTs presented in Figure 3 are an average for the region. In many cities, such as Santiago de Chile, Chile, and Bogota, Colombia, electric buses have reached cost parity with ICE buses. Savings from lower levelized cost of transport can transfer to the wider economy.

Figure 3. Projected LCOTs, by transport modes and technology, 2017-2050



Source: Author's estimates using GACMO. LCOTs does not include charging stations.

132. LCOTs measure the levelized capital, operation and maintenance charges during the lifetime of the vehicle. The calculation for the LCOT includes depreciation costs, fuel costs, insurance, financing, repairs and maintenance cost. The only difference with total cost of ownership (TCO) is that it does not include fees and taxes. This explains why the LCOT curves for ICE vehicles remains flat in time instead of increasing.

Impact on energy use and energy efficiency

The coming onstream of large loads from the transport sector will represent a sizable demand requiring additional generation capacity and distribution infrastructure. The new demand will need to be carefully planned to minimize increasing capacity needs on the electric grid. As a good fraction of light vehicles will be charged at home or at the workplace, this growth will impact residential and commercial electricity use (Rocky Mountain Institute, 2018). Heavier vehicles and fleets are likely to be charged in dedicated facilities, at terminal or depot facilities. The opportunities for integration of electric transport demand in the overall load curve of the electric sector are explored in Chapter 6.



CHAPTER 6

CHALLENGES AND OPPORTUNITIES OF A COUPLED TRANSITION.



Bogotá, Colombia.
Photo by R. Institute, Unsplash

This chapter deals with the strategic opportunities, costs and benefits of a coupled decarbonization of the energy and transport sectors. A coupled transition refers to the combined decarbonization of the power and transport sector taking advantage of the synergies and linkages between these two to accelerate the decarbonization process. The aspects considered in this chapter include:

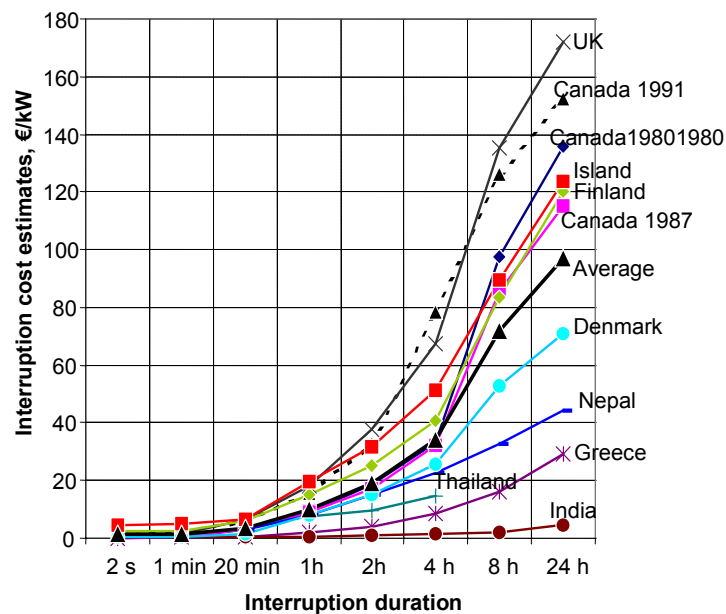
- a) Benefits on energy security.
- b) Impact on power generators (load balancing).
- c) Health benefits from improvements in air quality.
- d) Impact on refining costs and infrastructure.
- e) A dimensioning of the implications of stranded assets in oil and gas reserves and power generation.

6.1 Energy security

A secure energy system has been characterized (USDOE, 2017) as having: a diverse blend of energy sources; a reduced carbon footprint; access to local or domestic supply; and capacity to recover from external impacts (resiliency). The more the nations consume power from local, clean resources, the less exposed they are to impacts such as price volatility or political disruptions from the energy seller country, which may result in an energy crisis for the buyer. While it is difficult to monetize all these aspects, it is however clear that failure to ensure adequate electricity supply can result in serious disruptions to the economy. The associated economic impacts can also go well beyond the direct loss of revenue to utilities and economic output of affected sector and the population. It has happened in the past. For example, in Colombia, serious shortages of energy

were caused by an intense El Niño Southern Oscillation (ENSO) during 1992/1993 resulting in the depletion of hydropower reservoirs and triggering major losses for the economy for an extended period. Chile was impacted with an interruption in the supply of natural gas in 2005. More recently, in June 2019, a short-term blackout disrupted power supply in Argentina, Uruguay, and parts of Brazil. This section reviews the impacts of power interruption in the region and examines whether and under what conditions moving to a fully renewable power matrix would contribute to an increase in energy security in the power sectors of the countries in the analysis. Several methods have been proposed to assess the impacts, including the measurement of direct costs and/or valuation of prevention measures (UPME, 2015). There have also been a few studies assessing costs resulting from interruptions of power supply.¹³³ An assessment of the cost of power interruption in several countries

Figure 1. Estimate of cost of interruption of power supply



Source: Raessar P. et al., 2006.

133. (Shuai M., et. Al., 2018; A. Sanstad, 2016, Larse P., et. al, 2018). For example, an analysis of the cost of power interruptions in the US (K. Hamachi and J. Eto, 2006) concluded that the economy lost \$79 billion, most of it (72%) from the loss of commercial output due to power interruptions in 2002. A review of data from the blackouts in Los Angeles County in the USA, resulted in an estimated of 7% loss in regional GDP (Rose et al, 2005). Targosz and Manson (2007) conducted a survey to estimate the cost of inadequate power quality within the EU-25, which they quantified over 150.000 million Euros (90% arising in the industrial sector). Another study, LaCommare and Eto (2006), estimated the cost to US consumers related to power quality problems (interruptions and other quality events), finding out that the annual costs amounted 79.000 million US\$ with 70% arising in the commercial sector. In Latin America, in the Chilean Central Interconnected System (CIS), an analysis of the average outage costs for one month 10% energy outage were estimated at \$0.107/kWh (Fierro G., and P. Sierra, 1993). Direct costs of power interruption were estimated at about \$2000/kWh for the mining cost and between \$3-7/kWh for the residential cost (Cisterna, 2008).

(Raessar P. et. al., 2006), found an average cost of nearly \$20/kW for a two-hour interruption, that escalated depending on the duration of the event, reaching nearly \$100/kW for a disruption lasting one day (Figure 1).

Vulnerability of power systems in the region

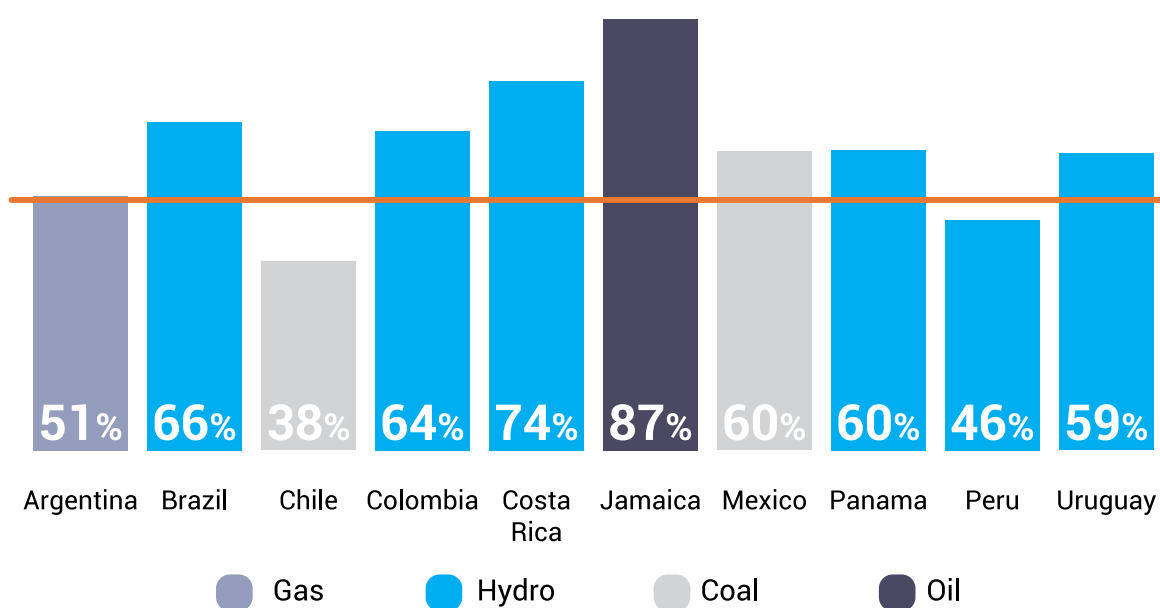
While these costs are large, the issue to address is whether moving the power matrix to a total reliance on renewables would contribute to a reduction in vulnerability. To assess the degree of energy insecurity, the analysis focuses on three aspects:¹³⁴ the diversity of the energy supply system; the dependence on imports; and greenhouse emissions (dependence on fossil sources). A suite of three corresponding indexes have been used in the technical literature (Gupta, 2016, U of Padua, 2016).

A more diverse power matrix and generation would confer better resilience to potential disruptions affecting any one source of power. The share of the largest power source in capacity and in actual generation in 2018 was used as an indicator of the diversity of the system. The results are summarized in Figure 2. Many countries in the region are reliant

on a single source in their generation capacity. The least diverse in 2018 were Jamaica (87% of generation from oil derivatives) and Costa Rica (74% of generation from hydropower). The most diverse were Chile and Peru with no source generating more than half of the electricity. Under a coupled decarbonization of the transport and power sector pathway, competition from solar, wind and geothermal would diversify the matrix.

The dependence on imports of energy feedstocks was characterized by the share of imports in total primary energy demand. This captures not only feedstocks for electricity generation but also the dependence on imported energy sources in other sectors of the economy, like transport. The most dependent nation in the sample is Chile, with 72% energy import dependence (Figure 3). Imports of transport fuels for transport have a sizable impact on energy dependence in Costa Rica and Uruguay. Under a zero emissions pathway in the transport and power sectors, imports of feedstocks for power generation and liquid fuels for transport would be obviated as these are replaced by local/domestic resources eliminating an important source of potential disruptions.

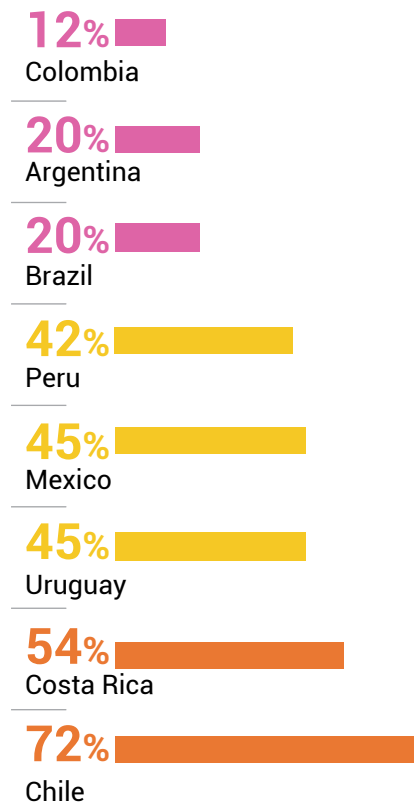
Figure 2. Share of largest generation of power supply, 2019



Source: Based on data from ENERDATA consulted September 2019.

134. A thorough assessment of types of risk in the energy sector can be consulted in University of Padua (2016).

Figure 3. Imports of energy feedstock as percentage of total primary energy supply (TPES), 2019



Source: Based on data from ENERDATA consulted September 2019,

Figure 4. Share of fossil fuel in electricity generation, 2019



Source: Based on data from ENERDATA consulted September 2019,

Finally, the reliance on fossil sources for power generation is reported in Figure 4. The countries most dependent on fossil fuels for power generation are Jamaica, Mexico and Argentina. Eliminating dependence on fossil fuels would eliminate potential price disruptions associated to the oil, coal, and gas markets and displace key sources of GHG emissions and most of the emissions of fossil CO₂.

In summary, under a simultaneous and coupled transition of the power and transport sectors, the diversity of supply will shift toward renewables, energy import dependence will be reduced as transport fuels and imports of power plant fuels would be eliminated and fossil fuel dependency of the power sector would be eliminated by mid-century. The largest change in the security indexes, would be experienced by countries with a large dependence on imported fossil resources (Chile and Jamaica), followed by countries with reliance on mostly one source of energy (like hydropower in Costa Rica, Colombia and Peru). Diversification of the power system with local/domestic resources that are oil-free would make the system more resilient to local and external shocks in these nations.

6.2 Impact on power generators (load balancing)

The entry of a large electric fleet in the region would add a substantial amount of additional power demand. The additional load has the potential to destabilize the grid unless new capacity and robust demand-management strategies are put into place that consider the characteristics of transport sector requirements. In addition, a grid with a substantial participation of intermittent sources (wind, solar, marine) will also require additional flexibility and storage capacity to maintain reliability of supply.

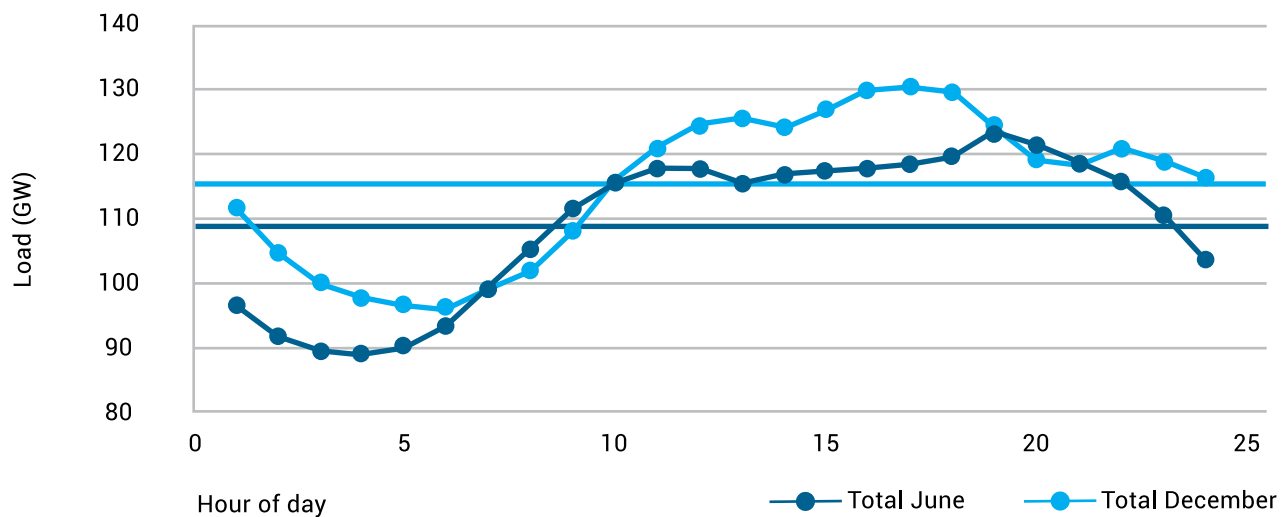
To visualize the potential characteristics of a sizable electric transport load, consider that the demand of one car commuting about 20 km would require 3-4 kWh/day, equivalent to the energy requirements of two middle class apartment dwellings in a typical urban area in the region. The load represented by these vehicles, if not properly steered, may require additional expensive capacity to meet peak demand or storage options. Some of the new transport demand will come through the commercial and

residential sectors for light vehicles and through the industrial and commercial sector for heavy duty and cargo vehicles.

The problem can also be appreciated by examining the aggregated load curve for the electricity system in Latin America, which assumes that all loads can be added in the region (for example through full integration at a regional level, as seen in Figure 5). Similar behavior exists at a national level.

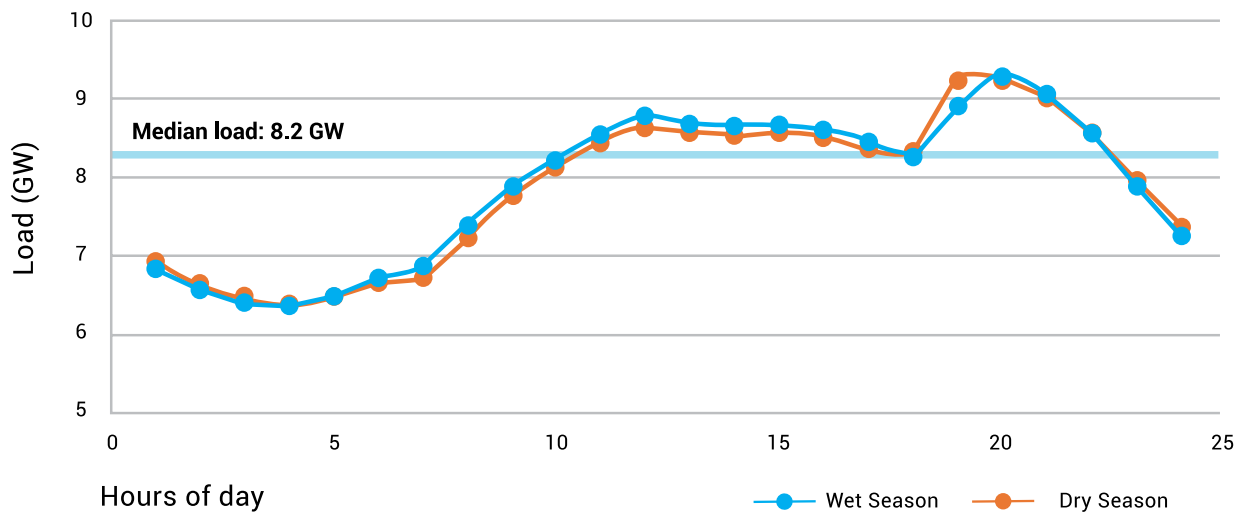
With proper management, transport charging demand in urban areas could be steered toward periods of lower load, in a process known as “valley filling” (Schmidt, E., 2017). In theory this process would enable the installed capacity to operate at a more efficient level by flattening the demand curve. In Colombia, for example, the valley area below the median daily demand has enough energy to meet 9% of the daily equivalent electric requirements of daily diesel use in transport (Figure 6).¹³⁵ If the supply in Colombia is readily available (if enough power storage capacity, in the form of water stored in the reservoirs or other means, like sizable batteries is available), the

Figure 5. Aggregated load curve for Latin America



Source: Compounded graph from country-based load curves provided through the Latin America Energy Organization (OLADE) in personal communication. Straight line indicates the mean load for each curve, 109 GW in June and 115 GW in December.

135. The area under the median daily load (8.2 GW) in figure 3 is estimated at 12 GWh/day (4416GWh/year). The diesel consumption from the transport sector in Colombia is equivalent to 59,800 GWh electric; 9% of the additional demand from transport, once fully electrified could be accommodated at the start of the transition, if those loads are scheduled during time periods that experience below the median demand for power. See annex 11 for details.

Figure 6. Load curve in Colombia and “valley filling” with electric equivalent of diesel demand

Source: Graph from country-based load curves provided through OLADE in personal communication.

addition of transport loads in periods of low demand would enable the generation of power at a lower cost. The reservoirs would be operating at a higher share of their capacity, delivering more energy against the same capital amortization charges as no additional capacity would be required. In practice, however, this would require management provisions at reservoirs to operate at a higher level of storage, implying some additional operation costs. This would apply to countries that are hydro-dependent in power systems today.

In addition, a large transport fleet (truck and buses) can also operate as a storage facility for energy, charging during low demand periods and potentially contributing to the grid during periods of high demand, as viable. This has been termed vehicle to grid operation (V2G) (J. Druiitt and Fruh W, 2012). This mode of operation would have a beneficial effect on costs of generation by preventing the use of peak supply plants. The deployment of V2G operations should be optimized in order to preserve (and extend) the lifespan of an EV battery.¹³⁶

6.3 Health benefits

Urban air pollution in Latin America, has long been identified as a major health concern.¹³⁷ It has also been linked to impacts on vegetation and in agriculture. The World Health Organization (WHO) has recommended human exposure indicators, including for particulate matter ($PM_{10} = 20 \mu\text{g}/\text{m}^3$ and $PM_{2.5} = 10 \mu\text{g}/\text{m}^3$), that should not be exceeded,¹³⁸ and national agencies like the U.S. Environmental Protection Agency have issued thresholds¹³⁹ that require attention from a health perspective, including for children, the elderly and other vulnerable groups. Exposure to harmful levels of some pollutants (particulate matter and ground level ozone) has been linked to increases in morbidity and mortality levels and losses in productivity. Even lower levels of exposure have some effects on health and productivity.¹⁴⁰ Many cities in Latin America exceed the safe thresholds set by WHO and despite efforts to address the problem, unhealthy levels of particulate matter (Figure 7 and 8) and other airborne pollutants continue to prevail.

136. https://ec.europa.eu/environment/integration/research/newsalert/pdf/understanding_degradation_battery_life_key_successful_v2g_523na1_en.pdf

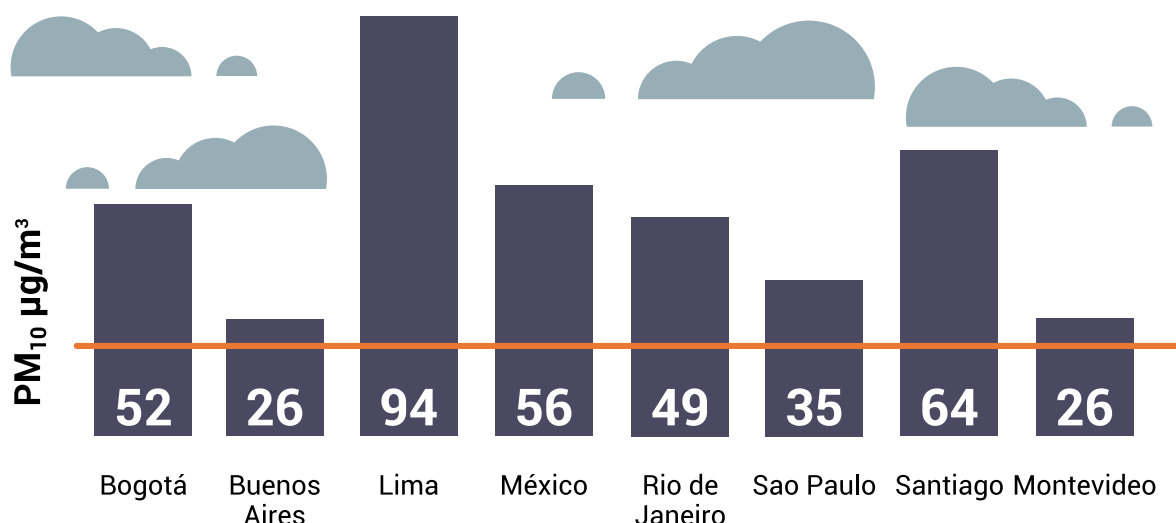
137. <https://publications.iadb.org/en/publication/urban-air-quality-and-human-health-latin-america-and-caribbean>

138. https://apps.who.int/iris/bitstream/handle/10665/69477/WHO_SDE_PHE_OEH_06.02_eng.pdf;jsessionid=AFB0FCE10BF597AD230326327D2D5E61?sequence=1

139. <https://www.epa.gov/criteria-air-pollutants/naaqs-table>

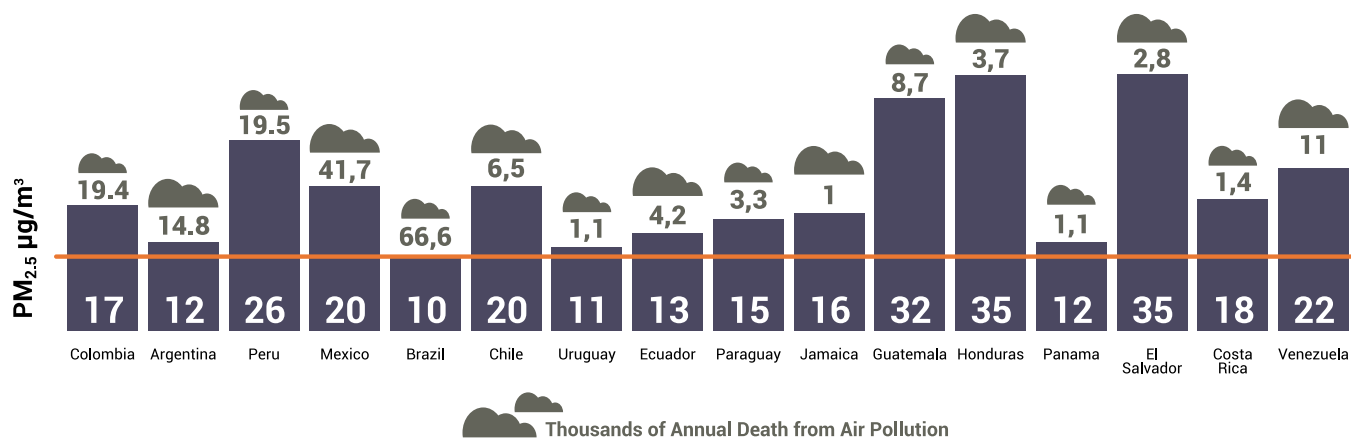
140. A recent study (UNEP, 2018 <https://www.unenvironment.org/news-and-stories/press-release/efforts-reduce-air-and-climate-pollutants-latin-america-could-reap>) estimated that 64,000 people died prematurely in the region from exposure to fine particulate matter (PM_{2.5}) and ground level (tropospheric) ozone. Ozone was also responsible for an estimated 7.4 million tonnes in yield losses of soybean, maize, wheat, and rice. If no action is taken to improve air quality, by 2050 annual premature mortality from PM_{2.5} and ozone exposure is expected to almost double while annual crop losses could rise to about 9 million tonnes.

Figure 7. Annual average of PM₁₀ in some cities in Latin America exceeding recommended levels of exposure, 2016



Source: WHO¹⁴¹; Rioja-Rodriguez et al, 2016. WHO Standard for PM₁₀: not to exceed 20 µg/m³ annual mean.

Figure 8. National annual average of PM_{2.5} for some countries in Latin America, 2019



Source: BreathLife campaign. WHO Standard for PM_{2.5}: not to exceed 10 µg/m³ annual mean.

The region is highly urbanized and therefore a high percentage of the total population in Latin American nations is exposed to these effects. PM₁₀ and PM_{2.5} are respirable particulate matter that can penetrate deeply into the lungs producing harmful effects on human health. Emissions of airborne criteria pollutants by stationary and mobile sources have been recognized to be a major source of concern with levels of emissions that can pose health and environmental costs.¹⁴²

141. https://www.who.int/phe/health_topics/outdoorair/databases/en/; https://apps.who.int/iris/bitstream/handle/10665/69477/WHO_SDE_PHE_OEH_06.02_eng.pdf?jsessionid=AFB0FCE10BF597AD230326327D2D5E61?sequence=

142. Besides being GHG emitters, power plants burning fossil fuels are potential sources of criteria pollutants (NO_x, SO_x, CO, and in the case of coal, can emit particulate matter (PM). The transport and distribution systems for these fuels can be net emitters of fugitive emissions containing volatile organic compounds. Internal combustion engines in the transport sector can also be emitters of PM and NO_x. Exposure to these pollutants has been linked to health impacts in some urban populations (World Bank, 2002).

Congestion in urban areas increases the exposure through reductions in fuel-use efficiency and associated increases in emissions. Estimates indicate that 19% of global black carbon emissions come from transport sources (World Bank, 2014). Incomplete combustion in stationary and mobile sources can be a source of black carbon as well (Vergara W., et al, 2014).¹⁴³

The assessment of health and environmental costs of air pollution in Latin America has been the subject of other studies (see Table 1). These include economic valuations of air quality in the Mexico City metropolitan area (World Bank, 2002), evaluation of health risks of air pollution in urban areas (Romero-Lankao, P. et. al., 2013), regional assessments using a damage function approach (UNEP, 2017), analysis of co-benefits for air pollution measures (Rioja-Rodriguez H et. al., 2016), and the quantification of the cost of measures required to improve air quality in urban areas in the region (IMF, 2017, Cifuentes L.A., et. al., 2005).¹⁴⁴ See details of this studies in Annex 9.

For example, Cifuentes and colleagues (Cifuentes L., et al., 2005) made a valuation of the health benefits based on a combination of U.S. based health impact models and transfer of valuations to Latin America. According to the analysis, for populations exposed to particulate matter (PM), the willingness to pay (WTP) to attain a 10% reduction in exposure was estimated at US\$ 44-103 per person year. This translates to costs of between US\$ 23 and 53 billion (2005) for the urban population in the region.¹⁴⁵

Table 1. Comparison of health benefit estimates from avoided exposure to PM (U.S. million \$/year)

Method	Value of health benefits (Billion US\$ 2018 /year)
Avoided exposure resulting from a 10% reduction of PM to urban populations (Cifuentes et al, 2005)	30-68
Elimination of PM from diesel combustion in transport (based on estimates for Mexico; OECD, 2014)	113
Elimination of PM from diesel combustion in transport in urban areas (based on region-wide estimates; Karagulian et. al., 2015)	32

Source: Author's compilation.



143. Emissions of black carbon from diesel engines used in road transport and agricultural machinery are of particular concern for their impact on health but also for their effect on reducing albedo in glaciers and mountain snow in the Andes.

144. The chemistry of ozone formation is much more complex and the valuation of exposure more difficult to assess. The cost of exposure to NOx has been assessed linking exposure to ozone concentrations and NOx emissions (Mauzeral et al, 2004). The benefits of reducing exposure in the United States was estimated by Lange S.S and colleagues (2018).

145. The total population of the region in 2018 was 642 million, with an estimated 80% living in urban areas.

Impact of mass electrification of the transport sector in air quality

The mass electrification of transport in urban areas would eliminate the emissions of PM from mobile sources, mainly by eliminating diesel fuel in transport. For the purposes of this report, the lower range of the most conservative value of the different studies was used as the avoided costs from the elimination of PM emitted by transport, for an annual avoided health costs of US\$ 30 billion (2018) (the quantification by Cifuentes, L.A. et al., 2005 for the entire region). The results are included in Table 1. UN Environment Programme and The Clean Air Institute are developing a brand-new study assessing the impact of electric mobility on air quality in 5 cities in Latin America. The results show that changing the entire vehicle fleet to electric vehicles in targeted cities – Buenos Aires, Santiago, San Jose, Mexico City and Cali– would avoid the early deaths of 435,378 people¹⁴⁶ due to reduced air pollutants by 2050.

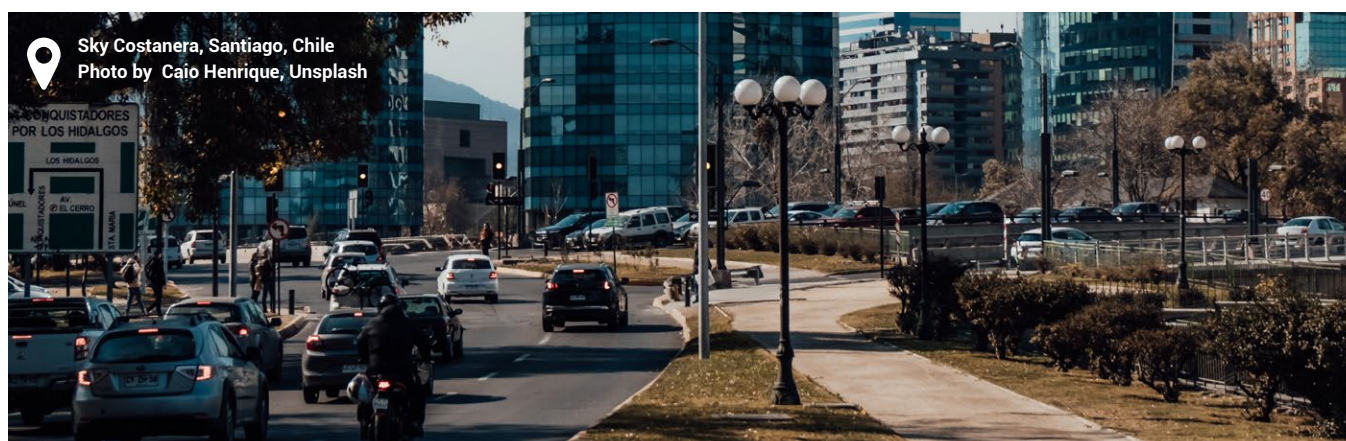
Avoided cost from reductions in exposure to ground level ozone

Likewise, mass electrification of transport in urban areas would reduce ground-level ozone concentrations and exposure, through the elimination of nitrogen oxides and volatile organic compounds (VOCs) from tailpipes. There is lack of information in the region to provide an estimated avoided cost of illness due to a reduction of VOCs.

6.4 Impact on refining operations

The transport sector drives demand for liquid fossil fuels and compressed natural gas in the regional economies. Total demand for gasoline and diesel has been growing rapidly to meet the requirements of a growing transport fleet. In 2018, demand for transport fuels, was estimated at 2.7 and 2.6 billion barrels per day (bbpd), respectively. This was met through an overall production of gasoline and diesel from domestic refineries of 2.3 and 1.9 bbpd (Stratas Advisors, 2018), equivalent to 29% and 32% in weight of the refined oil, with the balance provided by imports.¹⁴⁷

Typically, domestic refineries will try to maximize the production of the most valuable light or middle distillates (gasoline, diesel and jet fuel), with heavier products acting essentially as byproducts. To maximize their production, refineries use cracking operations to break heavier products into lighter distillates, but this causes an increase in refinery costs and an increase in the carbon footprint of refinery operations. Under a BAU scenario (see section 2), the demand for gasoline, diesel and other light distillates will continue to grow requiring expensive cracking operations and/or imports. However, under a scenario considering complete electrification of transport, domestic consumption of gasoline and diesel (middle distillates) and natural gas for transportation would be eliminated.



146. Estimates made by UN Environment Programme through the Methodology for the evaluation of integrated benefits of electric mobility policies, carried out by Clean Air Institute (2019). The estimates assume a gradual electrification of transport in the studied cities reaching 50% electrification by 2030 and 100% by 2050.

147. Total refining capacity in the region is about 7.9 bbpd (Strata Advisors, 2018)

The elimination of demand for gasoline and diesel will reduce the need for most refinery operations. Initially, entry of electric fleets, of the magnitude anticipated under the intervention scenario (all BRTs and 10% of car fleet by 2025), would reduce the need for imports of gasoline and diesel (estimated at 0.5 bbpd and 1.0 bbpd respectively by 2030); but, it may also result in a reduction in the refining costs of gasoline and diesel. The total electrification of fleets would eliminate the need for refining of middle distillates. While the transition takes place the savings in the refining costs of gasoline and diesel constitute an economic benefit from transport electrification.

For the purposes of this report, the refining cost savings have been estimated using the differential costs in refining per gallon of middle distillates between atmospheric distillation and fluid catalytic cracking (FCC, as an example of a secondary process to increase production of middle distillates) in a typical refinery. The capital cost for an atmospheric distillation plant can be 10% of the cost of an FCC

plant but can result in just 27% of the production cost per unit of refined product when compared with FCC (M. J. Kaiser, 2017). Refining costs are estimated at the order of 10-15% of total fuel production. Thus, by avoiding more complex and energy intensive refining processes, it is estimated that fleet electrification would also cause a reduction in the domestic production cost per unit of gasoline and diesel of about 3% in the total refining cost. Over the longer term, and as fleet electrification advances, there will also be impacts on other refined products like heavy fuel oil for marine transport. Eventually the refining market could be severely impacted by wholesale electrification of transport. The decarbonization pathway for the sector would then initially imply a reduction on production with the consequently reduction in profits of the refinery sector, leading ultimately to the mothballing of refineries. Some products from the refinery process used for industrial purposes would still maintain a demand which might be met through imports. The implications in terms of stranded assets are discussed below.





6.5 The stranding of capital assets from power generation and refining

The value of stranded assets from rapid decarbonization of the power sector in the region has been recently estimated between US\$ 20 to 70 billion depending on the pace of displacement of fossil fuels in the region (Binsted M. et. al, 2019) and along the path implied by the Paris Agreement or the 1.5°C pathway. But no analysis has been made on the consequences of a coupled transition of the power and transport sectors for full decarbonization by 2050.

The complete transition of the electricity sector would displace all fossil fuels used in the generation of power (coal, natural gas, fuel oil, and lignite). The mass electrification of the transport sector would displace all liquid fuels and compressed natural gas use in the sector. Together with the displacement of these fuels, there would be an impact on the use and value of associated production, refining, transport and distribution infrastructure. This section attempts to value the economic consequences of the transition caused by these displacements in the region. This is done by assessing the loss of future production, in net present value, from the sale of fossil fuels. It also estimates the value lost in capital assets made

obsolete. Net oil, gas and coal exporters would also incur in a loss in the value of reserves. This loss is not included in the analysis as it would also be linked to decarbonization processes in other regions and therefore is beyond the scope of the current study. If decarbonization proceeds along a similar path in other regions, fossil fuel reserves will lose significant value. The annual decline in value of fossil fuel reserves (if prices fall 1% on a yearly basis) has been estimated (Manley D. et. al. 2017) at US\$ 1 billion just for Venezuela.

Value of displaced generation capacity

The implications of the projected transition curve on early retirement of capacity of generation with fossil fuels and refining capacity for transport fuels was also estimated. The retirement of capacity from the market is likewise based on the pathway presented in the previous report and considers the age of the individual thermal units, assuming typical depreciations timetables for each type of unit.¹⁴⁸ The region has an installed capacity of 172 GW of thermal power plants which are located across the continent. The location, fuel and relative size of thermal power plants in operation and with more than 0.5 GW of nominal capacity can be seen in Figure 10.

148. The schedules are based on a linear 60 year depreciation with no residual value. The timing of the mothballing is defined in the intervention scenario. All plants will be retired by 2050.

Figure 10. Location and relative size of thermal power plants with nominal capacity above 0.5 GW, as of October 2019



Source: Global Energy Observatory, Google, KTH Royal Institute of Technology in Stockholm, Enipedia, World Resources Institute. 2019. Global Power Plant Database v1.2.0. Published on Resource Watch (<http://resourcewatch.org/>) and Google Earth Engine (<https://earthengine.google.com/>). Accessed through Resource Watch, (October, 2019). www.resourcewatch.org.

The estimate also considers the anticipated natural retirement of existing units during the period and assumes that these will be substituted by renewable energy plants. Coal and oil units are retired earlier than natural gas plants. The schedule of retirements for power plants is presented in Table 2 with the estimate value at retirement. The value of the stranded assets is estimated at US\$ 40.5 billion for the countries listed in Table 2. The stranded asset value for the region is US\$ 80 billion (depreciation of all thermal power plant assets by 2050).

Value of displaced refining capacity

As the market for gasoline and diesel shrinks, two effects on refining capacity are expected: (i) refiners will first likely see a cost reduction as most expensive refining units are in use to maximize the middle distillate (gasoline and diesel)¹⁴⁹ range of production; and (ii) as the volume of displaced fuels escalates market demand will be gradually restricted to industrial gases and heavy fractions, eventually leading to non-profitability and early closure. If industry undergoes

149. Sales of gasoline and diesel command higher volumes in typical refinery operations.

Table 2. Value of retired generation capacity & schedule of retirement¹⁵⁰

Country	Number of coal and oil power plants	Nominal capacity (GW)	Investment (US\$ billion)	Value not depreciated by 2030 (US\$ billion)	Number of gas power plants	Nominal capacity (GW)	Investment (US\$ billion)	Value not depreciated by 2050 (US\$ billion)
Argentina	8	4.8	3.6	2.0	32	13.3	10.7	4.1
Brazil	36	7.7	2.4	1.8	28	10.4	8.4	3.6
Chile	24	6.7	5.3	3.1	6	2.9	2.3	1.0
Colombia	6	1.6	1.2	1.1	5	2.5	2.0	0.8
Costa Rica	2	0.4	0.4	0.3	0	0	0	0
Jamaica	2	0.5	0.4	0.2	1	0.1	0.1	0
Mexico	26	5.4	15.2	13.2	61	25.7	20.5	8.6
Panama	2	0.2	0.2	0.1	1	0.2	0.1	0
Peru	1	0.1	0.1	0.1	9	4.2	3.3	0.3
Uruguay	1	0.3	0.3	0.2	1	0.2	0.2	0
Total countries listed		27.7		22.1		59.5		18.4
Total Region (all fuels)		172						80.0

Source: Author's estimates. Assets were depreciated on a simple linear schedule with a projected shelf life of 60 years. The total value not depreciated for the entire region was estimated based on the estimated values for the listed countries.

a simultaneous electrification transition, the rate of retirement would also accelerate. Some refiners in the region (for example in Trinidad and Tobago and Venezuela) cater to markets in the US and these were not included in the retirement list. Otherwise, for purposes of the analysis, it is assumed that refiners will not substitute domestic market loss with exports. The corresponding estimates for refineries are presented in Table 3.

Other assets displaced

Full decarbonization would also make substantial storage, distribution and retail facilities obsolete. Unless other uses are found,¹⁵¹ gas and oil pipelines will be put out of service. There is not a readily available estimate of all investment in pipelines or storage depots. The issue of net impacts on jobs will be discussed in Chapter 8.

150. The list of fossil fuel power capacity by technology and country is included in annex 6. The annex also lists the refining capacity.

151. It has been suggested that gas pipelines could be used in hydrogen transport. The use of hydrogen has not been considered under the intervention scenario.

Table 3. Value of retired refinery capacity

Country	Nominal capacity (1000 BLD)	Investment (US\$ billion)	Value not depreciated by 2050 (US\$ billion)
Argentina	580	2.3	0.8
Brazil	2285	9.1	3.0
Chile	258	1.0	0.3
Colombia	421	1.7	1.1
Mexico	1546	6.2	13.2
Peru	253	1.0	0.1
Total Region	7690	30.8	10.2

Source: Author's estimates. Assets were depreciated on a simple linear schedule with an estimated shelf life of 60 years.

Macro-economic impacts

Besides the direct impact on infrastructure and production, the full decarbonization of the power and transport sectors in the region would have a direct impact on the value of reserves and the wealth of nations relying on these reserves for economic development. The decarbonization process will reduce the amount of fugitive emissions released during oil and gas operations, further impacting the region's carbon footprint. The current analysis does not include these aspects, but the stranding of fossil fuel reserves has been shown to have significant repercussions in fossil-energy rich developing nations (Mercure J.F. et al, 2018). Whether decarbonization takes place at a rate consistent with the urgency of the climate crisis, or on a slower timetable, there is consensus that most of the existing fuel reserves for coal, oil and gas may never be developed. It is therefore important for countries in the region with large fossil fuel reserves to start developing and implementing divestment policies (Manley D et al 2017).

CHAPTER 7

PATHWAY TO A COUPLED DECARBONIZATION OF POWER AND TRANSPORT

This chapter describes the decarbonization pathway proposed to reach zero carbon in the transport and power sector by 2050. It describes the installed capacity by technology, the capital investments requirements, analyses the projected energy demand under a coupled transition and summarizes the cost and benefits of the intervention scenario.

 Antofagasta, Chile


Decarbonization of power sector


The intervention scenario would lead to zero emissions from the power sector by 2050 (as described in UNEP Zero Carbon Latin America, 2015) while meeting a demand of 16.7 EJ as projected under GCAM BAU. All future demand is met through expansion of renewable energy capacity. The new capacity is allocated proportionally between wind, solar PV, solar CSP, hydro and geothermal power,¹⁵² making allowances for those countries where geothermal potential is not available. Nuclear and biomass are kept constant at current values. The scenario foresees that starting in 2020 no new fossil fuel-based power units would be commissioned. This assumption is anchored on the growing competitive edge of wind and solar as power sources in the region, under an open market environment. The existing capacity for coal is decommissioned by 2030 and that of gas by 2050. No gains in additional efficiency are considered beyond those considered under the reference scenario A more detailed description of the intervention scenario is included in Annex 7.


Intervention Scenario:


Power sector demand
16.7 EJ by 2050


Power generation
provided by:


 Wind

 Nuclear

 Solar (PV, CSP)

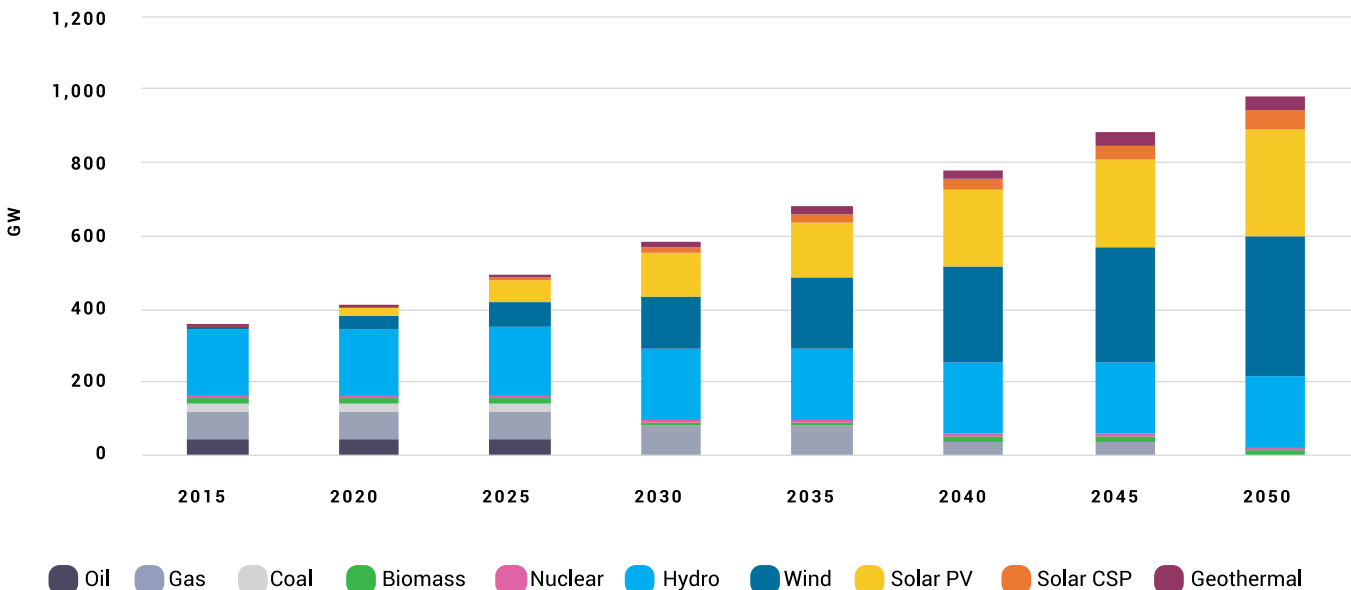
 Hydro

 Biomass

 Geothermal

Reaching 0 GHG emissions

Figure 1. Cumulative installed capacity, by source, under the intervention scenario, 2015-2050 (net additions)



Source: Author's estimates.

152. The ratio of new installed capacity considered in the zero emissions scenario is 50% wind, 38% solar PV, 5% solar CSP, 2% hydro (considering climate change impact on runoff availability resulting in a decrease of hydro generation capacity) and 5% geothermal. The PV fraction includes utility size and distributed capacity. See Annex 7 for additional details on the Intervention scenario.



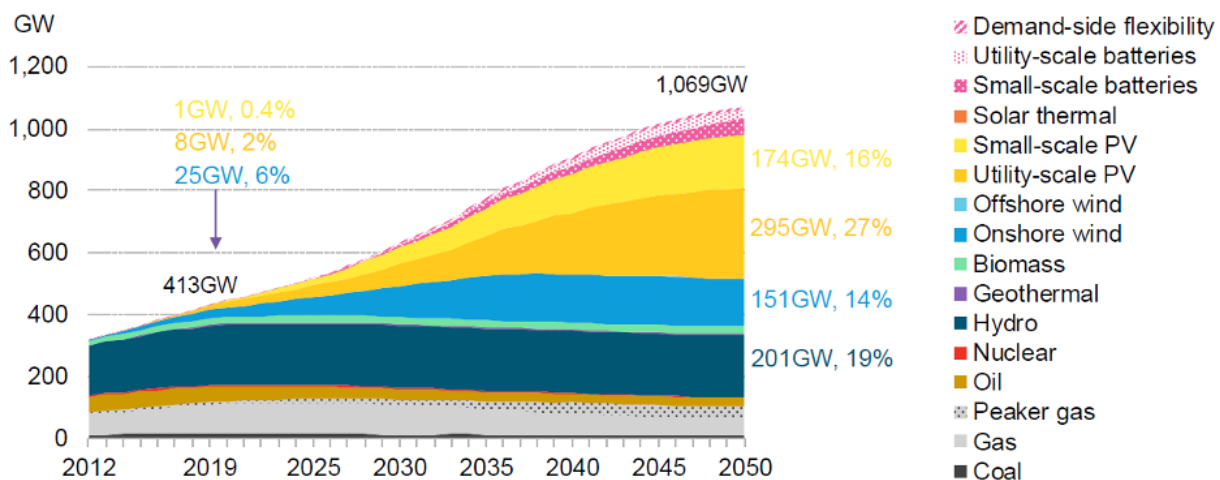
The makeup of future capacity, under the intervention scenario is depicted in Figure 1. The solar PV fraction includes not only utility size but also distributed capacity. Currently, many countries are developing legal and regulatory frameworks that create the enabling conditions for distributed solar PV deployment (Chapter 4 & 9). In some nations, distributed PV is already an important market (Mexico, Brazil, Chile and Dominican Republic), in others is rapidly growing (Colombia, Argentina and Honduras). If the current trends continue, under the intervention scenario, it is estimated that the distributed solar PV will reach a great percentage of the total solar PV installed capacity by 2050.

For comparison purposes, a scenario consistent with the Paris Agreement (GCAM RCP 2.6 - goal of 2°C anomaly at the end of the 21st century) was also run using GCAM. The pathway places an emphasis on

carbon capture and storage while maintaining a hefty participation of fossil fuels in the future power matrix. A recent regional projection (BNEF, 2019) that considers current market momentum for renewables, places renewable capacity at 82% of the total by mid-century. Specifically, the projection calls for hydro to have an installed capacity of 201 GW, reflecting a net addition of just 16 GW; major participations of wind (14% of total); PV (43%), utility and small-size battery storage as well as demand side flexibility (Figure 2). The projection still allows oil, coal and gas to remain with a participation of about 110 GW. It is a majority-renewables but not a zero-carbon scenario.

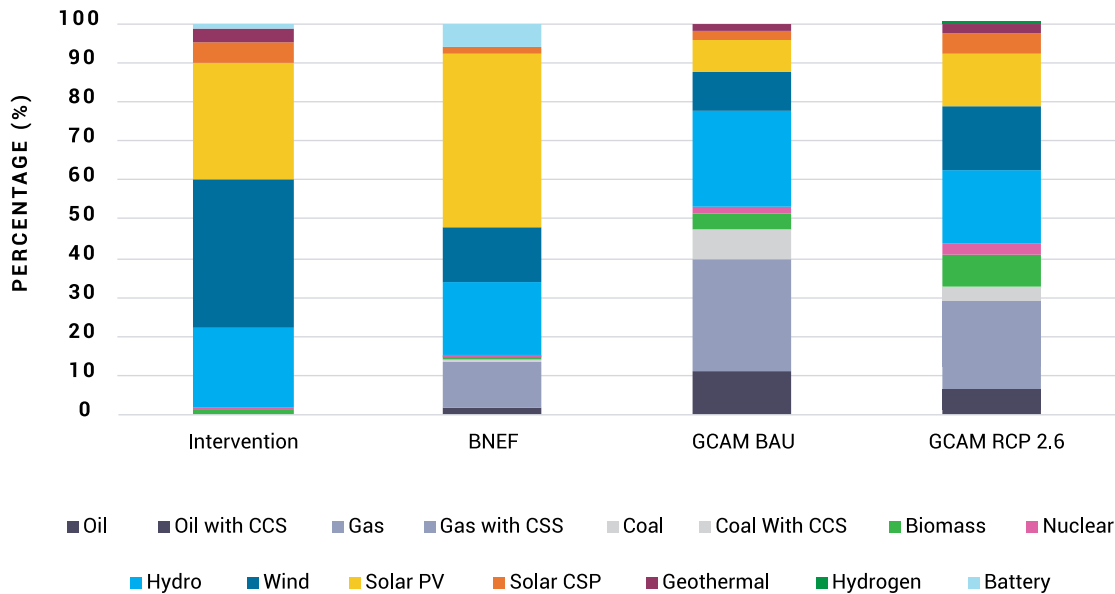
To facilitate comparison between the scenarios, the projected composition of the power matrix for the GCAM BAU and GCAM RCP as well as the BNEF projections and the composition resulting from the intervention scenario are compared in Figure 3.

Figure 2. Bloomberg’s New Energy Outlook: Total installed capacity in the region by mid-century



Source: BNEF, 2019

Figure 3. Approximate installed capacity of the power matrix in GW in operation by mid-century under different scenarios



Source: Author's estimates and based on outputs from GCAM and BNEF, 2019. BNEF scenario includes 11 GW of demand-side flexibility and the solar PV fraction is composed of 63% utility size PV and 27% of distributed PV.



Converting to a fully renewable system under the assumptions indicated in the intervention scenario is estimated to require cumulative investments¹⁵³ of the order of 800 US\$ billion 2018 and deliver zero CO₂ emissions (Figure 4).

The estimated investment in some countries in the region are also included in Annex 7. This investment reflects the anticipated requirements to meet the projected power demand of energy under the reference scenario by mid-century (16.7 EJ).

The investment associated with the reference scenario is estimated at US\$ 1083 billion (2018) (US\$ 943 billion (2010); see Figure 7, Chapter 2). On the other hand, capital investments linked to the scenario with compliance of the Paris Agreement (RCP 2.6), that includes instead heavy reliance on carbon capture and storage would be about US\$ 2.2

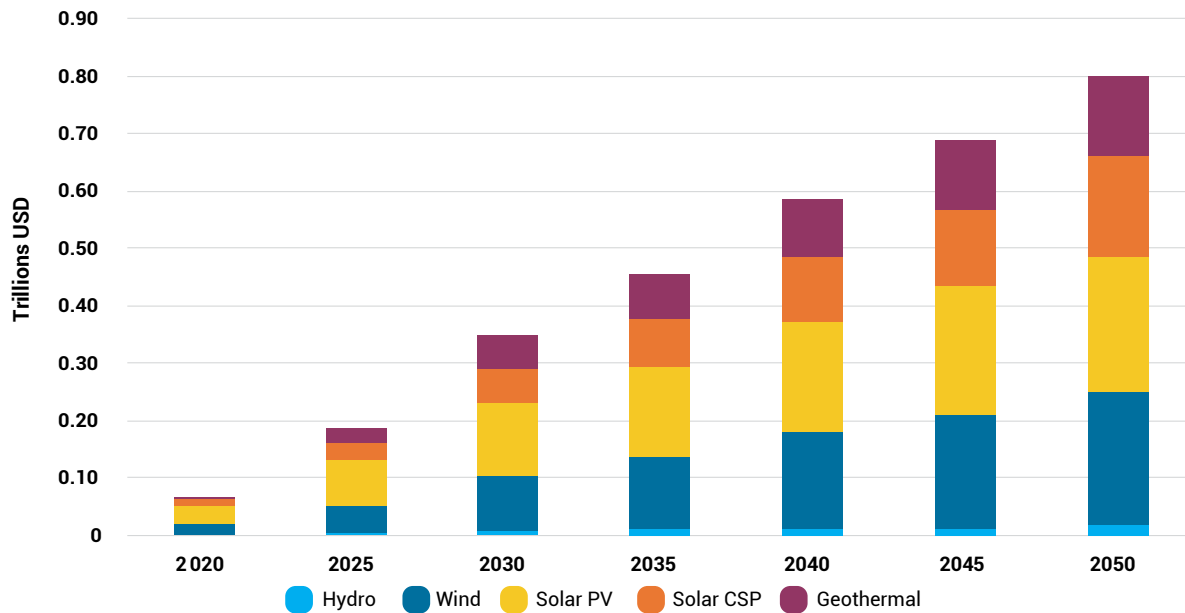
trillion (2018) (US\$ 2.1 trillion (2010)), mainly due to the use of expensive carbon capture and storage technology to achieve zero emissions by mid-century (Figure 5). Clearly, a pathway that takes advantage of the competitiveness of renewables in the region is less capital intensive.

In addition, the lower capital and operational costs associated with the capacity matrix under the intervention scenario should result in projected lower electricity generation costs. The projected composite LCOE, under the intervention scenario, is estimated to be \$0.048/kWh by 2050 (Figure 6).¹⁵⁴

153. The investment amounts only reflect investments in installed power generation capacity.

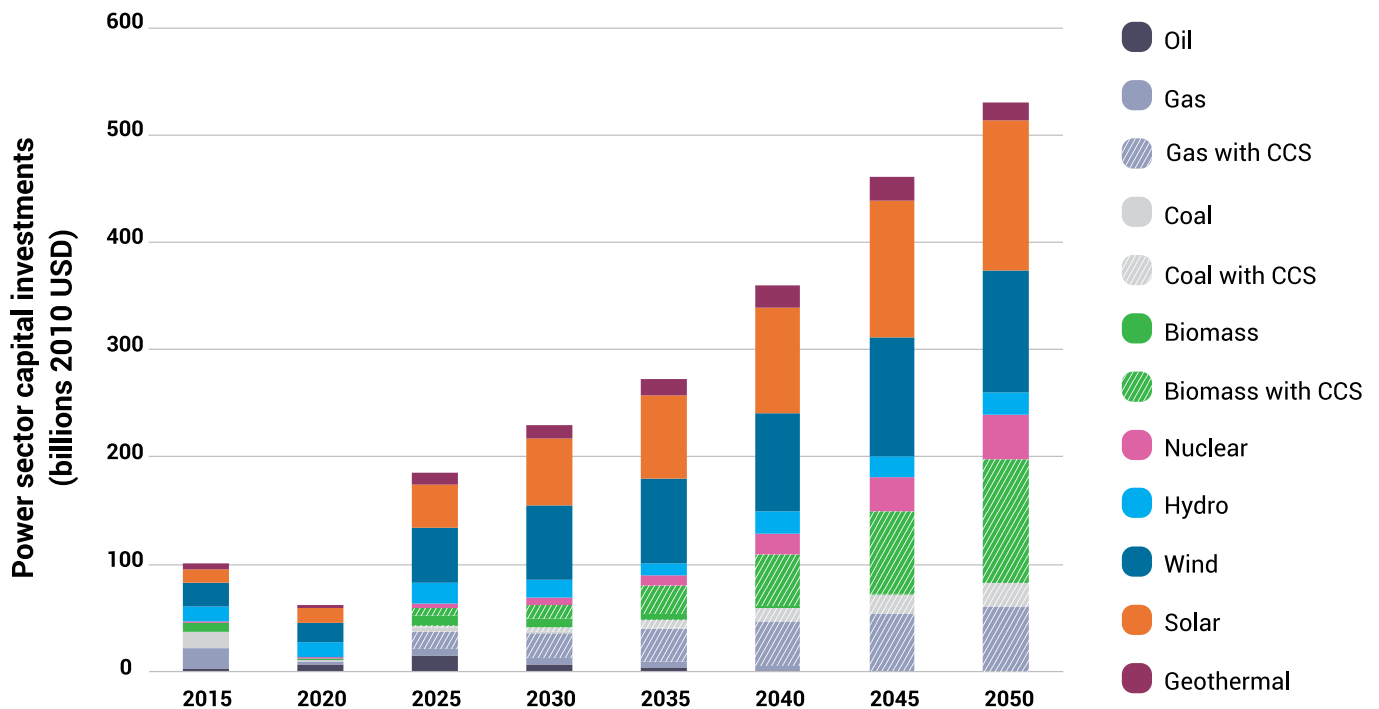
154. The projected LCOE was estimated on the basis of the LCOEs for each technology and the corresponding share of generation under the intervention and BAU scenarios.

Figure 4. Cumulative annual capital investments required in the power sector, 2020-2050, under the intervention scenario



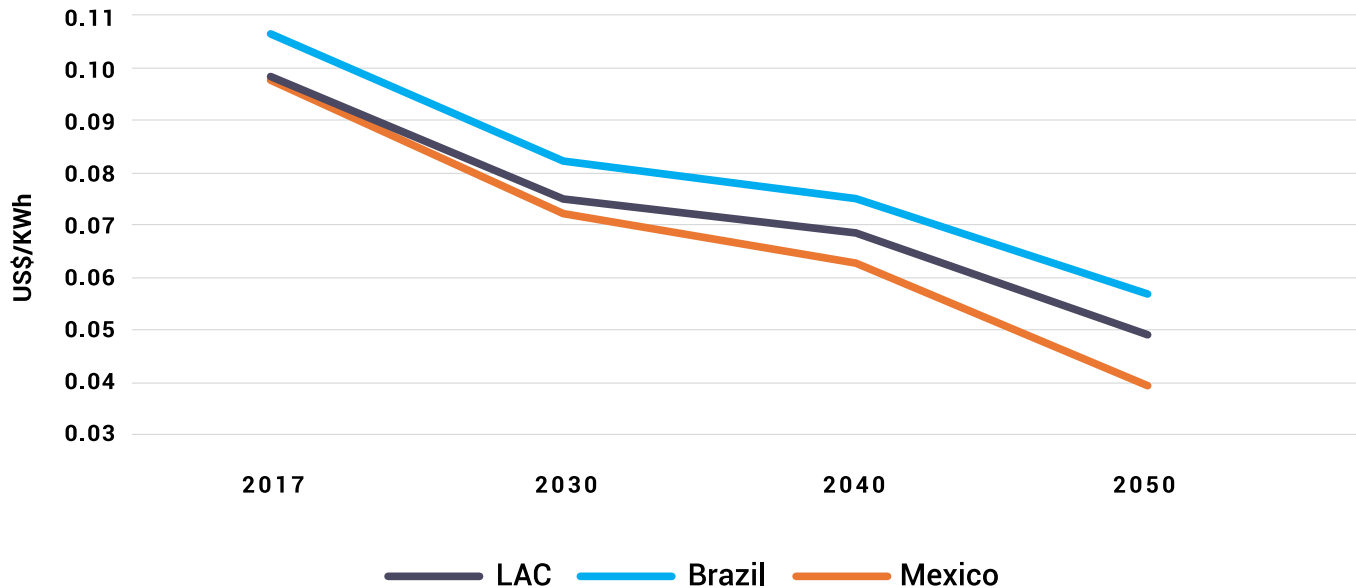
Source: Author's estimates.

Figure 5. Capital investments required in the power sector, 2020-2050, under the Paris Agreement compliance scenario (RCP 2.6)



Source: As projected under GCAM RCP 2.6 scenario, August 2019.

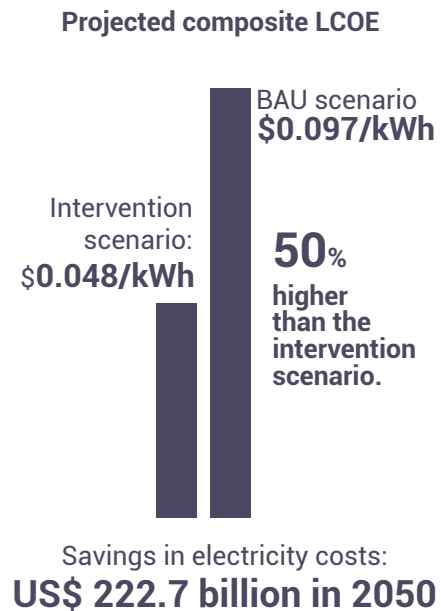
Figure 6. Projected compounded LCOEs from technology makeup of the power matrix under intervention scenario (US\$/kWh), 2017-2050



Source: Author's estimates, based on GACMO outputs

The estimated cost of generation under the BAU scenario is \$0.097/kWh, 50% higher than the intervention scenario. Therefore, the overall savings in electricity costs are estimated at US\$ 222.7 billion in 2050¹⁵⁵ (which does not include the future demand caused by an electrified transport sector). Shifting to a renewable energy matrix would result in savings to the regional economy. The reductions in generation costs could be directly accrued by all consumers of electricity making manufacture more competitive and delivering savings to households.

The zero emissions pathway implies that future investment in fossil sources is avoided and that the installed fossil fuel power plants will be decommissioned ahead of their full depreciation schedule. The value of stranded assets in the power sector was estimated at US\$ 80 billion (2018) by mid-century. The cost to the economy of the stranded assets in the power sector are easily compensated by the overall capital savings.



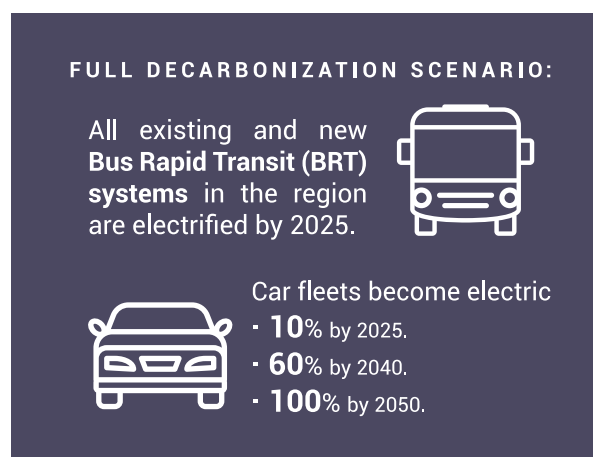
155. Based on a demand of 16.7 EJ

Although the intervention scenario may seem hard to attain, the prospects for the transition by mid-century toward a fully decarbonized sector are aided by several positive factors, which strengthens renewables, primarily wind and solar, as the “technologies of choice” for the region. These include:

- a) The currently installed hydro capacity which can provide a baseload capacity in many of the countries, allowing for an increased level of intermittent sources to participate in the power matrix; and, a regional, albeit currently disconnected storage capacity bordering on 0.22 TWh. The firm capacity of hydropower however is being affected by changes in rainfall patterns,¹⁵⁶ in which some doubt the ability to continue to deliver the nominal installed power in the future (UNEP, 2017).
- b) The global-size assets of renewable energy resources, represented by the energy endowments in wind fields, solar irradiance, geothermal and marine potential and hydropower, discussed in Chapter 3.
- c) The rapid decline in installed and generation costs for most intermittent, new baseload and power storage technologies, also discussed in Chapter 3.
- d) The potential for electrification in other sectors of the economy, that would result from trends in generation costs from renewable resources and improved security of supply (Chapters 3 and 6).
- e) The potential for distributed generation in the region.
- f) Improving support through ongoing policy and regulatory reform favoring entry and access of renewables to the electricity market.

Electrification of the transport sector

In the scenario considered for full decarbonization of the transport sector, all modes for cargo and passenger transport, except air travel,¹⁵⁷ switch to electric drives by mid-century; and no ICE fleet is in operation by then.¹⁵⁸ More specifically, all existing and new Bus Rapid Transit (BRT) systems in the region are electrified by 2025.¹⁵⁹ It also assumes that the car fleet becomes 10% electric by 2025, 60% electric by 2040 and is fully electrified by 2050. The same conversion rate is expected from light trucks and all buses, while all railroad cargo and passenger transport are electrified by 2040. Also, all marine and heavy road cargo transport is fully electrified by 2050.



As the energy efficiency of electric drives is three times higher than for ICE, the energy demand of the transport sector under the intervention scenario is much lower compared to the BAU scenario.



Energy efficiency of electric drives is three times higher than for ICE.

156. A UNEP publication (UNEP, 2017) raises questions about the long-term availability of current nominal firm capacity in a warming climate affecting rainfall patterns. An example of how drought is affecting dams and electricity generation in the largest system of dams in Brazil can be seen here: <https://economia.estadao.com.br/noticias/geral,sete-usinas-bebem-a-agua-do-reservatorio,70001973929>.

157. Air travel was not considered in the intervention scenario (see Chapter 2).

158. The intervention scenario assumes that there is a faster transition to electric drives for cars and buses, a slower transition for trucks and rails and an even slower transition for vessels. Details of the schedule of transition are included in Annex 7.

159. While this shift will not produce substantial reductions in fossil fuels, it could be an emblematic change with visible co-benefits in urban areas, as well as stimulate development of the market in electric drives for public transport vehicles.



Transitioning the transport sector to electric drives is calculated to represent savings of the order of 12 EJ by mid-century.¹⁶⁰

The transition to electric transport has the net effect of reducing total energy demand in the region while increasing future power requirements. The combined power requirements are shown in Figure 7.

On the other hand, electrification would add to the installed capacity and investment requirements of the power sector. The additional demand on the power sector from a fully electrified transport has been estimated at 5.5 EJ by 2050, which represents a 33% of the total power demand (16.7 EJ) by 2050. The additional capacity required is estimated at about 327 GW,¹⁶¹ mostly required by 2040 and afterwards. A fraction of this demand (about 40,000 GWh/year or an estimated equivalent to 10 GW) can be expected

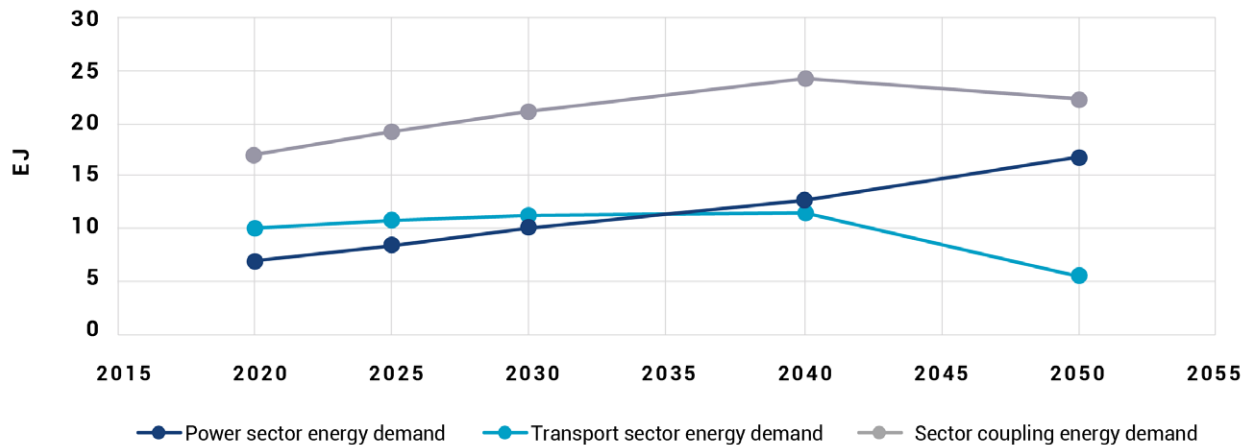
to be met through demand side flexibility (valley filling). The calculation is included in Annex 11. If the electrification of transport is coupled to the full decarbonization of the power sector, the investment associated to the remainder of the additional power demand is estimated at US\$ 214 billion by 2050. Otherwise, if the electrification of transport occurs under a BAU power sector scenario, the investment associated to the remainder of the additional power demand is estimated at US\$ 317 billion. The cost of the additional capacity to meet this power demand is lower under the coupled transition because the capital costs associated to power generation under the intervention scenario is lower (see Chapter 3).



The difference in costs of electrification of transport under a BAU and an intervention power scenario is US\$ 103 billion.

This is an additional benefit of coupling the transition process. The estimate details are included in Annex 8.¹⁶²

Figure 7. Projected energy demand (EJ) under a coupled decarbonization of power and transport sectors, 2020-2050



Source: Author's estimates.

160. The energy savings in 2050 would represent an avoided cost for the transport sector of US\$ 160 billion at the projected cost of electricity. These savings are included in the reduction of total costs of transport.

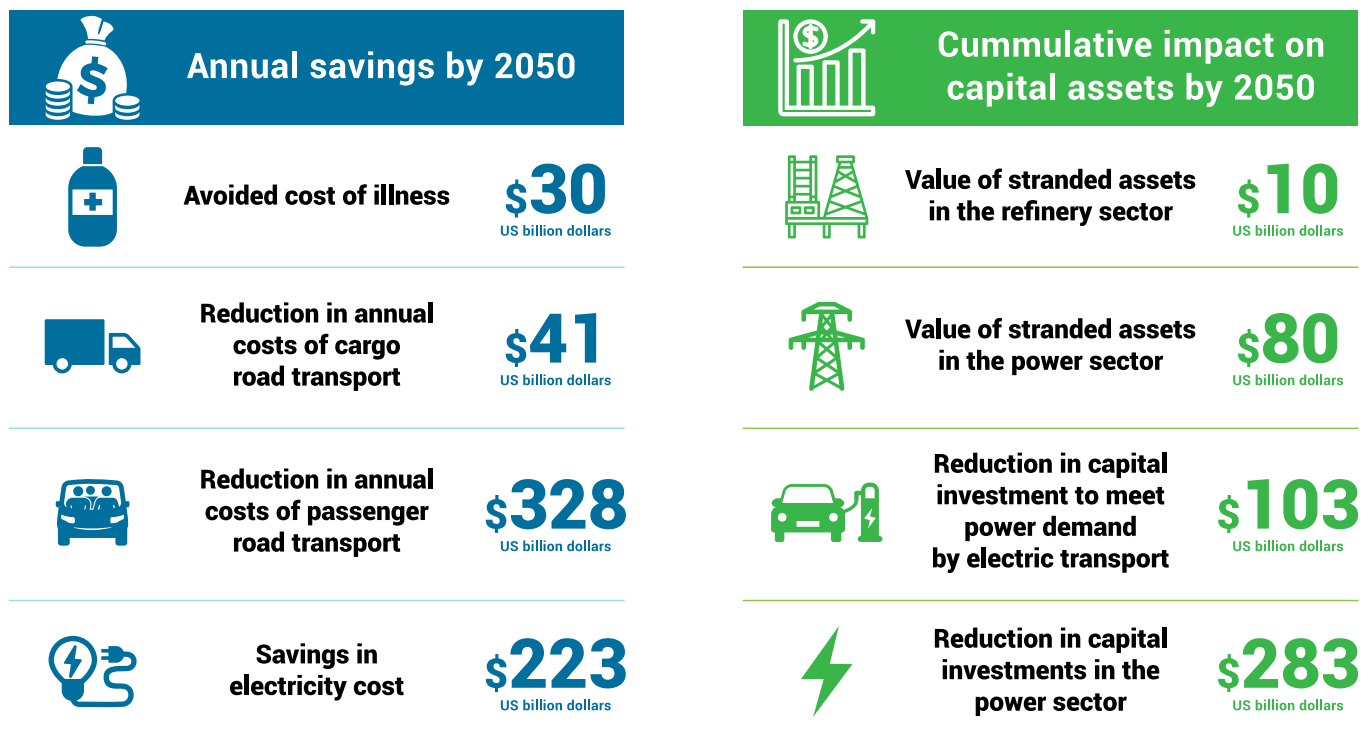
161. This is proportional to the 993 GW attending the 16.7 EJ of demand of electricity by 2050.

162. The analysis only shows the advantage in capital costs of coupling the electrification of the transport sector to the decarbonization of the power sector. A full accounting of the savings in capital costs of the intervention scenario as compared to the BAU scenario for power and for transport has not been attempted.

Additionally, as it transitions, the transport sector becomes capable of storing and managing larger amounts of energy. It is difficult to project the role that the storage of power in transport can play under the supply/demand characteristics of the region. For example, it is estimated that the combined electric truck fleet would represent a power storage capacity of the order of 8 GWh by mid-century.¹⁶³ If properly managed, electric transport demand would also improve the operation of baseload generation capacity through its flattening of demand.

A fully electric transport sector by mid-century would also result in the displacement of all diesel and gasoline used for transport fuels and therefore the early retirement of refinery capacity for middle distillates in the region. The assets retired have been calculated to have a residual value of US\$ 10.2 billion. As a result of lower future electricity costs and lower equipment costs, the LCOEs for electric transport are projected to become lower than vehicles with IC engines.

Figure 8. Combined costs, benefits and avoided costs by mid-century under a coupled power and transport zero emissions pathway (in billion dollars), 2018



Source: Author's estimates. *Does not include reduction in electricity costs for the transport sector which is captured in the reduction in costs for road transport. **Is calculated as the difference in capital costs to provide the required energy under the GCAM-BAU power system and the Intervention Scenario.

163. Based on a fleet of 20,000 trucks each equipped with a battery storage of 400 kWh, for an autonomy of 200 miles. Energy efficiency as calculated by CARB, 2018 for electric trucks (<https://ww3.arb.ca.gov/msprog/actruck/docs/180124hdbevefficiency.pdf>)



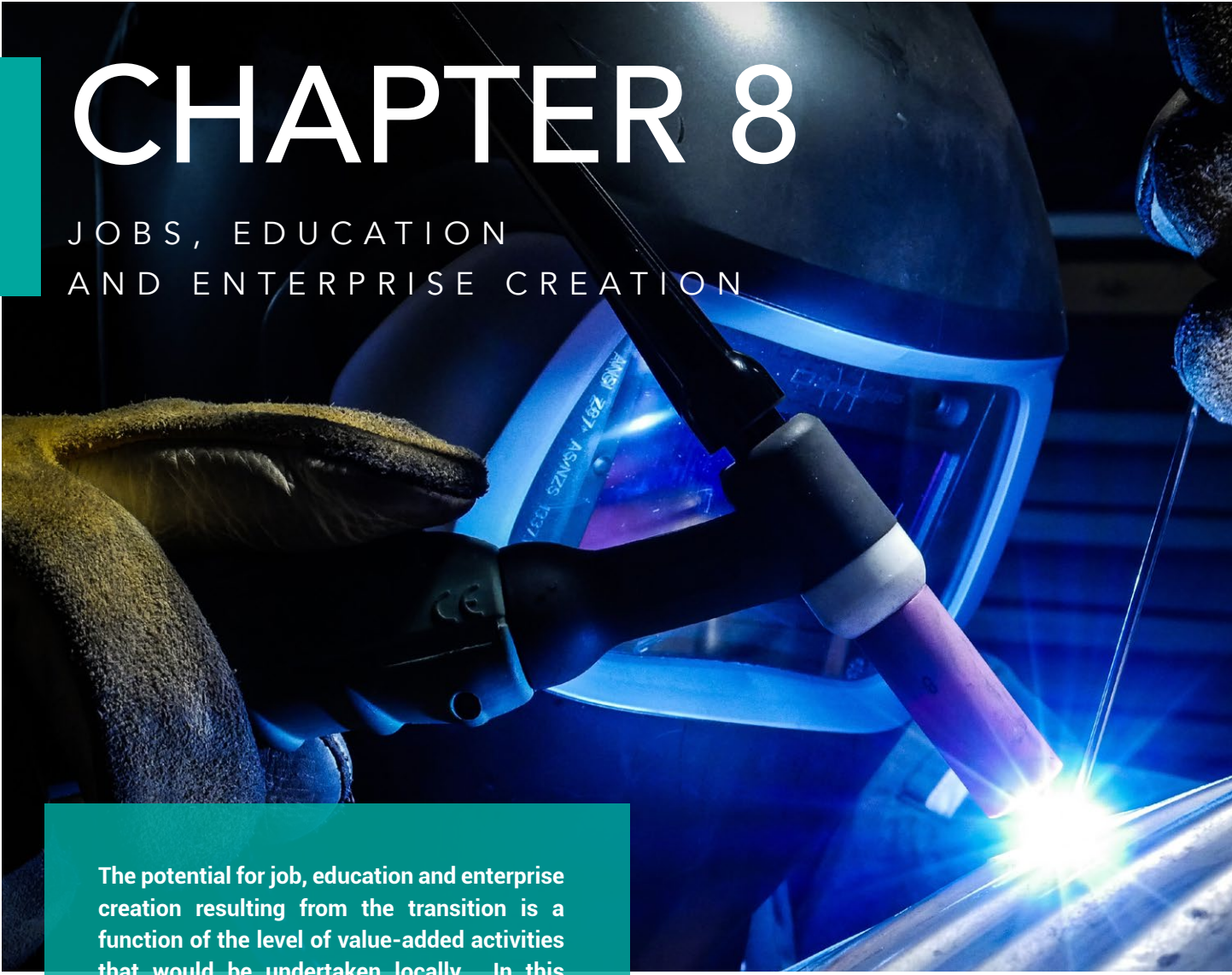
Most of the service is projected to be delivered through road transport. For passenger road transport, big reductions in LCOTs are anticipated for electric light vehicles while electric buses will at most have the same costs of the diesel options. The intervention scenario assumes that the car fleet will not increase more than 30% its current size by 2050, while the bus fleet will more than double its size to compensate the reduction in light vehicles transport measured in passenger kilometers. Under these assumptions, it is estimated that the overall savings in passenger transport costs to the economy would be of the order of US\$ 328 billion in passenger transport. No estimates were made for passenger transport in other modes (rail, vessels).

For cargo transport, the calculated LCOTs for electric light trucks (90% of the road cargo fleet) are also lower while heavy duty vehicles continue to be more expensive by mid-century. The composition of the fleet (90% light trucks; 10% heavy trucks) is kept constant. Under these conditions, it is estimated that the overall savings in capital costs to the economy would be of the order of US\$ 41 billion in cargo road transport. No estimates were made for cargo transport in other modes (rail, vessels).

The coupled transition includes an estimated US\$ 30 billion in avoided health costs. Improved security of supply and efficiency were not monetized. A summary of the costs and benefits of the coupled transition pathway is presented in Figure 8. Annual savings linked to the coupled transition by 2050 are valued at: US\$ 621 billion. Cumulative savings in capital costs by 2050 are valued at US\$ 386 billion against the BAU scenario. Cumulative losses by 2050 in capital of retired fossil generation and refinery capacity were estimated at about US\$ 90 billion by 2050.

CHAPTER 8

JOBS, EDUCATION AND ENTERPRISE CREATION



The potential for job, education and enterprise creation resulting from the transition is a function of the level of value-added activities that would be undertaken locally. In this section, the potential for new jobs, education, and enterprises is reviewed for the following industries: solar, wind, electric batteries for vehicles and for fixed installations, electric bus manufacture, smart grid operations, and associated R&D as representative of the type of opportunities as the energy and transport transition takes place. Additionally, examples of current business models addressing key elements of the transition in the region are described in this chapter.

In all these areas, new jobs, educational opportunities and business models will be developed for the design, implementation and management of installations, the manufacturing, supply and assemblage of components, and the provision of auxiliary services such as information technologies that will play a major role in the nexus between energy and transport. This transition may be an opportunity for a rekindling of manufacturing, engineering, and financial activity in the region. But a call for efforts in education and training is critical to generate local employment for new technologies in the region. Public and private educational institutions will need to develop specific courses, in a wide range of disciplinary backgrounds, including engineering, energy analysis, economics and planning for the new industries.

8.1 Job creation

The scale and extent of net job creation during the transition will depend on the speed and scope of market changes in both sectors. A recent analysis¹⁶⁴ by the Secretariat to the UNFCCC found that job creation and enterprise formation will be a function of the speed and depth of the transformation of the economy. It found that the 1.5 °C scenario would increase the renewable energy capacity faster, so employment will increase faster. It recommends that policymakers support the transformation by developing just transition policies for workers, enterprises and their communities. These policies would provide training and education assistance, acquisition of new skills and relocation services for employment affected by the transition. An analysis on job generation associated to the evolution of the economy toward decarbonization¹⁶⁵ has estimated job generation coefficients for each energy technology and multipliers to reflect conditions in different countries and regions. For the region, the sectors that will see job creation will be onshore/offshore wind, solar, geothermal, hydro (O&M), and small hydro (construction and O&M), grid maintenance and digital services, civil construction, assemblage and



manufacturing of electric drives, storage systems and vehicles. Sectors that will be negatively affected will be coal, oil and gas power generation, distribution of fossil fuels, refinery operations, and retail sales of transport fuels.

Solar energy

The large endowment, distributed character, and economic potential for solar energy use in the region bode well for the development of a dedicated manufacturing, management, development, and implementation solar power industry. Solar and wind energy related jobs are already the fastest growing segment of the labor green-jobs market in the U.S. (US Bureau of Labor Statistics, 2019).¹⁶⁶ Demand for small scale PV projects (roof installations) as well as utility size plants are generating opportunities for new enterprises and the repositioning of others. Most manufacturing capacity today is in China (IRENA Renewable Energy and Jobs, 2019). Information available today places the job creation in solar energy¹⁶⁷ in Germany and the United States between

164. <https://unfccc.int/sites/default/files/resource/Just%20transition.pdf>

165. https://link.springer.com/chapter/10.1007/978-3-030-05843-2_10

166. <https://www.bls.gov/careeroutlook/2018/data-on-display/green-growth.htm>

167. Globally, IRENA has estimated 3.6 million jobs in the solar PV industry (IRENA, 2019)

3,600 and 22,000 jobs created per GW installed in 2018;¹⁶⁸ today, there are an estimated 10,000 solar energy companies in the United States alone. In Mexico, it is estimated that the PV industry employed 23,000 people in 2018 when additional 400 MW were installed in an industry now with an accumulated PV capacity of 3 GW.¹⁶⁹

The development of competency standards for the distributed solar PV industry in Mexico was a driving engine in the enabling of a favorable business environment that resulted in one of the largest markets in the region. The first competency standard (EC 0586.01) in the distributed solar PV industry was operational in 2017, focusing on validating the skills of a person installing a photovoltaic system in the residential, commercial and industrial segments.¹⁶⁸ To date, two additional standards were introduced in 2019, technical-commercial advice on photovoltaic distributed generation projects¹⁷⁰ and supervision of photovoltaic systems in residence, commerce and industry.¹⁷¹ The former establishes the competences required in a commercial-technical advisor and the latter the ones needed for a supervisor of the process

from design to installation. These standards contribute to strengthening the standardization of these tasks in the value chain of the national distributed solar PV market, to offer better services for customers ensuring greater and more efficient use of the technology and to create new qualified jobs (9,258 jobs up to 2018).

Under the intervention scenario, 30 GW of new solar installations would be required per year in the region. While many will be large, utility-size facilities, many more will entail the implementation of distributed and household installations. Attending this demand will require of an entire new industry, including project developers, engineering companies, installation operation, maintenance and digital management companies. It will also open a new line of activity for the financial sector. The high intensity of solar energy hotspots like Atacama, Chihuahua, and others would also promote the development of high-end applications in concentrated solar power that should propel the region to a top position in this sector of the industry. Additional jobs generated in the solar industry, have been in the range of 800 to 1000 jobs per GW installed.¹⁷²



Mexico distributed solar PV industry has created 9,258 qualified jobs up to 2018.

168. <https://www.cleanenergywire.org/factsheets/solar-power-germany-output-business-perspectives>; <https://www.seia.org/solar-industry-research-data>
 169. <https://www.statista.com/statistics/987629/renewable-energy-jobs-industry-mexico/>; <https://ccea.mx/blog/energia-solar-fotovoltaica/la-energia-solar-en-mexico-triplico-su-capacidad-en-2018>
 170. https://www.conocer.gob.mx/contenido/publicaciones_dof/2017/EC0586.01.pdf
 171. https://www.conocer.gob.mx/contenido/publicaciones_dof/2019/EC1180.pdf
 172. https://www.conocer.gob.mx/contenido/publicaciones_dof/2019/EC1181.pdf
 173. This is based on the job generation in Germany, with 36,000 jobs for 43 GW installed: (<https://www.cleanenergywire.org/factsheets/solar-power-germany-output-business-perspectives>);



Photo by Science in HD, Unsplash

Wind energy

Akin to solar, the wind energy industry is developing rapidly in the region. Its deployment will also promote the creation of a dedicated industry, probably tilted toward larger scale installations. Similar occupations to those in solar energy will be created but they will also exist in turbine operation and maintenance. In the US, turbine technician is one of the fastest growing green occupation in the labor market (US Bureau of Labor Statistics, 2019). In the U.S. there are 1370 jobs per GW of wind energy installed.¹⁷⁴ In Denmark, there is an estimated 6,000 jobs per GW of wind installed. Furthermore, the offshore wind option has a large potential in the region and its deployment will require substantial investment in a local supplies industry and a supporting nearby infrastructure. This means investing in port or depot facilities and creating jobs in nearby coastal communities so that there are workers available with the skills to build and maintain the wind farms.¹⁷⁵ Over the course of two years (2014-2016), employment in the wind energy sector rose by 9% in Latin America and the Caribbean and 5% in Brazil in 2015.¹⁷⁶ The wind industry in Brazil has been growing quickly, with the prospect of wind being the second greatest source of energy

in 2019 after hydroelectricity. It already has 15 GW installed.¹⁷⁷ The quick uptake is driving the market to the local manufacture and assembly of turbines and components as well as the ancillary services.

Electric batteries

The market for electric batteries is expected to grow exponentially in the region, both for vehicles and for fixed installations. The region today is a major supplier of lithium for battery packs. Argentina, Bolivia and Chile hold above 75% of the world's lithium resources. With the recent new discoveries in Peru this share could increase. This segment of the renewable energy industry could be vertically integrated, with the region potentially developing a refined lithium industry including the manufacture of cathodes and even batteries. This would be a major undertaking attending not only to growing local demand but also global requirements. Investing in value-add production in the lithium industry would change the dynamics in the region from being just an extractive industry to a value-add industrial activity including ore extraction, processing and battery manufacture. Chile, Bolivia, and Argentina have sizable lithium

174. <https://www.awea.org/wind-101/benefits-of-wind/powering-job-growth>

175. <https://spectra.mhi.com/why-offshore-wind-creates-so-many-jobs>

176. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Jun/IRENA_Leveraging_for_Onshore_Wind_2017.pdf

177. <https://www.evwind.es/2019/07/07/wind-power-in-brazil-reaches-15-1-gw/67910>

reserves and appropriate experience and skills in the mining sector. But these countries would need to create the required infrastructure, develop the workforce, promote innovation and the development of high technology industries and implement the required policy instruments and environmental safeguards, as it concerns the supply of water.

Electric vehicle manufacture and assemblage

The region constitutes a large marketplace for electric buses. The development of BRT systems, and the characteristics and size of the required fleet also makes the region an attractive niche market for electric bus manufacture. Assembly of articulated and standard buses is already done in the region, with substantial manufacturing in Mexico and Brazil. The inclusion of electric drive and ancillary components would be a natural next step for bus manufacturers in the region. In the U.S., it has been estimated that one job is created per electric bus manufactured.¹⁷⁸ Other heavy vehicles share a similar platform. One recent study¹⁷⁹ on the automotive market in Europe has estimated the net creation of about 0.01 permanent jobs per electric vehicle in service. This estimate considers spillover effects in the job market in industrial and power generation sectors. Job gains in the shift to electricity in transport have been estimated based on the reports cited but considers the fact that there will be minimal change in net jobs and economic activity in light vehicle manufacture, assembly and retail sales.

Grid modernization

Distributed systems as well as modernization of national grids, digitalization and international links with HDVC systems are necessary steps to adapt the grid to the system of systems the energy sector will become in the future. The current trends show that numerous fields of the electricity sector will be affected by digitalization. Aspects like load and congestion control, market operation, smart meters, assets awareness, demand-response, renewables forecast, and many others could be shaken by revolutionary technologies like artificial intelligence, internet of things (IoT), blockchain or big data.

The list of services information technologies can provide will expand and evolve in the future, and these evolutions will bring issues like cybersecurity and private life concerns that will need to be tackled from a market, technological and policy point of view. The modernization of the grid will present many opportunities for job creation and new business models showing how the transition of the electricity sector should be an opportunity and not like a burden.

A study by KEMA for the GridWise Alliance found that in the United States, a US\$ 16 billion investment in smart grid could create up to 280,000 new jobs. A similar assessment found that US\$ 50 billion additional investment in the smart grid over five years (US\$ 10 billion per year), could create approximately 239,000 new or retained jobs for each of the 5 years



178. <http://laborcenter.berkeley.edu/bringing-back-good-manufacturing-jobs-america-one-electric-bus-time/>

179. https://download.dalicloud.com/fis/download/66a8abe211271fa0ec3e2b07/c572c686-f52f-4c0d-88fc-51f9061126c5/Powering_a_new_value_chain_in_the_automotive_sector_-_the_job_potential_of_transport_electrification.pdf

on average, in the United States.¹⁸⁰ Investments in smart grids in South America have been estimated at US\$ 20.1 billion until 2017.¹⁸¹ Industry sources also estimate an investment of US\$ 6.4 billion in smart grids in Mexico over the next decade.¹⁸²

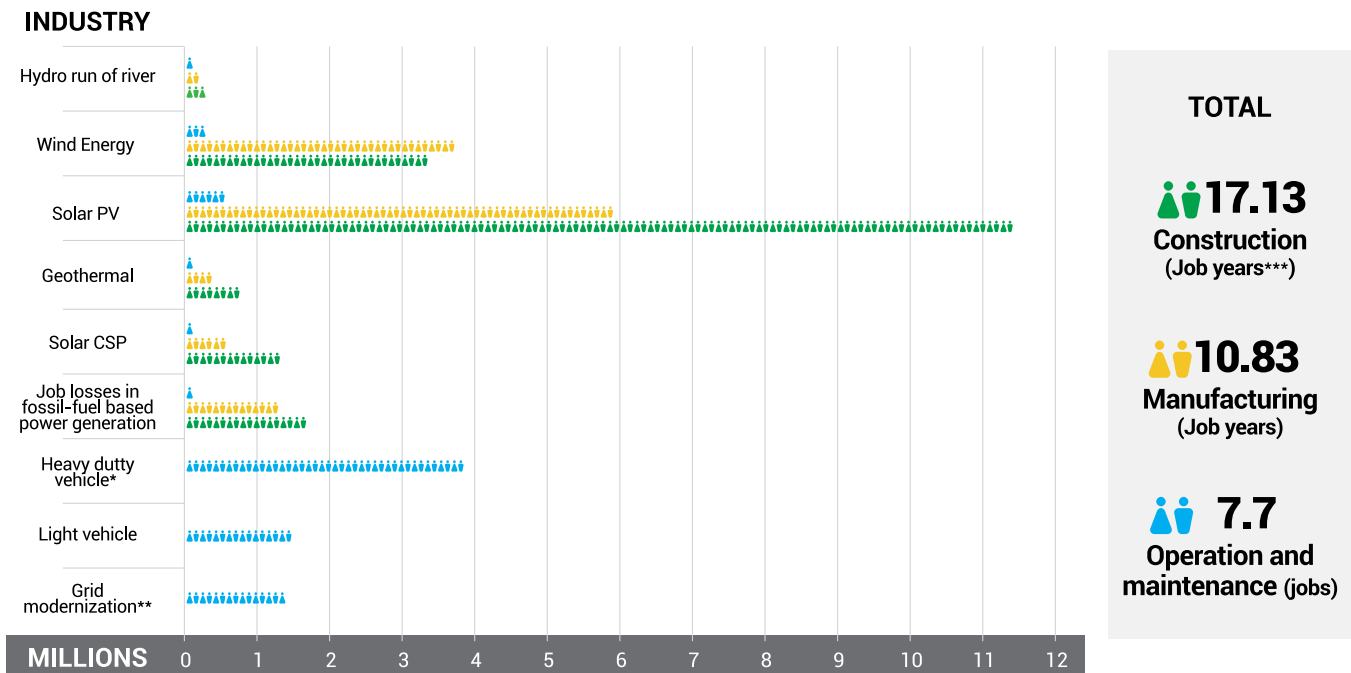
Job losses

As the coupled transitions of power and transport advance, there will be job losses in the fossil fuel industry as well as in assembly and maintenance of the retired fleet. Job impacts are also anticipated in fuel transport and distribution. Not all of these will be taken up by the new industries and thus there is importance for skill acquisition and training programs for displaced workers.

8.2 Estimated additional jobs generated regionally under the intervention scenario

For the purposes of this report, the net job generation factors reported for the power sector by Dominich¹⁸³ has been used for anticipated new investment in renewable energy alternatives. The job losses from closure of refineries and fossil power plants have also used been calculated. The estimates of job generation in electric transport and in grid modernization have been taken from industry data referenced above. Net job generation in the electric vehicle industry has used estimates by the Labor Center at University of California, Berkeley, and estimates by the European Association of Electric Contractors (AIE, 2018). The results are presented in Figure 1.

Figure 1. Estimate of additional jobs (millions) generated regionally under the intervention scenario per energy technology by mid century¹⁸⁴



Source: Author's estimate based on of factors an multipliers reported by Dominish E., et. al. 2018. * Job estimates based on a constant fleet of 150 million cars; 4 million buses and 34 million trucks by 2050. See assumptions and details in Annexes 5 & 12. ** Job estimates based on an investment of 26 billion USD between now and 2030 and using the factors for job creation of a smart energy study¹⁸⁵ ***Job years is a metric used to assess the size of temporary jobs created by activities with a limited time frame.

180. <https://www.smart-energy.com/regional-news/north-america/new-study-confirms-job-creation-potential-of-smart-grids-in-u-s/>
 181. <https://www.smart-energy.com/industry-sectors/smart-grid/smart-metering-to-cover-50-of-south-americas-smart-grid-investments/>
 182. <https://www.tdworld.com/metering/mexico-smart-grid-and-smart-cities-market-84-billion-over-next-decade>
 183. Dominish, E., Teske S., Briggs, C., Mey, F., and Rutovitz, J. (2018). Just Transition: A global social plan for the fossil fuel industry. Report prepared by ISF for German Greenpeace Foundation, November 2018.
 184. Job estimates on the basis of factors reported by Dominish E., et. al. 2018 https://link.springer.com/chapter/10.1007/978-3-030-05843-2_10 and proposed multipliers to reflect conditions in Latin America. The estimated new jobs in transport electrification are underestimated given that ancillary jobs for this sector such as those associated to charging infrastructure are not considered.
 185. <https://www.smart-energy.com/regional-news/north-america/new-study-confirms-job-creation-potential-of-smart-grids-in-u-s/>

8.3 Enterprise creation

New avenues of economic activity are envisioned as part of the transition. There are opportunities for manufacturing and commercial activity and associated R&D for wind turbines, PV modules assembly and manufacture and electric vehicles design, manufacture and assembly. All these activities would generate a demand for component design, manufacture and assembly in the region, which will in turn create opportunities for additional industrial activity. Areas around wind and solar hotspots are strong candidates for providing local manufacture and maintenance services. Such are the examples of Brazil and Mexico in the solar market. Brazil has an industrial policy for panels that favors national production. Developers that use panels made in Brazil can access different sources of financing. The largest manufacturer in the country is Canadian Solar with an assemble factory of 360 MW. It was the first company to take advantage of financing from BNDES, Brazil's development bank. Similarly, in Mexico there is policy support for local manufacturers through the National Content Strategy developed by the Economy Secretariat.¹⁸⁶ Initiatives like this enables companies like Iusasol, a solar module producer,

to build solar parks with their custom made panels, and sell the energy to the government through power purchase agreements (PPA). Additionally, the solar market counts with companies like Sunwise, who is developing Software as a Service (SaaS) by providing a platform for installers to systematize processes and increase sales.

Mexico is a great case example where the coexistence of competency standards, policy incentives, financial support creates a thriving business environment for the development of the solar market. This type of environment should be replicated elsewhere to accelerate the transition to a decarbonized power sector, allowing for innovative business to flourish, promoting partnerships between different sectors and encourage digital service participation in the market.

Regarding transport, the electric bus market in the region, although at an incipient stage, could undergo a similar transition given its size. An example is the BYD that inaugurated a chassis assembly line in Campinas, Brazil in 2016. Other countries in the region have plans of establish an assembly factory of electric buses. The promotion of a suitable business environment, as that of the solar market in Mexico, is



186. National content unit and promotion of productive chains and investment in the energy sector.

crucial to accelerate the deployment of electric buses in the region while establishing new job opportunities for the transition.

Marine energy is of growing interest in the region. This is an area suited for investment in R&D. There is already a growing interest on future development and application of the technology in Chile. The *Centro de Investigación e Innovación en Energía Marina (MERIC)* was established in Chile with the objective of making the competitive use of marine energy for power generation a reality. In response to a study commissioned by the Inter-American Development Bank,¹⁸⁷ the Chilean government has announced its commitment to further develop its marine energy resources.

Likewise, CSP applications and battery assembly present conditions (access to resources, regional demand) that should attract investment in R&D and commercial development. A summary of some of these opportunities is presented in Table 1.

8.4 New business models to progress towards a coupled decarbonization of power and transport sectors by 2050

The power sector is undergoing a profound transformation towards decarbonization, decentralization and digitalization. This implies an increase of renewable energy in the power matrix, the installation of distributed energy resources (DER) closer to load centers and the management of this new and connected system through powerful computing tools, respectively. Digitalization is the enabler for a coupled transition of the power and transport sectors towards decarbonization. Figure 2 summarizes the elements of this transition.

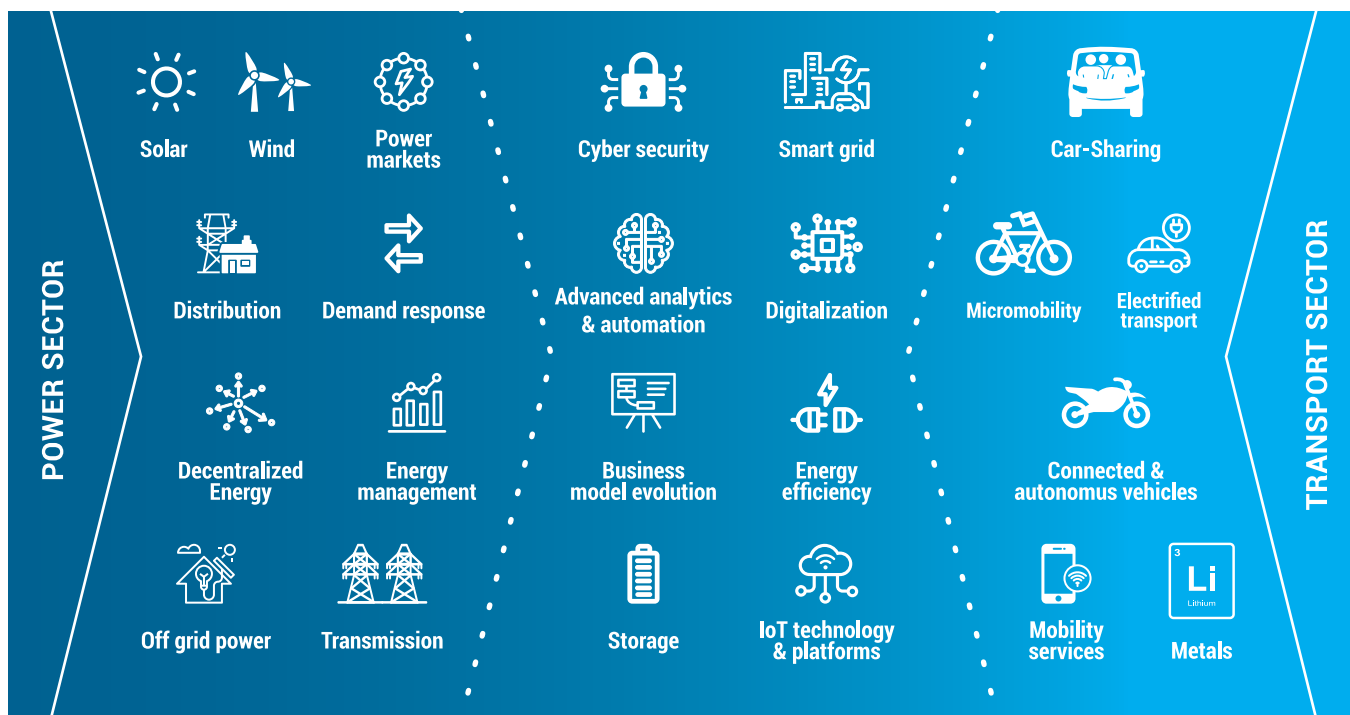
The region has an excellent endowment of renewable energy resources but in order to ensure cost-effectiveness, reliability and security of power supply, existing business models will have to adapt, and others will be created according to the new market characteristics. The same is true for the transport

Table 1. Opportunities for new/expanded economic activity

Opportunity	Location	Considerations
Vertical integration of wind energy power plants	Brazil, Argentina	Significant domestic industrial capacity; large generation potential
Marine energy development	Chile	Unique access to resources. Strong R&D capacity in the area.
PV modules assembly	Brazil, Mexico, Chile	Significant domestic industrial capacity; large generation potential.
Value added Li mining and manufacture	Argentina, Chile, Bolivia	Access to raw materials.
Electric bus assembly and manufacture	Brazil, Mexico, Colombia	Significant domestic industrial capacity; large domestic markets.
BRT software and management tools	Brazil, Colombia, Chile	Management experience with BRTs

Source: author's elaboration.

187. <https://publications.iadb.org/publications/english/document/Marine-Energy-in-Chile.pdf>

Figure 2. Business opportunities in the coupled decarbonization of power and transport sectors

Source: author's elaboration.

sector given the high urbanization and motorization rates that characterize the region. Additionally, this transition will enable new avenues of revenues and job creation. Countless business models will be developed in the coupled decarbonization of the transport and power sector. Some of these business models addressing major areas of change are listed below and exemplify the trends in the transition of both sectors, showing that the couple decarbonization has already started in the region and is picking up fast following global patterns.

Utilities

Decarbonization, decentralization and digitalization of the power system has driven utilities to face new challenges to their traditional business model with the integration of variable renewable energy (VRE), the rise of prosumers and decentralized resources, the increased connectivity and requirements for energy management, and new customer needs. The utility is now forced to adapt to new conditions and to lead to the development of personalized services with sustainable approaches, which will require

management across different value chain segments. There is no one model fits all. Each utility will have to consider the conditions and needs of the market which is immersed in and decide how to participate in it. Though, it is certain that utilities will reduce reliance on capital investments and focus on providing added value to customers and the grid.

New utility business models are emerging as part of the transition and have been described in the literature (Strategy&, 2019). Utilities can focus on developing infrastructure whether transmission lines for connecting decentralized generators to local distributor or owning generation assets and selling the energy in different markets (wholesale or contracts) or even at retail levels. Some utilities will see value on becoming energy service providers or selling behind the meter products with service and pricing packages. Others could evolve to network managers by providing data and services for the integration of distributed energy resources (DER). Virtual utilities invest in DG and storage, partners with IT companies and increases customer engagement with connectivity and tools such as demand response services.

Some examples in the region are companies like Enel and Engie in Chile and CFE (Federal Electricity Commission) in Mexico, who have diversified their services to invest in EV charging infrastructure. ENSA in Panama is offering a multitude of services to their customers such as installation of solar panels in residencies and commercial buildings for which they partnered with Ercoenergia, a Colombian enterprise with expertise in installation of solar PV systems (see Inspiring example 1). A similar partnership is that of Engie and Enlight in Mexico to promote self-generation through PV systems in residential and commercial rooftops. Utilities are also aiming at advance metering infrastructure (AMI) to offer cost savings and efficiency solutions through

asset modernization, customer service upgrades, remote meter reading, interval read capabilities, outage management and aggregate demand among others. CFE in Mexico has been deploying smart meter infrastructure with the goal to reach 30.2 million customers by 2025. CGE and Enel in Chile are following suit and expect to complete replacement of all meters by 2026. Neoenergia (Iberdrola Group), through its project Energia do Futuro, is developing the smart grid in three cities in São Paulo state, Atibaia, Bom Jesus dos Perdões and Nazaré Paulista (200,000 inhabitants). This is a pioneering project combining the installation of 78,000 smart meters, deployment of grid intelligence and automation, and a 4G telecommunication network to exchange real

1 INSPIRING EXAMPLE

• *Utility business model adapting to a renewable future – ENSA's case*

ENSA is an energy distribution company in Panama that has foreseen the need to adapt their business model to the upcoming transformation in the sector. In order to do so, in August 2018, the company started a pilot project of 146 kWp through the **installation of 396 solar panels at their Arco Iris offices in Colon province of Panama**. The project covered 65% of the consumption of this branch,



resulting in **savings of more than US\$ 25,000 and a reduction of 138 tons of CO₂ in the first year of operation**.



ENSA is part of Grupo EPM, a Colombian group formed by enterprises based in different countries in Latin America. Similar projects have been developed in other companies that are part of Grupo EPM in Colombia, El Salvador and Guatemala, making in it a sub-regional effort towards decarbonization. The project developed by ENSA in Panama allowed to gather information on technical aspects of the installation, cost savings and efficiency.

As a result, the company has created ENSA Servicios (ENSA Services) to provide diverse energetic solutions to their clients such as solar distributed generation, solar water heaters, charging infrastructure for EVs and energy efficiency services. Regarding solar energy, the company is currently selling the equipment, installation, operation and maintenance services to their clients, for whom they provide financing as well. In order to offer a first-class service, ENSA has officialized an alliance with ERCO Energy, a company in which the EPM Private Equity Entrepreneurship and Innovation Fund is a partner, with expertise in PV installations, high-quality products and system operation services. As part of this cooperation, ERCO Energy is also building capacity within ENSA Services workers. In the electric mobility arena, ENSA has form a partnership with an EV manufacturer to install the charging stations that come with the purchase of an EV of this brand. ENSA's case is a good example of a utility that has diversified its services to offer clean energy solutions by adapting to the trends and needs of the market.

time information (see Inspiring example 2). Utilities in the Caribbean are also changing their business models to increase resilience of the power system. They are moving towards utility owned solar PV recent projects such as St. Lucia Electricity Services Limited (LUCELEC) 3MW Solar Farm, the first utility-scale solar project in Saint Lucia, and the Grenada Electricity Services Ltd (GRENLEC) 937 kW aggregated solar project consisting of multiple rooftop, carport, and ground-mount solar installations. Additionally,

St. Vincent Electricity Services Limited (VINLEC) is moving forward with its first Solar-Battery Storage Microgrid System in the Grenadines to experiment the resiliency a storage system can offer to islands that can be severely affected by extreme weather events. An ambitious initiative is that of PREPA the Puerto Rican utility that is restructuring their whole power system to fit a decentralized model as a result of extreme weather events that hit the island with devastating consequences (see Inspiring example 3).

2 INSPIRING EXAMPLE

• *Energy of the Future Project*

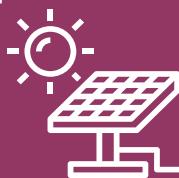
The Energy of the Future Project, is a project developed by Neoenergia, part of the Iberdrola Group, which will transform the energy distribution model and make it intelligent in Atibaia, Nazaré Paulista and Bom Jesus dos Perdões, cities located in the State of São Paulo, Brazil. The project will enhance the quality of energy supply with the use of modern equipment and automation systems which will significantly reduce the energy distribution interruptions. **In addition, smart meters will provide customers**



with daily consumption management experience, allowing them to better understand their consumption habits and set their own consumption goals.

In order to support all this technology, the devices will have a reliable communication solution, the deployment of a private 4G LTE communication network. A more robust distribution network will be prepared for the massive installation of solar panels, allowing safe integration with the electricity grid. **The project foresees the installation of 1,600 photovoltaic systems.**

This project will entail substantial benefits for the customers and the efficiency of the network:

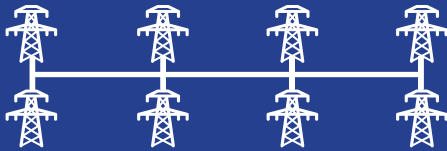


- The automation equipment and notification of energy supply failure will cause agility in power restoration, as well as a faster and assertive identification of where the issue occurred.
- The reduction of the DEC (Brazilian KPI that measures the average time a customer is without energy per year) will be of 40% implying a higher quality of energy supply.
- The smart meters will report any change in the equipment and in the energy balance. This will increase the assertiveness in locating a possible fraud or equipment malfunction, resulting in reduction in losses, better quality of energy supply and reduction in carbon emissions, as the energy generated will no longer be lost avoiding unnecessary generation.
- The remote connection and disconnection function will improve the control of default rate and efficiency in the procedure.
- Remote reading will provide about 30% in Reading Efficiency as all customers will be billed through the remote system.
- The smart meter, in addition to communicate with the distribution company, records the customer's consumption daily, maintaining a consumption history, which will allow the customer to perform a consumption management and project and monitor consumption goals.

3 INSPIRING EXAMPLE

• *Moving to decentralized generation resources*

The Puerto Rico Power Authority (PREPA) put forward a plan to radically reform the electric power system of the island. The Integrated Resource Plan (IRP) proposes to divide the island into pockets of critical loads, specifically 8 mini-grids, that can operate in grid-connected and island modes. This design management of energy systematically improves resiliency in the case of extreme weather events.



On June 7, 2019, PREPA submitted a revised 2019-2038 IRP to the Puerto Rico Energy Bureau, with the objective to reach 1,400 MW of solar capacity and 920 MW of energy storage in the first four years of the plan. Siemens, the plan developer, recommended that PREPA issues request for proposals (RFPs) for solar PV in blocks of approximately 250 MW, and depending on pricing and PREPA's capability to interconnect, continue adding blocks till the goal is reached. In the case of storage, the RFPs should be added in blocks of 150 and 200 MW and with the option to be combined with RFPs for solar so bidders can co-locate storage with PV and share advantages of sharing equipment. PREPA's IRP comes with a price tag of \$14.4 billion. The LCOE for PV was estimated at about \$80/MWh for the period of implementation of the new IRP.

This is an extremely ambitious plan considering that only 2% of the electricity in Puerto Rico is generated from renewables and that the plan targets almost the same amount of storage that

is online currently in all the US. Furthermore, the plan is aligned with the newly signed Puerto Rico Energy Public Policy Act (April 11, 2019), which requires the island to generate 40% of its energy from renewable sources by 2025 and 100% by 2050.



The main driver to set up such an ambitious initiative was the devastation caused by hurricane Maria, which knocked down 80 percent of the utility poles and damaged critical power generators, leaving millions of customers without power for months. Almost 3,000 people died in the wake of the storm. Without electricity, critical medical equipment shut off, food spoiled, drugs became unusable, and sanitation systems went offline, allowing infections to spread.

This reform towards a decentralized and cleaner grid puts Puerto Rico in line with international climate agreements, resulting in improved energy security, increased resilience against extreme weather events, improved people's livelihoods in terms of security, stability, air quality, as well as a more flexible grid. Moreover, there is opportunity for developers to enter Puerto Rico's market by responding to RFPs or exploring behind the meter projects. The IRP puts Puerto Rico on a path to consume more than two-thirds renewable electricity by 2038 and reducing its carbon emissions by 88%. Examples like this one can be replicated or adopted in other islands in the Caribbean that face extreme weather events and have similar grid conditions. In addition, behind the meter PV systems can be incorporated online to increase the flexibility of the grid even further.

In Cordoba, a province of Argentina, recent policies development supporting DG encourage the state-owned utility to divert generation assets to solar energy, promote the deployment of electric charges and the first electric bus for public transport. ICE, the Costa Rican Institute of Electricity, is moving rapidly towards a smart grid approach. The company has installed over 120,000 smart meters in the country. In other respects, ICE has established an alliance with Siemens and Ad Astra Rocket to study the possibilities for developing a hydrogen market in the country. In Uruguay, a pilot project is under development to produce hydrogen from wind surplus energy to fuel 10 trucks and 1 bus (see Inspiring example 4).

Throughout the examples presented in this section, is evident the need for partnerships between public and private sector companies, as well as a favorable policy environment that supports a decarbonized economy.

Large renewable power plants

The cost of renewables has decreased significantly in the last decade and is expected to keep falling further well below cost parity with conventional power generation sources. Therefore, nations have developed a regulatory and policy environment that supports the investment of large-scale renewable energy projects, namely through the establishment of energy auctions. Auctions are turning more competitive each year, establishing record low prices (see Figure 7 in Chapter 3). This market segment is only accessible for big players, known as independent power producers (IPP) such as large project developer companies and multinationals, due to economic and guarantee requirements.

Under the new energy law of Mexico, developer companies such as Acciona have become IPP by winning contracts to build large renewable energy projects to supply clean power to the grid. Similarly, Engie, a company that has been shifting away from fossil fuels and investing in renewable energy since 2014, was awarded, in 2016 and 2017, 7 renewable generation projects in Mexico's long-term electricity auctions. Among the most common mechanisms for IPP to sell energy to the national utility is by a power purchase agreement (PPA). Such is the case of wind

IPP in Uruguay selling energy to the national electric utility, UTE. Another example is the case of the Metro of Santiago, which runs 60% on renewable energy coming from large wind and solar power plants with energy contracted through PPAs (see Inspiring example 5).

Each year, the auction market is becoming increasingly crowded. Therefore, new opportunities are arising in the large-scale renewable energy sector, in countries where regulations are supportive, by establishing bilateral contracts among private companies through PPAs as well. Mexico is undergoing the first private long-term auction for electricity exchange through bilateral contracts (PPAs) among private companies. With already 70 participants enrolled, the private auction is expected to conclude in January 2020 with an expectation of achieving 745 MW of generation capacity and investments of US\$ 240 million. The first private PPA to be signed in Chile was in 2015 between SunEdision (now Atlas) and Los Pelambres mining company. With a capacity of 67.5 MW, the solar plant located in Atacama will provide energy to the mining company through a 20 years PPA.

Utilities-scale energy storage



Battery storage is transforming the global electric grid and is an increasingly important element to integrate variable renewable energy (VRE) and provide ancillary services to the grid.

As the world's transition to sustainable energy continues to accelerate, the market for advanced battery storage solutions is growing rapidly. In 2015, the Bahamas Electricity Act open the floor for renewable power generation allowing independent power production. Today, a new project called Family Islands Solarization Program, developed by State-owned utility Bahamas Power & Light (BPL), with support from the Rocky Mountain Institute (RMI) and Carbon War Room's Islands Energy Program, is turning to IPPs to combine solar plus storage and hybrid microgrids to extend sustainable energy access. These types of projects coupled with the right policies in place have the upper hand to accelerate the transition to a sustainable power system with its spillover effects to other sectors.

4 INSPIRING EXAMPLE

• *Hydrogen for transport in Uruguay*

The Ministry of Energy, the National Electric Utility (UTE) and the state-owned petroleum company (ANCAP), are working in the development of a hydrogen pilot project for transport, which aims to produce green hydrogen through electrolysis, taking advantage of the high renewable power mix in Uruguay. The project will include an electrolysis unit, a refueling station and 10 vehicles (trucks and long-distance buses).

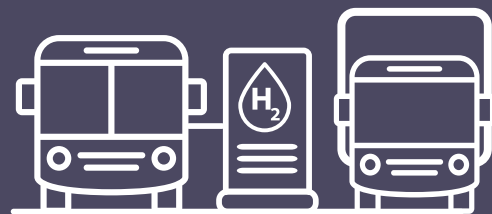


For some years now, the country has promoted battery-powered electromobility, which has allowed the introduction of electric buses, taxis and light utility vehicles. Heavy load trucks and buses represent 4% of the Uruguayan vehicle fleet and 36% of the total greenhouse gas emissions of the transport sector. This sub-sector, with a potential to decrease CO₂ emissions by 1.2 million tons per year, is the object to be addressed with hydrogen electric vehicles.

The expected evolution of RE-electricity cost and the cost reduction of hydrogen production, are showing that “Green Hydrogen” may be produced at competitive costs with diesel in the mid-term. This implies positive externalities associated with greater energy independence, reducing vulnerability to oil price volatility, foreign exchange savings and price stability for a strategic sector of the economy.

The transport hydrogen pilot project is expected to be operational in 2021 and will allow to:

- a) Test a hydrogen ecosystem under the specific conditions of Uruguay, identifying technical, legal and regulatory gaps and barriers, generating local expertise, reducing emissions and providing inputs for the preparation of a Roadmap for the development of hydrogen in Uruguay.
- b) Contribute to the formulation of a systematic process to strengthen capabilities in different human resources (vehicle's operators, hydrogen production and conditioning plant operators, equipment and service providers, etc.).
- c) Build win-win relationships between private sector companies and public institutions.
- d) Approach to the quantification of the benefits this technology can contribute to the electrical system.
- e) Generate new areas of knowledge in interaction with the academy.
- f) Generate and disseminate a cultural change in relation to de-carbonization in hydrogen fuel cell based electric transport, complementing what has already been done with electric battery vehicles.



5 INSPIRING EXAMPLE

• *The case of the Santiago's metro, Chile – coupling of power and transport sector*

The Metro of Santiago was the world's first public transport system to run on renewable energy. In January 2018, the metro set a record by covering 60% of its electricity needs with non-conventional renewables. The energy is provided by two companies: San Juan, a wind park, and El Pelicano, a solar farm. Both contracts were awarded on May 2016 with a duration of 15 years. In December 2019, El Pelicano was sold to SunPower without affecting supply of electricity. The power purchase agreement (PPA), for which the initial project committed to supply about 300GWh of clean energy every year, remain unmodified. Santiago metro system transports

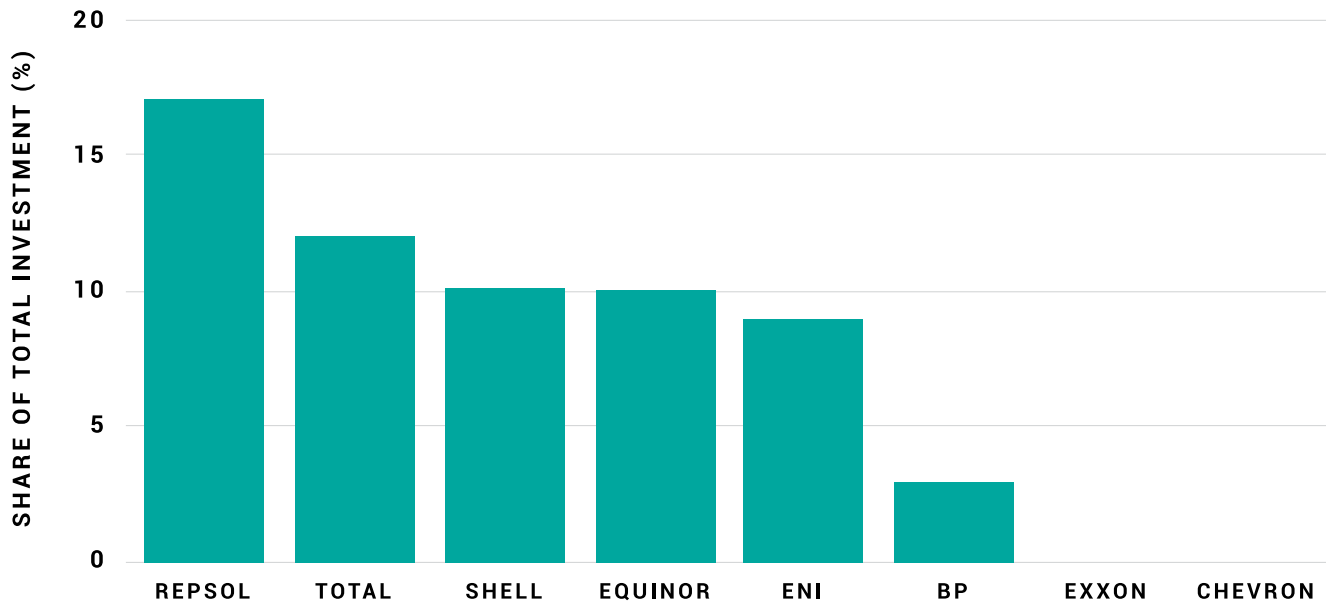
2.2 million passengers per day. Guaranteeing environmental sustainability is part of the strategic guidelines of the company. The end goal is to reach 100% of renewable energy-based electricity. The remaining 40% is supplied by the utility ENEL, with whom a contract was signed in September 2015 and will be coming to an end by December 2023. Therefore, there will be opportunity to cover this demand with non-conventional renewable energy projects, attaining a fully renewable powered metro system.



Oil companies' investment in renewables

It is worth highlighting the global tendency in the diversification of oil companies' investment portfolios in the renewable energy sector. Figure 3 shows the share of total investment allocated to renewables. Oil companies in the region are not lagging behind. Petrobras, Brazil's publicly-held company operating in the oil, natural gas and energy industry, has signed an agreement with the french company Total SA, to invest in solar energy and on-shore wind. Moreover, has signed a Memorandum of Understanding with Equinor to study off-shore wind projects. YPF, Argentinian oil company, has created the subdivision YPF Light through which aims to become the largest generator of electricity from renewable energy in the Southern Cone. An example in the Caribbean is the Jamaica's state-owned oil company Petroleum Corporation of Jamaica (PCJ), which is investing in solar and wind power business to diversify their offer. So far this examples show that creating alliances between companies is crucial to further develop the market and achieve the decarbonization objectives for the region.



Figure 3. Investments of big oil companies in renewable energy

Source: El Economista, 2019.

Distributed generation and storage behind-the-meter

With the entrance of renewable energy technology, the size of the plants can be significantly smaller allowing the entrance of new market players to build up distributed generation capacity. Third-party companies can now generate and sell energy to the grid. In addition, consumers have become producers by installing rooftop solar and selling their surplus energy to the grid, they are known as prosumers. Decentralization opens a new window of opportunities for companies to develop businesses in the renewable energy sector. La Casa de las Baterías, a private sector company in Panama, has expanded their business model to create the first national electric charging corridor in the country by using the strategic location of their subsidiaries. The EV chargers are powered by solar panels representing an example of sector coupling as well (see Inspiring example 6).

Another distributed generation business model is the case of CETSA in Colombia. The company installs solar PV systems in a facility and sells a certain amount of energy through a power purchase agreement (PPA) to the owner of the facility. The company keeps the equipment after the contract ends and ensures revenue

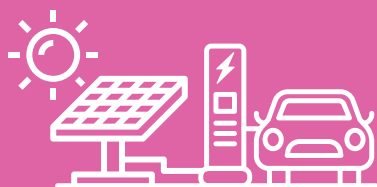
through the PPA and by selling the surplus energy to the grid. The owner of the facility benefits from lower electricity prices, green energy consumption and avoids initial upfront cost of systems.

The distributed generation sphere also counts with financiers to support the development of these projects. Banverde, a private capital investment fund in Mexico, focus on smart financing for distributed generation and alternative energy. They invest through and asset-based structure creating partnerships with solar installers in the country to finance solar systems to customers through PPAs. Another example is the case of Cibanco, who offers financing for the acquisition of solar panels for residential and small commercial customers. With a similar end but with a different business model, Telmex, a phone service company in Mexico offers financing of solar panels through their bill to their clients how spent above a certain amount of electricity per month. Business angles are also investing in PV solar system installer companies in the region, such is the case of the Mexican company Bright that installs solar panels for free and then charges a subscription fee. The company was funded through several investment firms as well as angel investors.

6 INSPIRING EXAMPLE

• *Panamanian company redefining business model through coupling power and mobility transitions.*

La Casa de las Baterías is a family owned business from Panama with operations extending to other countries in Central America. The company's core business is to sell starter batteries for internal combustion vehicles, as well as solar panels with or without batteries. Through the project "Somos Energía" (We Are Energy) the company is looking to reduce CO₂ emissions and promote the use of green technologies by installing PV systems in their stores, which will also feed charging infrastructure for EVs. The company has taken advantage of the strategic location of their stores along Panama territory to set up the first national EV charging corridor in the country.



By the end of 2019, the company will have implemented a nation-wide grid of EV chargers with the installation of 24 chargers that go through the Inter-American Highway and Panama City. The main goal of these EV charging stations is to become a catalyzer for electric mobility in the country. By installing these stations, the company expects to reduce the public's range anxiety of EVs and stimulate adoption of these technologies by making them visible to users and other companies.

Furthermore, La Casa de las Baterías is looking to partner with other commerce and organizations to expand their EV chargers' grid on a national and international level. The transport sector is one of the main sources of pollution in the country. The company's commitment to environmental sustainability has brought them to become one of Panama's early adopters of green technologies but also the fact that the business makes economic sense. The PV panels installed will generate an annual estimate of 488,210 MWh which translate into a yearly reduction of 155 CO₂ eq tons emitted to the atmosphere with a return on investment of 4 to 5 years, after which the company will have eliminated expenditure on electricity to operate.

In the long term, the CEO of the company envisions an expansion of their business model towards EV batteries, such as establishing a service center, providing check-ups of the status of the battery, and eventually replacement of batteries and use old ones (80% of life cycle left) as stand-alone storage, stabilizers of charging infrastructure or behind the meter uses. Another issue envisioned is the need for retraining personnel to adapt to these new market trends. Today, La Casa de las Baterías workers are being trained directly from electric vehicle manufacturers but educational institutions will also have to prepare for the transition to a decarbonized economy.

Enlight is an example of a Mexican company that saw an opportunity with the Mexican energy reform of 2014 and adapted their business model to fit a decentralized market focusing on solar installations for homes and small businesses. Additionally, the company partnered with Atlas Desarrollos, a property developer in Mexico to develop the first solar community in the country by designing and building 450 new residences with an individual PV system on each roof. It is worth noting that all these projects require hardware and software, which has led to the appearance of equipment importers and distribution companies in this new market.

Behind the meter storage is a very incipient market in the region but expected to grow significantly in the coming years. Amigo Solar, a Chilean microgrid provider, offers behind the meter solutions such as rooftop PV systems, peak-demand storage systems, smart meters and data loggers, which allows them to manage and optimize customer's demand and create favorable economic conditions for the supply of electricity. They aggregate demand and create smart microgrids through its proprietary Intelligent Solar Electricity Network platform. In Mexico, develop ON Energy installed the first behind the meter battery to provide frequency regulation to the grid. The company provides energy storage and energy management solutions. Companies providing these types of services to integrate renewable energy are necessary if a zero-carbon power system is to be achieved.

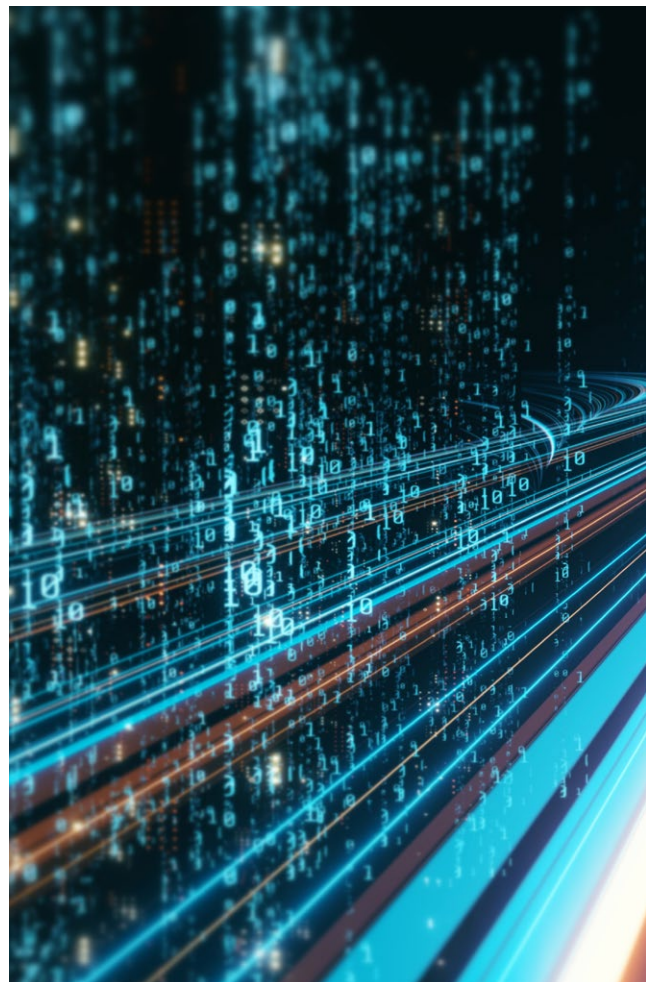
Digital services

As the electric system becomes decentralized there is greater need for information technology to coordinate and assure quality and reliability of power supply. Management of distributed energy resources, processing data from sensors and smart meters, and the protection and communication of this information to stakeholders will require powerful computing tools. Digitalization is the enabler for the transition of the power system and the electrification of other sectors.

Developing the smart grid necessary for a fully electrified economy will create countless opportunities for new business to arise in the digitalization arena such as digital services,

connecting platforms, online secure transactions and new protocols. There are several examples of this in the region. The city of Bogota started an Integrated Transport System that involves real-time data analysis. On the island of Fernando de Noronha in Brazil, the power utility, Neoenergia, is carrying out a controlled test of a smart grid city in the island with the development of several initiatives in collaboration with different stakeholders (see Inspiring example 7). Another case from Brazil is the deployment of advanced metering infrastructure in Electrobras' network to reduce distribution losses and improve operational efficiency of the system.

Dhemax, an SME in Chile, started developing the electromobility side of their business not long ago. The company was crucial for developing the management system that made possible the expansion of electric buses in Santiago (see Inspiring example 8). Among other efforts in the region, is the development of the first EV charging



7 INSPIRING EXAMPLE

• *Controlled test of a smart grid city in the Fernando de Noronha Island, Brazil.*

Neoenergia, part of the Iberdrola Group, has developed, through its electric power distribution company Celpe in the state of Pernambuco, a set of projects focused on sustainability and innovation in the Fernando de Noronha archipelago, which comprehends energy efficiency, increasing the share of renewable sources, monitoring the reduction of consumption and energy storage system, among other initiatives. The objective is to optimize the relief of current energy sources and improve the use of renewable energy in the island.



Neoenergia, has a regulated budget defined by the regulatory agency (ANEEL), in which a percentage of the company's profits must be invested exclusively in energy efficiency and research & development projects. In the process of defining how and where to invest this amount, one of Neoenergia's strategies is to encourage sustainable and innovative projects in Fernando de Noronha, in order to converge with the company's objectives and make the island an example of a cleaner and better service.

That said, some of the Noronha ANEEL's projects are: Noronha Solar Power Plants I and II, REI (acronym for Smart Grids, in Portuguese), Storage System through Batteries, "Energy Classes" Project (which is a space for environmental education in the Tubarão Power Plant), an Environmental Managing System,

and the structural modification of the Tubarão Power Plant in order to achieve energy efficiency. On top of the regulated budget, Neoenergia also invests in operation and maintenance of the island. The aforementioned projects have brought many benefits such as:



(i) Solar plants have avoided the consumption of about 10% of the fossil fuel used for electricity generation, (ii) 90% of the consumer units of the island are benefited by the Smart Grids infrastructure, and (iii) the Storage System will allow the relief of one of the biodiesel generators under certain conditions. Additionally, storing energy in batteries solves the intermittence of solar energy and decreases CO₂ emissions from fossil-fuel-based power generation.



Furthermore, it reduces the risks of damage to an endangered species ecosystem by a potential contamination of diesel accidents. Collaboration between stakeholders such as the Government of Pernambuco, public entities and Neoenergia were crucial to carry out these projects, which demonstrated to consumers and governments the relevance of investing in sustainability and technology, especially in isolated areas such as islands. As a result, the government of Pernambuco is now willing to expand the insertion of renewable sources in the territory.

network between Argentina and Chile, which will require interoperability between the devices and is a first step towards regional integration effort (see Inspiring example 9). Distributed ledger technology (DLT) will have a big role in a decarbonized and decentralized energy market. LO3 Energy, a New York based company it is using blockchain in its Exergy Platform where prosumers can transact their energy in almost real-time with consumers in the platform in their local marketplace. Chile's Energy National Commission is implementing a Blockchain pilot project to certify the quality, accuracy and transparency of the cost statements and fuel stock

of the power sector as a first approach. Eventually, will pursue further DLT applications in the energy sector based on the premise that trustworthy public information is crucial for investment decision-making, policy elaboration and creation of tools at the service of society. Overall, the digitalization sector is advancing and changing at a high speed and is a crucial part of a decarbonized power sector. Therefore, R&D is a must in this arena, as well making alliances with digital service companies, in the region and internationally, that can help provide digital solutions that are up to the standards required for a fast-paced transition.

8 INSPIRING EXAMPLE

• *Electromobility Transformation of a SME*

The transition to electromobility requires deep transformations such as the modification of existing business models. A case example is the Chilean company Dhemax, which transformed its core business model from IoT and Security (CCTV and access control) services to electromobility.

In 2008, Dhemax was composed by 10 technicians and engineers, and no income from electromobility. As the company was starting to look into IoT and Energy Management as new fields to dive into, they received their first contact on electromobility with the arrival of the i-REVA electric car. The back then Endesa group, today known as ENEL, asked Dhemax to build a charger for this car.

Since then, the company has been evolving in the electromobility sector by developing project in recharge infrastructure engineering, EV startup projects, electromobility introduction strategies and management systems among others. Up to date, Dhemax took part in more than 30 projects related

to electromobility, among them developing the management system and supporting the business model that made possible the expansion of electric buses in Santiago.



Electromobility has become the core business of Dhemax, growing from less than USD10.000 of income in this area in 2016, to reaching more than USD200.000 in 2018. The

company expects a steady 20% to 30% growth per year without external funding. Moreover, the technical team has increased by 6 as a direct cause of this new business area. The company has started a fundraising process to develop I+D and expand internationally, seeking business opportunities in Latin America and the Caribbean as well as Europe. As a result, Dhemax projects to grow by at least 100% per year for the next 5 years enabling a SME to reach a higher stage with innovation and technology.

9 INSPIRING EXAMPLE

• *The first multinational EV Charging network of the southern hemisphere*

A working group conformed by Saesa, Dhemax and Agencia de Inversiones de Neuquen (ADI-NQN), with the collaboration of AGEA Wind) has put forward an initiative to develop the first interconnection of EV charging networks between Chile and Argentina. This project is a step forward in the creation of an interoperability policy between Latin-American countries to pave the way for a regional integration effort.

The integrated system, once completed, will allow the free flow of electric vehicles through the Cardenal Samoré border control thanks to the installation of a charging station in the border that will be linked to systems on each side of the Andes mountains.

On the Chilean side, the interconnection will be supported by Saesa's charging network, composed by 20+ public charging stations (2 x 22kW in AC), which connects more than 1200 km in routes between the Araucania to Aysen regions. On the Argentina side, thanks to the support of ADI-NQN and AGEA Wind, the charging network is being deployed along the 7 lakes route and will consist of 3 charging stations in the towns of San Martin de Los Andes, Villa la Angostura and Bariloche.

The initiative was discussed during the UN Environment Programme Latin American Workshop about Legislation and Sustainable Electric Mobility held in Buenos Aires, April 2019, and was supported by Argentinean and Chilean congress members. It aims to:

- Provide a strong sign of standardization of charging formats and interoperability between networks/countries.
- Develop sustainable international tourism
- Reduce range anxiety by electric car owners or potential owners

Unification of standard and interoperability between charging networks within a country and across borders is a must to achieve zero-emission transportation. The results of this project can provide support to scale-up interoperability of networks in the region. Additionally, this type of initiatives sends a signal to carmakers and equipment providers of a unified market, which consequently, can help to propel the adoption of electric mobility in America Latina and the Caribbean.





The transformation of the transport sector can be described from the following perspectives:

Higher utilization rate of vehicles

Average vehicles spent 95% of their life parked, which makes this mode of transport very inefficient. The vehicle incurs on maintenance costs whether is being used or not. Additionally, younger generations have shown to care less about owning a car, a trend that could be related to the many transport options available in the market, as well as the need for a better air quality and less traffic jams. All this, together with the digitalization of the transport sector has resulted in a transition from a vehicle-centric focus to a person centric scope, known as Mobility as a service (MaaS).

Cars could be used more efficiently through car-sharing, ride-hailing, micro mobility as well as other on-demand services. Ride-hailing companies are already present in several countries in Latina America and the Caribbean. While these services increase the utilization of cars, they do not solve the problem of traffic jams. The latter could be addressed by business models including pooling services such as the one offered by Uber in Mexico. In 2014, the app 'Voy en Taxi' (I go by taxi) was developed in Uruguay with the objective of increasing efficiency of taxi services and competing with other ride-hailing companies. A Chilean company, Dhemax, has recently set up a new business model for on-demand electric cars

that will be driven by women (see Inspiring example 10). The business model opportunities related to mobility are huge. The company Grow Mobility, with presence in Chile, Colombia, Uruguay, Mexico, Brazil, Argentina and Peru, has more than 5 million users and more than 2500 employees in the region. They offer micro-mobility services such as dock less bikes and electric scooters. The company keeps evolving by now partnering with Transmilenio-BRT system in Bogota to provide their services in collaboration with the bus system. Latin America counts with car-sharing services in several countries but only 3 companies offer mixed fleets with alternative fuels other than internal combustion engines, these are Urbano in Brazil, CARB in Colombia and Zipcar in Costa Rica. This tendency is expected to increase as electric vehicle prices decrease and regulations for ICE vehicles become stringent.

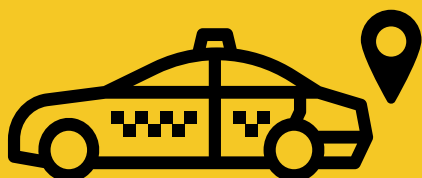
As part of the transformation, the transport system is also changing and taking advantage of the digitalization of the sector to provide customer centric services to increase the utilization of public transport and reduce congestion of vehicles. This is achieved using apps that can show estimated time of arrival of a bus to a certain stop or real-time trajectory on a map among other features. Additionally, new fleets of electric buses that are entering the regional market are noise-free and emission-free vehicles with amenities such as Wi-Fi, USB chargers and ergonomic seats to attend customer needs.

10 INSPIRING EXAMPLE

• *Electric and women driven taxis business model*

With the raise of electromobility as a cleaner way of transport, governments around the world started to look for incentives to accelerate its adoption. Among the options adopted by the Chilean government, was one to release packages of free taxi operation permits exclusively for electric cars. These permits allow a car to operate in a certain geographical zone and typically have a market cost above USD 10,000 each.

In May 2019, the SEREMI MTT (Regional Secretary of Transport and Telecommunications Ministry) of Valparaíso, released 92 permits to operate in the cities of Viña del Mar and Valparaíso. Key innovations in the operation model of permits such as allowing taxis to work in a hybrid mode were introduced. A hybrid mode means that the cars can be used as a taxi under the Chilean regulation but with the capacity to make additional transport contracts with customers. Instead of only picking up passengers in the street, these taxis can also be requested through an app for example.



Two companies, Dhemax and 30 de Mayo, came together to build a business model (Tax-e) that could guarantee the success of the project. This business model was created considering the advantages of electromobility (noise reduction, less maintenance requirements, air quality

improvements, etc.), energy management and improvement of company's image for the using cleaner transport mechanisms. Additionally, the initiative integrates a gender component by targeting women in low-income segment of society to be the drivers of taxis, thus addressing inequality and gender disparities. Both companies adopted this measure as a key element of the business model and an opportunity to encourage a just transition to decarbonization.



Tax-e is developing a sustainable transport service where women are in the front seat to fight climate change. Beyond addressing environmental and social issues, this innovative business model is creating capabilities. The regional government has trained so far 35 women in the driving skills needed to be a taxi driver. The overall initiative is supported by the private sector and customers such as Universidad Santa María, who have committed beforehand to ensure 70% of the kilometers needed per day to make this a sustainable business. The leading team projects to have 10 units on the road by the end of December 2019 and another 80 more units by 2020, creating in this way new job opportunities for women from the poorest sectors of the society while mitigating environmental consequences using electric transport.

Non-traditional actors in electromobility

The transition to a decarbonized transport sector has brought opportunities for new players, non-automotive related, to enter this market by offering ancillary services that were not possible in the traditional structure of the sector.

Service stations requirements are way more stringent than those for electric charging stations. EV charging infrastructure can be set anywhere with access to the grid or an off-grid source of renewable energy to provide the service. This opens the floor for several actors to participate in this market. In the case of the Caribbean, the company

Megapower, based in Barbados with presence in Antigua, Grenada, Dominica and Saint Vincent, was a pioneer in the introduction of EVs coupled with the development of electric chargers powered by renewable energy. They also extended their business to provide a second life for EV batteries within their renewable energy projects (see Inspiring example 11). An example of a business expansion in this area, is the case of DHL, who created a new division inside the company to develop their own electric vehicles. In 2018, the company started to incorporate these vehicles in their fleets in Mexico, Argentina and Colombia. New business models have emerged in electromobility with the participation of banks and financiers. Bancolombia is an example of

11 INSPIRING EXAMPLE

• Private sector charging stations in the Caribbean – (Barbados)

Barbados is the third highest user of electric vehicles (EV) in the world in relative terms - amount of EVs per 1000 people. Over 350 vehicles are driven in the roads of a nation whose population is a little over 285,000 inhabitants.



The success of electric vehicles in Barbados is due to private sector initiatives such as that of Megapower, who pioneered the introduction of EVs in Barbados through the roll out of a network of publicly accessible charging stations powered by renewable energy resources. The company realized that Barbados, as some other countries in the Caribbean, enjoys over 220 days of high solar radiation every year. In addition, they took advantage of the flat terrain and short

distances traveled within the islands, especially in the Lesser Antilles, (e.g. the extension of the island of Barbados is around 34 Km), which make it feasible to cover the main roads of the island with a little over 50 charging stations. To complement their business, Megapower reuse



and upcycles old EV batteries for new projects such as stand-alone storage systems, streetlight and others.

Benefits include: (i) power stored in electric vehicles could serve as repositories of electricity in case of a natural disaster, (ii) a decrease in the number of combustion engine vehicles in the island will result in less local pollutants and, (iii) in the medium and long term, significant reduction on expenses on fossil fuel imports.

Barbados has proven sustainability of EVs, creating trust for all other Caribbean islands to act in this regard.



a national bank that provides support through its Bancolombia Group partner, Renting Colombia, to stimulate the deployment of electric vehicles in the private sector through leasing mechanisms (see Inspiring example 12). Another case in Colombia is the recent alliance between Enel-Condensa and Bancoldex to promote electromobility projects in the country as financiers, investors or proponents of projects. Similarly, banks of Costa Rica such as Banco Popular and Banco de Costa Rica offer financing for the purchase of private electric vehicles and commercial fleets, whereas Banco Nacional focused on financing the electric bus segment.

12 INSPIRING EXAMPLE

• *Private sector alliance for electric mobility transition*

The private sector has a crucial role to play in the decarbonization of power and transport sectors. Bavaria, a Colombian beer company, launched the first project of electric trucks for distribution of beverages in Colombia through an alliance with Renting Colombia, an enterprise from the Bancolombia Group.



Bavaria announced it would incorporate 200 electric trucks into their fleet by 2021, accounting for 20% of the fleet. Bavaria started with the deployment of 12 trucks in 2019 driving through Bogota and Medellin, the cities with the highest particulate matter (PM) concentration due to combustion engines. Renting Colombia provides electric trucks with a range of 240 km to Bavaria through a leasing mechanism.

Through this initiative, Bavaria puts in evidence their sustainability commitment to reduce 25% of CO₂ emission by 2025. By incorporating electric transport within their fleet, the company is reducing GHG emissions and contributing to the fight against climate change. Furthermore, the project was developed in the framework of the National Strategy on Electric Mobility and Sustainability of the country, which states as

a priority the improvement of air quality and health of all Colombians. This initiative occurred in the framework of Bancolombia's project to deploy '1,000 electric trucks' with the aim to boost electric mobility in the nation to improve air quality and support the fight against climate change. Bancolombia has an ambitious goal of becoming the most sustainable bank worldwide and pretends to do so by connecting needs with opportunities in the clean energy arena.



This private sector initiative shows the importance of the participation of the banks to accelerate the decarbonization of the economy. Moreover, the bank involvement in this type of endeavor is a clear signal that it makes economic sense to diversify their businesses towards cleaner technologies. Other national banks in the region can replicate initiatives like this and support the private sector to implement clean technology projects. Projects of the kind will help bring down the price of new technology making it more accessible to the rest of the population. Additionally, initiatives as such encourages trust of the population in the technology, facilitating the deployment of electric vehicles in this case.

With the promotion of electromobility new business models will be required to attend the ancillary services of the market. An example is the need for development or transformation of the car workshops. Costa Rica has seen a significant increase in privately owned electric vehicles in the last 3 years. Calderon workshop, which was a regular car workshop with more than 30 years in the market has incorporated the equipment necessary and trained their personnel to offer services of revision, maintenance and repair of electric vehicles. Another business model is that of Autolibre, a Uruguayan company, is a leader company in the conversion of ICE vehicles to electric modes, they have been operating in the region for 16 years and among their services are trainings for organizations interested in designing EVs and converting ICE vehicles.

Car manufacturers, oil and gas companies and utilities are entering the business of charging infrastructure. The car manufacturer BMW developed electric charging networks in Brazil and Mexico to stimulate the adoption of electric vehicles in these markets by reducing range anxiety (see Inspiring example 13 – under construction). Argentinian oil company, YPF, established an alliance in 2017 with QEV, an engineering company specializing in electromobility, to deploy electric chargers in 110 gas stations. ENSA Services, a subsidiary of ENSA, a Panamanian utility, has signed an agreement with Bavarian Motors S.A., representative of BMW brand within the country, to install residential electric chargers. In Colombia, the oil and gas company Terpel, has open the first EV charging station in the country with the goal of installing a total of 30 charging stations connecting different cities of Colombia before the end of 2020.

A new alliance in the electromobility arena was former between utilities and bus operators to provide electric buses through bilateral contracts. The case of Santiago de Chile and its 386 buses currently in operation is an example of this type of partnerships. Enel, Met Bus (bus operator) and BYD form an

13 INSPIRING EXAMPLE

Car manufacturer developing electric corridors to boost EVs sales

The car manufacturer BMW is helping to boost e-mobility in Latin America through the development of fast charging electric corridors. Mexico has the largest free corridor in the regions with 412 km operating between San Luis Potosí and Mexico City with 6 stations fully operating and another one waiting for CFE approval. This corridor is under expansion to end in Puebla for a total of 620 km and 8 stations. An important highlight of the stations is that they count with different types of chargers that can power EVs from different manufacturers. Additionally, 20 DC stations will be built through Public Private Partnerships (PPP). There is another ongoing project to develop a national highway corridor connecting Monterrey to the U.S. border.



Similarly, BMW partnered with EDP and Ipiranga in Brazil to develop a corridor connecting Sao Paulo and Rio de Janeiro, totaling 430 km and 6 charging stations. BMW is currently developing a DC corridor in Colombia that will connect the cities of Bogota and Medellin. This type of initiatives helps to boost the adoption of EVs in the region by decreasing range anxiety issues – fear that a vehicle has insufficient charge to reach the desired destination. Once again, this case shows how the development of partnerships is crucial to undertake the transition to electromobility.

alliance to introduce the first 100 electric buses. In addition, 11 solar PV parking lots were installed that will serve as charging points for these new means of transport. A similar partnership was formed later between Engie (another electric utility with operations in Chile), Vule (bus operator) and STP to bring 100 additional electric buses (see Inspiring example 14). The investment decision making under this business models was based on the TCO rather than the purchase price. In this sense, the TCO of electric buses was lower than that of ICE buses, mainly due to a 70% reduction in operating expenses. However, in this case, the purchase price of electric buses was close to that of ICE buses as a result of a commercial negotiation due to the large volume of the acquisition.

The business models presented here highlights the role of partnership between different actors to develop and advance the infrastructure associated not only to electric vehicles but also to a renewable power sector, in order to achieve the decarbonization goals.

V2X

With the deployment of electric vehicles and digitalization, V2X (vehicle to everything) communications are evolving at a fast pace and are useful in countless applications and services. The communication between vehicles to grid, to infrastructure, to other vehicles and to homes among others create benefits such as road safety, traffic efficiency, smart mobility and environmental sustainability among others.

This type of communication is provided through DSCR (dedicated short-range communication) based on Wi-Fi standard, a well-established technology, or C-V2X based on LTE communication standard (soon next generation 5G networks), that was developed in 2018. The V2X market is just now starting to be developed and it is expected to achieve a global worth of billions in the next few years. The evolution of this market has great potential for alliances between automakers, telecom and ICT companies, as well as the creation of new business models given that V2X provides the foundation upon which countless commercial services and applications can be developed.

Among V2X technologies is the example of V2G (vehicle to grid), which offers diverse opportunities for business development within the sector coupling transition as vehicles can be used to balance the grid through bidirectional charging. It is worth noting that this is an incipient market with many opportunities to be discovered. In 2017, Virta, charging operator, installed the first bidirectional charger in Finland. Everybody can access the smart electric vehicle charging stations, but registered customers have benefits such as lower recharge payments. Additionally, Virta's business model offers a smart platform for companies to manage their own electric vehicle charging network, which is adaptable to different business models and can be customized to meet customers' needs. Over 250 charging network owners use the Virta platform to run charging services with over 80,000 registered end-users in 26 countries.

Another V2G example is that of MotorWerks case, a subsidiary of Enel X, who deployed a 30 MW of virtual energy storage battery, which comprises of more than 6,000 eMotorWerks residential JuiceBox and other JuiceNet-enabled chargers in California. By controlling these chargers and enrolling EV drivers through rewards programs, MotorWerks can offer demand response services when needed.



14 INSPIRING EXAMPLE

• *Innovative business model for the introduction of electric mobility in public transport*

As part of the efforts to boost electric mobility, the business sector and the Chilean government launched a procurement plan that included technical and business model innovations to position Chile as the country with the highest number of electric buses in the world after China. In 2017, a new bus acquisition structure was created, using existing elements such as the provision contract. In this contract, the state takes as its own the obligations and rights of an organization providing services to the state, in the case this organization ceases to fulfill its obligations. Thanks to this element, which adds financial support to transport operators, the local electric utility ENEL bought the buses to BYD and delivered them to Metbus in an operating leasing mode.

With this new business model, the acquisition of 100 buses was guaranteed initially and thanks to the development of a similar model, which used as a basis what was done between ENEL and Metbus, Engie (another electric utility with operations in Chile) in alliance with the bus operators Vule and STP, made the acquisition of 100 more electric buses. This acquisition model was later complemented with an efficient charging infrastructure model design, in order to minimize risks and, in turn, size the infrastructure to the optimum levels to allow recharging without the project incurring in cost overrun. The main driver for the optimizations performed and the business model developed for the acquisition was to keep the total cost of ownership of an electric bus close to that of an internal combustion bus.



By keeping these values to similar level, the purchase of electric buses was enabled without using subsidies or other government support.



Two elements were key to accomplish this goal: (1) electric tariff negotiation and (2) dynamic power management, grounded on optimization of the use of infrastructure based on instantaneous energy costs. This included developments of dedicated software and hardware to interconnect individual bus chargers to create a network, allowing to optimize power management through real-time consumption of each charger. This innovation was developed locally by Dhemax (engineering company) in partnership with ENEL X (demand response provider of ENEL).



This case has set the precedent for an alliance between private parties, between a utility and a transport operator to develop an urban transport business with tremendous environmental and economic benefits, demonstrating that economic growth is compatible with environmental sustainability.

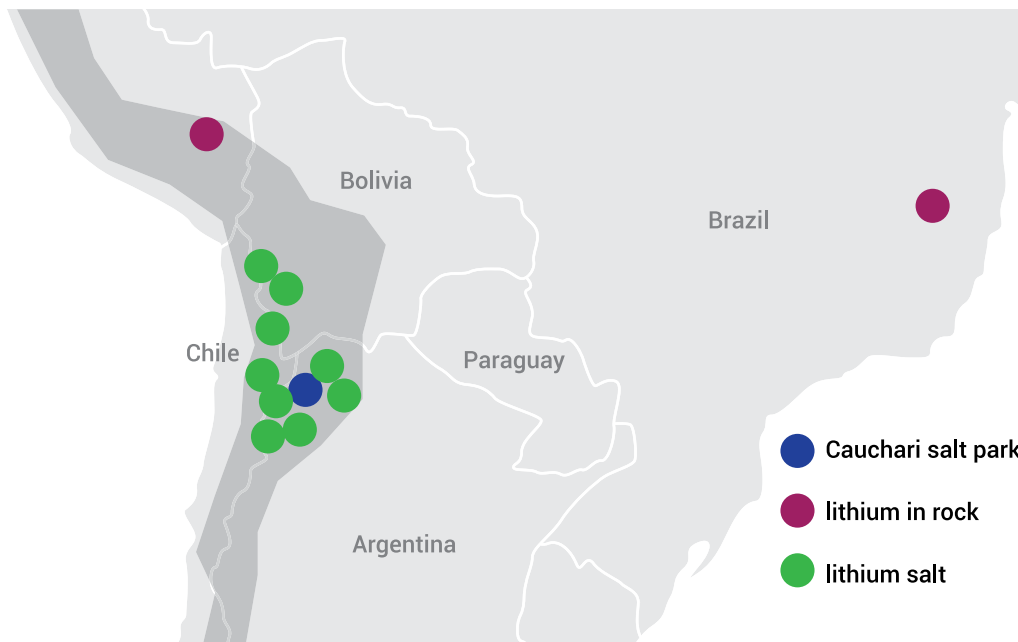


Sustainable Value Chain for lithium

Demand for lithium ion batteries is on the rise for their energy storage potential as utility-size and behind the meter storage, as well as for the deployment of electric vehicles. The lithium triangle country holds more than 60% of the world's lithium reserves (see Figure 3), and with recent discoveries in Peru the region could potentially lead production worldwide. China is the lead importer of lithium with most of this metal coming from South America. There is increasing competition among companies to be part of this market, which is bringing a lot of foreign investment into the region given that the country who controls lithium resources

will control the power sector and automobile industry transformations. There is a huge opportunity for the region to develop businesses around the lithium value chain. The exploitation of these metal must be done in a sustainable and inclusive way. A step forward in that direction was the recent creation of the regional Lithium Platform integrated by the aforementioned countries with the objective of strengthening the regional strategic management capacity for the development of the lithium industry (see Inspiring example 15). Once again, strategic alliances are key for the development of a well-grounded sustainable market. Countries with lithium production can create businesses around downstream value chain such as the production of batteries.

Figure 3. Lithium reserves in South America



Source: OBELA, 2019.

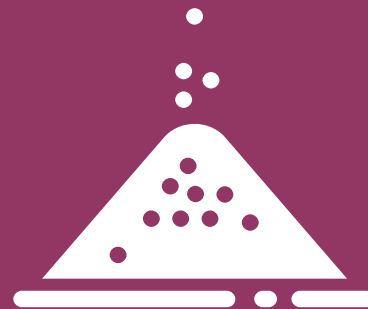
15 INSPIRING EXAMPLE

• *Lithium Sustainable Development - Regional Platform: Argentina, Bolivia, Chile and Peru*

Large endowments of mineral reserves can be found in Latin America and the Caribbean. The region is among the main producers of key natural resources for the global economy, such as copper, iron, lithium, silver and gold, among others. The sector accounts for almost 5% of regional GDP and is one of the main sources of foreign direct investment, as well as an important contributor of foreign currencies and tax revenue for countries. Salt Lakes in Argentina, Bolivia and Chile hold more than 60% of the available reserves around the world and the three countries together constitute the so-called “Lithium Triangle”. Additionally, hard rock lithium deposits were found recently in Peru. If the expectations of this discovery come to fruition, the region that covers lithium deposits in these four countries could become a dynamic epicenter of our planet energy transition.

The scalability of projects for exploitation of lithium reserves poses environmental and social challenges. Therefore, it is imperative to move forward in the design of proper accounting and internalization of environmental and social costs related to this activity. The exploitation and use of lithium constitute a great opportunity for sustainable, inclusive and long-term development at local and regional levels that must be suitably led. Consequently, the Lithium Sub-regional Platform was recently established between the governments of Argentina, Bolivia, Chile and Peru. The objective of the platform is to support the strengthening of regional strategic

management capacity for the development of the lithium industry. Some key aspects of the platform are: (i) the generation of cooperation between member states, (ii) the production of specialized technical knowledge, and (iii) the exchange of experiences and best practices around the exploitation of lithium. Through a collaborative understanding between government, academia, industry and civil society, the project seeks to face several topics such as: sustainable mining, environmental and social practices, direction of government efforts, equal encouragement of upstream and downstream chain values, requirements for the region to become the quintessential worldwide suppliers of lithium, adequate legislation to face upcoming challenges.



With the high-speed development of the lithium industry and its global implications, the regional platform will have a major role to play in supporting governments and companies to assure a sustainable extraction and production of this metal, as well as the business opportunities arising from the development of this value chain and associated industries in the region.

Many foreign companies (Chinese, German, Italian) are associating with local ones to form joint ventures (JV) to participate and develop the lithium value chain in the region such as the production of batteries. An example of this is the Argentinian mining company JEMSE formed a joint venture with the Italian company SERI to create a progressive business-model for production of ion-lithium batteries in Jujuy, Argentina, in the medium term at a competitive cost. This project includes a broad participation of academia and local communities and pretends to take advantage of the lithium triangle supply potential, the existing automobile industry in Argentina and the increasing demand in the region of electric vehicles. Additionally, lithium-ion battery production could take up in car manufacturing countries such as Brazil. The development of the lithium industry in the region could boost economic growth and create many job opportunities in the value chain or associated to this industry.

8.5 Implications for training and education

Opportunities for manufacture, assembly, and commercialization of the technologies involved in the transition will develop faster if efforts are made to provide the training, skills development and education required in these fields. The job generation potential warrants efforts by the public sector to address these needs. Also, a skilled, educated labor force will contribute to attract components manufacture and support local development of ancillary industries. There are already some efforts to provide new education and training tools in the region, notably in Uruguay, Mexico and Brazil but additional efforts are required.

8.6 A just transition

The transition to a climate resilient and low-carbon economy will bring drastic changes in the way we currently work and live. The uncertainties in this respect and the lack of a clear strategy on how these issues will be addressed leads to several social groups resisting the needed change.¹⁸⁸ A just transition seeks to minimize the negative impact on workers and communities dependent on unsustainable industries and energy sources (see Inspiring example 16). Moreover, this frames in a greater objective, which is to assure that social and economic inequalities are addressed in the transition to a low-carbon world (see Inspiring example 17).



188. <https://www.wri.org/climate/expert-perspective/embeddingv-just-transition-long-term-decarbonization-strategies-why-what>

16 INSPIRING EXAMPLE

• *How a shipbuilding company became a world leader in the offshore wind construction market*

Offshore wind energy has opened a new business niche for job and enterprise creation with positive impact in the Spanish economy. For companies in the shipbuilding sphere this is an opportunity to diversify their businesses through contracts for the design and construction of the large foundations and facilities required by offshore wind farms. Navantia, traditionally oriented to shipbuilding, was introduced to the offshore wind market in 2013. Its modern facilities together with the ideal climate throughout the year are excellent conditions for the fabrication of offshore wind structures.

The arrival of Navantia in the offshore wind sector came at the right time. The facilities in Fene, Galicia and Puerto Real, Andalucía were experiencing significant decrease in workloads, which opened the possibility to diversify its portfolio to this upcoming market at the time. The transition towards deeper waters required new concepts of substructures and large substations. This was the case for the first solo project of Iberdrola, the Wikingen project, which needed a different type of foundation that required high welding competence as well as large capacity manufacturing spaces; areas in which Navantia stood out.

An association was created between Iberdrola and Navantia. In the summer of 2016, Navantia delivered Iberdrola 2 topside modules of 2,500 tons for the 400 MW substation installed in the Wikingen Park, with its 6-legged jacket and 2,400 tons. Navantia also built and



delivered, together with the Windar company, 29 jacket-like structures for the same park, meeting strict timeframes. These are structures of more than 60 meters that must withstand a minimum of 25 years in the water, facing adverse erosion conditions and strong water flows. Each wind project employs an average of 600 direct workers reaching over 1,000 workers in key steps of development.

The good results encourage Iberdrola to trust other projects infrastructure to Navantia. The acquired experience allowed the latter to be at the forefront of offshore technology and successfully place large orders not only for this Spanish company, but also for other in the sector such as Equinor, EDP, Cobra, Siemens and Aibel. In time record the company had specialized in the construction of floating foundations. This exemplifies the existence of new opportunities for actors in other industries to turn to renewable energies to diversify their businesses and maintain their labor force. An enabling B2B environment can accelerate the process of knowledge transference and capacity building associated to a new or existing market.

17 INSPIRING EXAMPLE

• *Mainstreaming gender in the power sector – “Solar women” program*

Women are underrepresented in technical jobs in the energy sector, as well as in leadership positions. The Mexico energy reform was expected to bring about 135.000 new technical jobs which could be divided equally between women and men helping reduce gender inequalities within the country. Women may find in non-traditional jobs the following setbacks: discrimination, lack of credibility in their capabilities, hostile environment in their community and family, study guide or manuals that do not consider women as end users of that information.



The development of competence standards in Mexico's solar market together with the “solar women” program developed by GIZ, gave women the opportunity to earn a certification as installers of solar water heaters and solar PV systems. This program was created to demystify the sector as a men-only sector, close the gap between non-traditional jobs, reduce the participation of woman in the informal job market, generate economic



autonomy, improve living conditions and promote leadership. The goal was to empower women and support the transition towards gender equality. Incentives for women to attend the trainings were part of the initiative. Several national companies collaborated with subsidies, scholarships and cost reductions for training and certification of women. Other considerations were to adapt class schedule to women's needs as well as provide a safe space where they could leave the children during class time.

Empowering women has transformative effects in their surrounding society. Gender inequalities are socially constructed and therefore can be and are modified over time. It is imperative to recognize the participation of women in the energy sector to allow the same opportunities for all. The transition to decarbonization comes with the unique chance to balance the gender scale resulting in better economic outcomes for the whole society.



In order to achieve this, labor and social policies should be integrated with climate objectives. The International Labor Organization (ILO) developed the “Guidelines for a Just Transition Towards Environmentally Sustainable Economies and Societies for All” (2015). The guidelines introduce social-related policies that will support the transition to a carbon neutral economy. The recommendations comprise macroeconomic, sectoral, and enterprise policies; rights and occupational safety and health; social protection; skills development; active labor market policies; and social dialogue (see Inspiring example 18) and tripartism (ILO, 2015).¹⁸⁹

189. https://www.ilo.org/wcmsp5/groups/public/---ed_emp/---emp_ent/documents/publication/wcms_432859.pdf

18 INSPIRING EXAMPLE

• *Citizen engagement is critical in accelerating electric mobility, Costa Rica's case*

Costa Rica is an electromobility pioneer in Latin America. The number of electric cars and motorbikes grew by 832 from 2016 to 2018. After two years of debate, January 2018, the country passed the first law in Latin America and the Caribbean designed to boost zero-emissions electric transport (Law N° 9518 - Incentives and Promotion of Electric Transport). Institutional fleets are moving to electric vehicles, municipalities such as Grecia are incorporating electric motorbikes in their fleet, the national post office has a target of replacing all their motorbikes for electric ones and have already swapped 15 of them. A private electric bike scheme was introduced in 2019. As the demand grows, supply is adapted, with currently 8 brands and 35 different types of cars. It is also the first country in the region to test zero-emission fuel cell electric cars.



Citizen engagement has been a key driver for change.

For two years, a citizen group, Costa Rica Limpia, worked with the Congress representatives to push for legislation. It engaged the media showing citizen benefits of zero-emission mobility and designed several citizen innovations to build momentum for the law: the design of electric mobility citizen festivals, the formation of the Costa Rican Association of Electric Mobility (ASOMOVE) and collaboration with the electric mobility association of Norway to learn lessons from a mature market. Today, ASOMOVE has attracted a growing number of

pioneers EV users that collectively demonstrate that electric mobility is feasible in Costa Rica. Citizen festivals continue to succeed: EV users, not companies, showcase the ecosystem surrounding electric transport and how the technology works in practice. EV early adopters and active advocates are awarded, citizens test drive EVs and hear talks from owners regarding benefits, driving experience and cost savings of having an electric car, companies working in this environment are also present showcasing their products. Three festivals have been carried out in Costa Rica so far, having the last one an attendance of over 5,000 people per day. They are done during the weekend to create a family-friendly experience.

A lesson for other countries is that citizen engagement -EV users is crucial for the success of electric mobility public policy and deployment. In Costa Rica, ASOMOVE has taken a leading role in the implementation offering real-life testimonials, providing feedback to policy makers, supporting EV owners in the decision of acquiring an EV (and in the application of the law), and advising decision makers on where to deploy electric chargers. Moreover, it is independent and privately funded with the associate annual fees and the Festivals. They are currently affiliated to a Latin American electric mobility group - ALAMO - and collaborate with similar organizations in other countries to share experiences. The case of Costa Rica goes beyond the lessons from the law itself: electric mobility will go faster if civil society is organized and works actively in the passing of the laws and the implementation of the electric mobility law and policies.

CHAPTER 9

POLICY OPTIONS FOR AN ACCELERATED TRANSITION

The scope of this chapter is to analyze the key elements of a policy agenda that would support the pace of transition sought in both, the electricity generation and transport sectors and can exploit the synergies of their simultaneous evolution. Policies for the transition of the power and the transport sectors are reviewed, as well as policies for a coupled transition. Moreover, case studies addressing initiatives in the region are presented.



The policy environment has evolved throughout the region in support of a cleaner power matrix, low carbon and resilient development, and a cleaner transport system. In the vast majority of the nations this has resulted in the enactment of policy frameworks in support of a diversified and renewable energy matrix.¹⁹⁰ There are however substantial policy and regulatory differences between countries, and in a few countries, there has been a resurgence of policy stances that could delay the transition described in the report.¹⁹¹ The trends in technology and economics have contributed to the growth of the use of renewables, utility scale and DG, and are beginning to make a difference in the emergence of electric vehicles. Nonetheless, the degree and speed of change required to transition by mid-century makes leadership critical through a strong, bold policy agenda. Therefore, it is critical that decision-makers overcome silos and consider public policies that address these two sectors in a coupled manner. A well-constructed enabling environment will be critical to attract investment flows towards a coupled transition.

The policy environment should be dynamic and country customized. The economics of the transition are not set in stone as technology prices are coming down fast, new elements come into play and the impacts of climate change keep evolving. Therefore, policies should be reviewed periodically in order to help countries achieve their NDCs, and meet decarbonization objectives by 2050, as well as the SDGs in a changing environment.

9.1 Policy agenda for power sector transition

In order to assure the long-term electricity supply - in conditions of efficiency, quality, reliability and safety - and reduce the country's vulnerability to the effects of climate change, some countries in the region have developed a legal, regulatory and policy framework that promotes diversification and decentralization of the power matrix by renewable sources.

Adoption of renewable energy for power generation has been facilitated by at least four policy elements: (i) policy commitments and targets under the Paris agreement and a favorable policy posture to mitigate greenhouse gas emissions and improving the resilience of associated infrastructure to the impacts of climate change; (ii) the set-up of national targets for participation of renewables in the power matrix; (iii) adoption of enabling regulations to facilitate private investment and access to transmission and distribution infrastructure; (iv) encouragement of private players to compete in the electricity market and invest in electricity generation and trade.

Existing and new policy instruments to achieve the decarbonization of power sectors is summarized in Table 1 and described in more detail below as part of two big areas within the sector (decarbonization and decentralization measures).

190. Additional information can be consulted in: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_IEA_REN21_Policies_2018.pdf
191. For example, measures that would discourage market entry or renewables.

Table 1. Goals and main instruments of a bold policy agenda in support of the coupled decarbonization of the power and transport sectors

Goal	Policy Actions	Instruments
Reduce the cost of stranded assets in the power generation and refinery sector.	Discourage capital investments in the fossil industry.	<ul style="list-style-type: none"> • Clear energy and transport policy adopting zero emission goals by 2050. • Allow early depreciation of assets. • Eliminate fossil fuel subsidies.
Promote DG, storage capacity and auxiliary services to provide grid flexibility and integration of variable renewable energy.	<p>Promote investments in modern, smart generation, transmission and distribution infrastructure and auxiliary services to integrate VRE.</p> <p>Develop regulations on demand management, storage, self-generation and distributed options.</p>	<ul style="list-style-type: none"> • National targets on DER. • Development of technical standards for DG. • Development of public and private financial mechanisms. • Clean energy certificates and programs. • Permitting procedures for DG installations. • Net metering/net billing/self-consumption schemes. • Renewable energy mandate for new construction. • RE and/or storage auctions. • Update regulation to include RE in government procurement. • Industrial policies for renewable energy. • Distributed solar PV installers certification programs. • Fiscal incentives.
Optimize generation and transmission to meet demand.	Promote regional grid integration.	<ul style="list-style-type: none"> • Market-based power exchange with neighboring countries. • Regional integration of transmission system.
Internalize health and climate costs in transport emissions.	Develop fiscal or carbon pricing measures that allocates the costs of health and climate impacts.	<ul style="list-style-type: none"> • Fiscal measures to pass costs to emitters of air pollutants and GHGs. • Carbon emissions trading systems. • Use revenues to promote public investments in enabling infrastructure.
Facilitate market entry of electric transport.	Removal of regulatory and policy barriers.	<ul style="list-style-type: none"> • National targets on EV by segments. • Prohibitive measures over ICE vehicles. • Electric tariff incentives for EV owners. • Review/modify road standards. • Regulations for standardization and interoperability of charging stations. • Regulate composite fleet emissions. • Enact transit and parking preferences. • Standards for BEV. • Industrial policies for EV manufacture. • Fiscal incentives. • Vehicle emission and efficiency standards. • Ultra low emission zone.
Assure efficiency, quality, reliability and security of a connected power system	Assure resiliency of the system, quality of service and protection of stakeholder information.	<ul style="list-style-type: none"> • Implementation of cybersecurity standards. • Smart grid standard policy. • Stimulate investment in ICT services. • Cooperation between nations in the region and internationally to share information, lessons learnt and good practices.
Promote technology and business development in support of the transition.	Promote investments in R&D and technology development in zero carbon technologies.	<ul style="list-style-type: none"> • Science, technology and innovation policy in favor of zero emission goals by mid-century. • Fiscal measures to support investments in R&D. • Grants to escalate startups with a proven minimum viable product with substantial impact on decarbonization.
Address social and economic inequalities	Assure a just transition.	<ul style="list-style-type: none"> • Policies for social protection. • Ensure green jobs are decent. • Retraining of workers. • Promote inclusive participation in dialogues.



Colleton, Barbados
Photo by Scot Goodhart, Unsplash

Decarbonization measures

National targets

Targets determine the political commitment towards decarbonization of the power sector. This sends a signal for investments and trends for the private sector and transparency for the public. The existence of targets also helps to formulate policies. All countries in the region have set targets on renewable energy (See Table 2). Such is the case of Barbados with its National Energy Policy 2019-2030, aiming to attain a 100% renewable energy by 2030. Other countries, like Argentina, have specific targets for DG. Argentina defined a goal of installing 1 GW of renewable power sources by 2030.

RE/storage auctions

The competitiveness of renewable energy resources can be maximized using market auctions to set real market pricing and ensure transparency.¹⁹² Experience with auctions in the region has been encouraging and should continue to be promoted. Auctions should convey certainty to market actors and investors and provide clear policy directions while preserving flexibility to changing market conditions. Refer to Table 2 for the list of countries in the region that count with auction instruments. Specific auctions

on RE can further accelerate the process. The recent Colombian renewable auction allocated 2.2 GW of solar and wind power reaching an average price of US\$ 0.027/kWh. The capacity awarded corresponds to a 10% of total capacity of the current power system in the country and is equivalent to an investment of US\$ 2,000 million. This indicates how the RE sector is attracting investment.

Discourage investment in thermal power plants

The pathway to decarbonization requires an immediate change of direction. While there is a substantial installed capacity in power generation with gas, coal and to a lesser extent oil, most of the generation capacity necessary to meet the demand by mid-century (over 60%) has yet to be built. Power generation assets can operate over inter-generational periods¹⁹³ and thus it is important that a strong signal be issued now to prevent additional locking-in of emissions, which may at the end become stranded assets. An important first step is to ensure that any new capacity is based on renewable sources of energy. Policy directions are needed to steer investments away from fossil fuel for power generation and establish sunset provisions for thermal power plants. Examples of fiscal instruments include the elimination of fossil fuel subsidies (see Inspiring example 19) and taxation of fossil fuel generation capacity.

192. A good review of the criteria and advantages of power auctions can be consulted in : https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/Jun/IRENA_Renewable_Energy_Auctions_A_Guide_to_Design_2015.pdf;

193. <https://qz.com/61423/coal-fired-power-plants-near-retirement/>;

19 INSPIRING EXAMPLE

• Fossil fuel subsidies – social implications of their removal

In order to take on climate change a carbon pricing on fossil fuels is necessary but the reality in many countries is that these fuels have been subsidized for decades, and still are. The removal of subsidies will result in carbon emission reductions, better air quality for population and government savings. Nevertheless, if not managed in a proper way, the process can result in social upheaval as seen this last month in Latin American countries.



In Ecuador, the decision to end government subsidies on fuel prices, as part of an agreement with the International Monetary Fund (IMF) to cut public spending, set off a strike of the transport sector and protest across the nation. The clashes between protesters and the riot police drove the president to declare a national emergency state. Without subsidies fuel prices raised 123%, more specifically, diesel went from 1,03 US\$/gallon to 2,27 US\$/gallon whereas gasoline raised from 1,85 US\$/gallon to 2,30 US\$/gallon. A total of 1.300 million dollars are spent per year in fossil fuel subsidies. Peace was brought back to the capital after an agreement was reached between the government and indigenous leaders to reinstall the subsidies. The elimination

of fossil fuel subsidies was the most controversial measure among a package of measures present by the government that included a reduction of 20% in temporal jobs of the public sector, a holidays cut by half for public employees and a contribution representing a one-day of a month salary.



At the same time, Chile is undergoing massive unrest after the government announced a 4% rise on the subsidized subway fare, totaling \$30 pesos per ride. More than 1,2 million people were marching in the streets. This has been the largest protest the country has seen since the return of democracy 30 years ago. The President called for a state of emergency sending the military to patrol the streets with curfews in several cities across the nation. Despite the suspension of the price hike and promises of social and economic reforms, the riots continued evidencing Chilean's discontent with high economic inequalities, expensive health care, poor quality of services and low pensions among others. Both cases resemble that of the Yellow Vests Movement in France, which pursues economic justice towards rising fuel prices and high cost of living. Protest of this group involves demonstration, blocking of roads and some have developed into major riots.



19

INSPIRING EXAMPLE

- **Fossil fuel subsidies – social implications of their removal**

To comply with the Paris Agreement and keep temperatures below 1.5 °C it is imperative to eliminate subsidies to fossil fuels as other cleaner technologies are already cost competitive (wind) and/or about to reach cost parity (internal combustion engine cars) with fossil thermal based technologies.



Nevertheless, the elimination of subsidies must be done in a progressive way to reduce impact on consumers and needs to be coupled with compensation mechanisms for the most vulnerable

population, addressing areas of social inequality. It is advisable that these types of measures are not part of a package on new policies that might affect negatively sectors of the population. Instead they should be a package on its own with the compensation measures or associated with policies that generates a benefit for society.

Furthermore, citizen participation, as well as the involvement of all stakeholders in the discussion of new legislation is of the greatest importance to achieve a consensus and have all interests represented. In order to attain a successful and peaceful outcome is important to develop awareness raising and educational campaigns for the population to understand changes in policies and support the process.

Direct public support for investments in modern T&D infrastructure to enable integration of DER

The ownership and management of the transmission and distribution infrastructure is reflective of an increasing private participation and adoption of open market conditions. Still, many assets remain under the tutelage of the public sector. Failure to update T&D infrastructure might jeopardize the deployment of RE assets. Further inroads of renewable energy require of more flexibility, storage capacity and integration of distributed options to ensure that variable resources can operate in a cost-effective manner.

Regional integration of Transmission system

The region has already the building blocks of a regional transmission system. Linkages between Brazil, Argentina Uruguay and the Andes countries and linkage of the Andean market with Central America are amongst the next logical steps. Multi-national transmission systems have proven effective in enabling faster penetration of renewables. It potentially allows a more efficient allocation of generation capacity to meet the combined demand. Further, in principle it allows hydro power reservoirs to share any storage capacity to address baseloads. It can be promoted through the set-up of a market-based power exchange with neighboring countries. The inter connection needs to be done avoiding any impacts on natural ecosystems. In the case of Denmark and Uruguay, market-based power exchange with neighboring countries has been the most important tool for dealing with market entry of wind power. Denmark has also implemented cost effective price signals to promote demand side flexibility to accommodate the generation patterns of the wind option. The integration of disperse generation and ability to store energy has also been part of the transition of the power system in Germany.¹⁹⁴ Variable resources are integrated fully and very little of the net demand is now non-fluctuating.

¹⁹⁴. <https://energypost.eu/how-german-energiewendes-renewables-integration-points-the-way/>;



Industrial policies for RE

This type of policies supports the development of new industries and the adoption of new technologies by offering protections, incentives and priority to national industrials of a certain sector, in this case the renewable energy sector. A good example of this is Mexico's National Content Strategy developed by the unit of National Content and Promotion of Productive Chains and Investment in the energy Sector of the Economy Secretariat. The National Content strategy aims to promote the development of national providers by establishing a share of local products in government procurement. Thus, having an indirect positive effect over productive value chains and job creation within the country. Another example is the one implemented by the Government Secretary of Energy of Argentina, which has set up an instrument to promote National Manufacture of Systems, Equipment and Inputs related to Distributed Generation (Fomento para la Fabricación Nacional de Sistemas, Equipos e Insumos para Generación Distribuida - FANSIGED) with the aim of boosting the deployment of national suppliers of renewable distributed power systems. This will be achieved through the development of installer training programs and certification of technology standards and eligibility criteria for installation companies. Developing the local distributed PV industry will help create new sources of employment and increase the countries' competitiveness in an evolving global industry.

Decentralization measures

Net metering/net billing schemes

Many countries in the region have set billing schemes for inputting self-generation surplus to the grid. Policies determine the size of installations that can benefit from this incentive. Net metering policies are starting to be rethought given that the payment for distribution services is not accounted for in the scheme structure. Examples of updates are (i) the introduction of a minimum or fixed bill that cannot be offset by excess solar production and (ii) adjustments of the credits expiration structure of the energy inputted into the network. In any case, net metering is a crucial instrument for the adoption of DG, especially in the early stages of market development. Countries in the region with the most developed DG market, like Brazil and Mexico, count with net metering among their energy policies portfolio (see Table 2).

Storage

Policies promoting/habilitating market adoption and investments in storage capacity make sense to enable the system to accommodate increasing fractions of variable energy resources that would enable cost-effective management of peak demands including peak shaving. Additionally, it gives the grid stability. The Dominican Republic has adopted regulations to favor energy storage by remunerating frequency regulation services.

Table 2. Existing energy policies in some countries in the region

	RE National Targets	Net Metering	Accelerated Depreciation	VAT exemption	Import tax exemption	Carbon Tax	Clean energy certificates	Priority dispatch	Auctions
Antigua and Barbuda	■	■	■	■	■	■	■	■	■
Argentina	■	■	■	■	■	■	■	■	■
Bahamas	■	■	■	■	■	■	■	■	■
Barbados	■	■	■	■	■	■	■	■	■
Belize	■	■	■	■	■	■	■	■	■
Bolivia	■	■	■	■	■	■	■	■	■
Brazil	■	■	■	■	■	■	■	■	■
Chile	■	■	■	■	■	■	■	■	■
Colombia	■	■	■	■	■	■	■	■	■
Costa Rica	■	■	■	■	■	■	■	■	■
Cuba	■	■	■	■	■	■	■	■	■
Dominica	■	■	■	■	■	■	■	■	■
Dominican Rep.	■	■	■	■	■	■	■	■	■
Ecuador	■	■	■	■	■	■	■	■	■
El Salvador	■	■	■	■	■	■	■	■	■
Grenada	■	■	■	■	■	■	■	■	■
Guatemala	■	■	■	■	■	■	■	■	■
Guyana	■	■	■	■	■	■	■	■	■
Haiti	■	■	■	■	■	■	■	■	■
Honduras	■	■	■	■	■	■	■	■	■
Jamaica	■	■	■	■	■	■	■	■	■
Mexico	■	■	■	■	■	■	■	■	■
Nicaragua	■	■	■	■	■	■	■	■	■
Panama	■	■	■	■	■	■	■	■	■
Paraguay	■	■	■	■	■	■	■	■	■
Peru	■	■	■	■	■	■	■	■	■
Saint Kitts and Nevis	■	■	■	■	■	■	■	■	■
Saint Vincent and the Grenadines	■	■	■	■	■	■	■	■	■
Saint Lucia	■	■	■	■	■	■	■	■	■
Suriname	■	■	■	■	■	■	■	■	■
Trinidad and Tobago	■	■	■	■	■	■	■	■	■
Uruguay	■	■	■	■	■	■	■	■	■
Venezuela	■	■	■	■	■	■	■	■	■

Source: Climatescope (<http://global-climatescope.org/policies>), Regulatory indicators for sustainable energy (RISE, World Bank - <https://rise.esmap.org/>), IRENA 2015¹⁹⁵

195. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_RE_Latin_America_Policies/IRENA_RE_Latin_America_Policies_2015.pdf

Permitting and Interconnection procedures

The existence of generation and interconnection permitting procedures may hinder the deployment of DG renewable energy due to delays and mistrust in the process. In order to incentivize private investment, Mexico, in the framework of the Transition Energy Law, states that electric plants with less than 0.5 MW do not require a permit to generate electricity and it also simplifies the process of interconnection to the grid. Additionally, to accelerate DG deployment, the country has also standardized contracts models for energy suppliers. All these elements favor the development of a solar market.

Community solar

It refers to a local solar facility whose electricity is shared by more than one property in the area. This structure allows homeowners or renters to have access to clean and affordable energy regardless of the physical attributes or ownership of the building, as well as the customers who do not prefer a system installed on their rooftops. Consumers can subscribe through different type of plans according to their needs, offering flexibility to the customer and removing the anxiety of being subscribed to a long-term contract. Brooklyn has the largest community solar project in New York City with 200 residential and small commercial customers, of which 10% are low-income customer, showing that this type of project can address social inequalities offering opportunities accessible for all.

Third party owners

A solar company owns and maintains a solar rooftop system and sells the energy to the house owners through PPAs or lease the equipment for a fee, taking care in both cases for the upkeep of the system. Allowing this mechanism would accelerate the deployment of distributed generation as it eliminates the upfront cost of installing rooftop systems for homeowners.

Renewable energy voluntary programs

They can be provided by the government or other local organizations to stimulate the energy transition. These programs usually help a sector specific area to understand the benefits and opportunities to for example acquire EE measures or buy green energy or improve the transport system of the company. An example of a program in the region is the Renewable Energies and Energy Efficiency Programme for Public Buildings at Santiago, Chile led by the Ministry of Energy. One initiative of this program is The Solar Public Roofs Programme, in which 18 solar PV projects will be installed in public schools, hospitals, and some emblematic buildings in Santiago. This will make the technology visible to the public and promote its deployment. Another program, located in Brazil, “Minha Casa, Minha Vida” promotes the displacement of electricity by using solar thermal energy to heat water (see Inspiring example 20).



20 INSPIRING EXAMPLE

• *Solar Water heaters market In Brazil are responsible for displacing 9.7 GWh in 18 years*

The Federal Government of Brazil promoted the use of solar water heaters (SWH) through the “Minha Casa Minha Vida” program, offering new financial structures and stimulating the development of local SWH fabrication.



The “Minha Casa Minha Vida” program has leveraged the installation of 14.8 million m² in solar collectors during the last 18 years, producing 10% of that amount annually by local industrial companies. Since 2012, the installation of SWH system has become mandatory under this program for which subsidies of approximately USD 610 are offered for equipment and installation. The financing is granted by CAIXA, the State Bank, which requires that the financed equipment complies with the conformity assessment requirements of INMETRO (National Institute of Metrology, Standardization and Industrial Quality) and is installed in accordance with specific guidelines.

Brazil dependence on hydropower, which accounts for 70% of energy demand, unleashed an energy crisis during 2001-2002 due to a severe lack of rainfall, which resulted in a series of blackouts that

prompted Government to seek efficient and renewable alternatives to decrease the use of electricity and reduce power cuts in the country. One of the solutions identified by the decision makers was to replace electric water heaters in residences and industries (76% of household use electric water heaters) with SWH systems. The country has estimated the existence of 47,430,000 units of electric water heaters with a simultaneous consumption of 108,140 MW of power, which represents 24% of the total electricity demand. Their use generated an overload on the electrical system translated into peaks of electricity consumption between 7:00 and 8:00 in the morning and 18:00 and 20:00 in the afternoon.



By promoting the solar thermal market, the country was able to reduce 9.7 GWh in electricity consumption for water heating and 4.22 million tons of CO₂ from the grid. Brazil is currently the country with more m² of solar collectors installed in Latin America (14.8 million of m²) and the fifth worldwide. The local SWH industry has a value of USD 7,97 billions, generating a market of USD 616 million yearly, increasing national competitiveness.

Fiscal incentives

Governments in the region have used fiscal incentives to promote the deployment of renewable energy, especially in early times when LCOEs were above those of fossil-fuels. Despite some renewable technologies reaching cost parity with fossil-based generation plants, tax exemptions are still present in countries in LAC and are a way to incentivize investment as well and further develop the market, which is crucial if we are aiming for a fully renewable power sector. See Table 2 for a list of countries offering fiscal incentives.

9.2 Policy agenda and measures for electric transport

Regarding public policy and legal framework, countries and cities in the region have sought to guide and stimulate the development of electric mobility in various ways (Table 3). Countries like Colombia and Costa Rica have comprehensive electric mobility laws in force and there are several others with initiatives underway to formulate similar legal instruments. There is also a broader group of countries with partial legal or regulatory instruments, some provide fiscal and non-fiscal incentives, others regulate the efficiency of the car fleet and others encourage the development of industries and enterprises associated with electric mobility. There is also a broad group of countries with an incipient development of these instruments.

On the other hand, countries such as Colombia, Chile, Costa Rica and Panama already have national electric mobility strategies or plans - Argentina, Mexico and Paraguay are in the process of formulating their own strategies. In this regard, it is worth mentioning the emergence of goals associated with the deployment of electric mobility by countries and cities (Table 4). The transition to electric transport is at an earlier stage and will require a much more forceful support agenda. The region is at an early stage to assess the impact of these public policy instruments and legal framework. It is concluded that there is no single solution or approach in this regard and that there is great interest in the region to continue creating an enabling environment for the development and regulation of technologies such as electric mobility. Undoubtedly, it is worthwhile to monitor the impact of these types of instruments through periodic reviews to align the enabling environment with technological developments and the context and priorities of each country and city in the region.

All-segment commercial vehicles

National targets

As previously mentioned, national targets set the goal for policy formulation and reflect the commitment of the government to the cause. Chile has set a national target of achieving 40% of electric vehicles by 2050. Table 3 describes electric transport targets for several countries in the region.



Table 3. Existing transport policies in some countries in the region

	Antigua y Barbuda	Argentina	Brasil	Chile	Colombia	Costa Rica	Ecuador	México	Panamá	Paraguay	Perú	Rep. Dominicana	Uruguay
Value-added tax	Grey	Grey	Grey	Grey	Blue	Blue	Blue	Blue	Grey	Blue	Yellow	Blue	Yellow
Import tax	Blue	Blue	Blue	Grey	Blue	Blue	Blue	Blue	Yellow	Blue	Yellow	Blue	Blue
Other purchase incentives	Grey	Yellow	Yellow	Blue	Blue	Blue	Blue	Yellow	Yellow	Blue	Grey	Grey	Blue
Property & circulation tax	Grey	Grey	Grey	Grey	Grey	Blue	Grey	Yellow	Grey	Grey	Grey	Grey	Blue
Exemption of tolls and parking fees	Grey	Grey	Yellow	Grey	Blue	Blue	Blue	Yellow	Grey	Grey	Grey	Grey	Grey
Other incentives for use and circulation	Grey	Grey	Grey	Grey	Blue	Blue	Grey	Grey	Grey	Grey	Grey	Grey	Grey
Exemption of vehicular restriction	Grey	Grey	Grey	Grey	Blue	Blue	Grey	Grey	Grey	Grey	Grey	Grey	Grey
Differentiated electric rates	Grey	Grey	Grey	Blue	Grey	Blue	Blue	Blue	Grey	Grey	Grey	Grey	Yellow
Regulation for charging stations	Grey	Grey	Blue	Blue	Blue	Blue	Grey	Blue	Yellow	Yellow	Grey	Grey	Grey
National electricomobility strategy	Grey	Yellow	Grey	Blue	Blue	Blue	Grey	Yellow	Blue	Yellow	Grey	Grey	Grey

■ Completed incentive for electric vehicles / Approved and running instrument.
■ Partial incentive for electric vehicles / Instrument in design phase.

Source: MOVE, UNEP, 2019.

21 INSPIRING EXAMPLE

• *Electrifying Chile's bus public system through new tendering process*

Chile is now running a bidding process to renew the public transport bus fleet. Through this process the country will allow the entry of 2,000 buses that have to comply with certain characteristics of safety, accessibility and connectivity among others. A main feature of the tender is that it separates the supply of buses (capital expenditures) and the operation of routes (operating expenses) among different contractors. This will allow a better oversight of companies and a better-quality service. The process contemplates the acquisition of a variety of buses to suit different needs. The tender is not restricted

to electric buses only but there are additional incentives for this technology such as longer contract periods, 14 years compared to 10 for ICE buses. The structure of business model, together with the characteristics of the bus suppliers figure, will increase the participation of the financial private sector in terms of financing as well as investments.



Adopt all-electric mode in government fleets

The government can lead by example by updating national procurement requisites to assure that all future purchases of vehicles will be BEV. Through the Public Sector Smart Energy Program, the government of Barbados will finance a fleet of government electric vehicles powered by renewable energy to promote the use of low carbon transport in the country. Another example is the Independencia municipality in Chile that has renewed their fleet with 100% electric vehicles.

Adopt EVs in public transport system and fleets

The region is already a leader in the adoption of BRTs. BRTs have proven cost efficient and have relatively good acceptance. The adoption of electric mode for exclusive use in BRT systems should be a priority. It would have an effect in the acceptance of the systems and reduce emissions in urban areas. The economics are improving rapidly. Also, the bus market in the region warrant promotion of local solutions for the type and

characteristics of the vehicles. Beyond adoption of electric drives, expansion of BRTs and other public transport systems in urban areas would result in reduced congestion, reduced impact on productivity and morbidity. In 2019, Ecuador's energy efficiency organic law was approved, stating that all new acquisitions of public transport for the metropolitan area starting in 2025 will be electric. As anecdote, in January this year, Chile launched the first intercity bus in the region operating in a 90 km route from Santiago to the city of Rancagua (Turbus company).

Tendering process for public passenger transport

Developing tendering processes for public passenger transport is crucial to increase penetration of electric buses in the region. This will result in price reduction of electric buses which will accelerate their deployment. Furthermore, new tendering process structures are being developed to boost this market segment, such are the examples of Colombia and Chile (See Inspiring example 21). Colombia has just acquired 379 electric buses for the TransMilenio

metro bus system in Bogota, with BYD as the winning bidder. It is estimated that in its first year of operation the fleet will reduce CO₂ emissions by 21,900 tons and PM_{2.5} pollutant particles by 526 kilograms. Moreover, electric buses opex will be 60% cheaper compared to traditional diesel-powered buses.

CO₂ standards for heavy-duty vehicle

The establishment of this type of standards can help reduce emissions while incentivizing the shift to electric vehicles or other alternative sources (such as hydrogen) as complying with the standards will make the vehicle more expensive while EVs become more competitive. The EU has developed CO₂ standards for new heavy-duty vehicles that enter into force in January 2019. According to this standard, the targets will reduce the average CO₂ emissions from the highest emitting HDV segments by 15% in 2025 and by 30% in 2030, from a baseline created with 2019 and 2020 data.

Energy efficiency standards

These are crucial instruments to drive the transport sector towards sustainability and incentivize the deployment of electric vehicles as it increases the cost of ICE. Brazil's ROTA 2030 policy sets new energy efficiency and safety standards that manufacturers will have to comply with if they want to avoid fines. Regarding sustainability, car manufacturers will have to improve energy efficiency by 11%, which will directly affect fuel consumption. The efficiency requirement is measured across all models which is expected to increase the share of electric or hybrid vehicles to reach the 11% goal, thus, helping boost EVs within the country.

Feebate mechanisms for light vehicles

In order to achieve high penetrations of EVs, early stages of development require measures to disincentivize the use of ICE. Feebates deter the use of ICE vehicles by establishing a fee for high CO₂ emissions vehicles and a rebate for low emission vehicles.

Non-monetary incentives for EV adoption

Different instruments can be used to create additional incentives for EV adoption such as free parking spots, preferential lanes and toll exemptions (See Table 3). Costa Rica approved the first law focusing solely on incentives for electric transport in the region, which includes monetary and non-monetary incentives among access to credit (see Inspiring example 22 for more details)

Short-term fiscal measures to bridge existing price differentials with ICE

Offer tax credits, reduced sales tax, import exemptions for purchases of EVs. Many countries in the region offer today 0% import duties on EVs. Colombia is an example with Decree 2051 of 2019, by which the tax imports for electric vehicles were reduced to 0%. (See Table 3).

Charging infrastructure

Promote the deployment of charging infrastructure

Incentives to promote the development of charging infrastructure should be available to real estate developers, local governments, commercial areas, hospitality industry and other in order to provide alternatives for EV charging.



Table 4. Electric transport targets of some countries in LAC, 2019

<p>Barbados</p> <p>National Energy Policy for Barbados 2019-2030</p> <p>100% of renewable energy and carbon neutrality for 2050</p>	<p>Ecuador</p> <p>Draft Energy Efficiency Law</p> <p>EVERY vehicle incorporated in the public transportation should be electric and will have preferential differentiated energy fees from 2025</p>
<p>Chile</p> <p>National Electromobility Strategy</p> <p>100% of public transportation electrified by 2050</p> <p>40% of the private transportation electrified by 2050</p>	<p>Mexico</p> <p>Integrated mobility programme for Mexico City</p> <p>500 trolleybuses for the Zero Emissions Corridor of STE (Electric Transportation Services) in CDMX for 2024</p>
<p>Colombia</p> <p>National Development Plan</p> <p>600 thousand electric vehicles for 2030</p>	<p>Panama</p> <p>National electromobility Strategy of Panama</p> <p>10-20% of the total of private vehicle fleet will be electric for 2030</p> <p>25-40% of the private vehicle sales will be electric for 2030</p> <p>15-35% of the buses of the conceded authorized fleet will be electrified by 2030</p> <p>25-50% of the public fleet will be electric vehicles for 2030</p>
<p>Costa Rica</p> <p>Decarbonization Plan</p> <p>70% of buses and taxis with zero emissions by 2035</p> <p>100% of buses and taxis with zero emissions by 2050</p> <p>25% of the light-duty vehicle fleet will be zero emissions by 2035</p> <p>60% of the light-duty vehicle fleet will be zero emissions, with higher percentages for commercial and governmental use by 2050</p>	<p>Paraguay</p> <p>National Energy Policy 2040 (PEN 2040)</p> <p>20% of the state vehicles will be electric by 2020</p>

Source: MOVE, UNEP, 2019.



22 INSPIRING EXAMPLE

• *First law in the region exclusively addressing electric mobility*

In 2018, Costa Rica approved the first law focusing solely on incentives for electric transport in the region. The law contemplates not only economic incentives but also ease of use in circulation and access to finance. The country declared the promotion of electric transport as a public interest. This is in accordance with the international agreements ratified by the country as well as article 50 of the constitution, which states that **“every person has the right to a healthy and balanced environment”**.



The law establishes tax exemptions over general sales tax, the selective consumption taxes and import taxes. The percentage exempted in each case will depend on the price of the electric vehicle. In addition, electric



vehicles will be spared of paying property tax for five years from the moment of nationalization or production in the case of vehicles manufactured or assembled within the national territory. The amount exempted decreases in a percentage modality within the five-year timeframe. Additionally, each Municipal Council can specify whether and the mechanism by which electric vehicles can be exempted of parking fees.

Apart from economic incentives, cars, motorcycles, cargo transport vehicles, minibuses or buses with green plate will not be subject to vehicular restriction in the metropolitan area and may use special parking spaces that are designated in public or private parking lots. The law also promotes access to credit for the purchase of electric vehicles among other directions for utilities, government procurement, public transport and obligations for EVs importers.



It is important to highlight that the creation of this law incorporates the broad participation of various social actors, both private and public, as well as organized citizens. In addition, the law is aligned with the decarbonization project launched by Costa Rica to achieve carbon neutrality in its emissions by 2050, becoming the first country in the region to present an ambitious and concrete plan of the kind.



Interoperability and standards for charging infrastructure

In order to accelerate the market for EVs in the region and within countries it is important to develop standards and interoperability for charging infrastructure. There should be an open communication and exchange of information between the systems without proprietary fees for standards. This assures safety, reliability and usability of charging infrastructure, resulting in an integrated market. The first project of transnational interoperability in the region is being developed between Argentina and Chile (See Inspiring example 9 in Chapter 8).

Regulation for charging infrastructure installations

With the objective of offering a good service, regulation for safety and control of EV charging installations is a must. This will facilitate information gathering, verification of standards, inspections and the development of associated apps to serve customers. In this respect, Chile has an electromobility regulation in force that addresses vehicle issues such as labeling and safety, energy issues such as norms for electric installation, quality services for distribution systems and environmental issues associated to battery disposal. This regulation also states that EV charging stations installations must be declared through completion of an electronic form. In addition to the benefits mentioned above, this procedure will allow the government to determine gaps, opportunities and guide infrastructure developments. Furthermore, regulation under development involves technical requirements for charging infrastructure installations as well as homologation of EV chargers.

Discourage investment in refineries

As in the case of thermal power plants, there should be policies deterring the addition of refinery capacity. This would signal the sector that future demand of energy by internal combustion engines is being phased out. Additionally, plans of early retirement of refineries should be structured to minimize the value of stranded assets.

9.3 Policies for a coupled transition

In order to achieve a coupled transition of the power and transport sector there are a set of policies pertinent to both sectors, which are reviewed below. Nevertheless, policies mentioned specifically under transport and power sector should be formulated jointly to accelerate this transition.

Digitalization

Digitally enable technology is crucial to unlock the synergies between an electrified transport sector and a renewable energy power matrix. Development of security standards and open communication protocol to ensure interoperability is a crucial part of the puzzle to achieve the transition.

Carbon pricing/Carbon markets

This is one of the measures with potentially larger impact. There are already functioning carbon markets in the region, including in Colombia (see Inspiring example 23), Chile, Mexico and a proposed regional market for the Pacific nations. The experiences in the design and operation can inform expansion, adoption in other countries. A robust regional market based on environmental integrity would further improve economic efficiency. A key feature is the level of the cost of carbon which needs to be set at a level that makes a difference. Carbon pricing instruments, including fiscal measures, can play a key role in sending the signal based on a “polluter pays principle” as well as generating funds for the transition. The carbon taxes should reflect the level of emissions and have no lucrative ends. Instead, tax revenue should be directed towards green investments.



23 INSPIRING EXAMPLE

• *Colombia's national tax on fossil fuels*

In December 2016, in the framework of structural tax reform, the Government of Colombia introduced a national tax on fossil fuels, except coal and natural gas for energy generation. This tax can be considered as an innovation in fiscal policy due to three elements mainly: i) it establishes that the collection of the tax has a specific destination for climate change projects, ii) it allows the use of GHG emissions reductions as a compensation to avoid tax payment and iii) the tax incorporates environmental and social benefits, in particular, the reduction of GHG emissions as well as the non-impact of the poorest population.



This tax is a driver for climate policy in Colombia, has activated investments in the territory, has managed to deliver resources to the Colombian State to deal with climate change.

Another benefit of this instrument is the legally and technologically strengthen of information systems for monitoring, reporting and verification of mitigation and adaptation actions that are implemented in Colombia. This tax triggered the climate action in the country through several fronts such as the involvement of new government organizations, private sector, academy and investors in Colombian climate action. The implementation of the tax allowed the Ministry of Finance, the National Tax Authority, the financial superintendence, as well as the large fuel distributors and consumers to turn their attention to the Colombian NDC and thus to the Paris Agreement. This instrument



was very useful for inducing new schemes of organization and innovative institutional arrangements for climate change. The mechanism of to avoid the tax payment generated a growing interest on the part of the forest communities, the companies in the renewable energy sector, as well sub-national governments involved in projects of sustainable mobility or waste management. Within this mechanism many of them starting to accelerate the implementation of GHG emission reduction projects aimed to support national goals in climate change.

This is an example of how through an ambitious, dynamic and stable pricing signal is possible to guide investments and contribute to the organization of States and private sector around climate change management. This tax raised approximately 160 million dollars in its first year of implementation, it mobilized about 8 million tons of remissions reductions of CO₂-eq and has been considered by other countries in the region as an example for the design or updating of other taxes in Latin America. This tax boosted an important synergy between fossil fuel producing or importing companies, project developers and owners, as well with government organizations.



This tax is a way to promote effective mobilization of public investment and private capital towards adaptation actions and GHG emission reduction initiatives, respectively. It can be seen as a way to stimulate the internalization of climate change costs in Latin economies, as well as a catalyst for public and private investment in the region.

Internalization of health and environmental costs in transport and power decision making

The report illustrates the significant costs of air pollution from mobile and fixed sources. This is a direct cost to the economy. The avoided costs from shifting to renewables and electric can justify some level of incentives for electric vehicles at an early stage of the transition. The costs could be made to be paid by the emitters through the enactment of fiscal measures.

Encourage demand management of electric fleets

Allow the participation of fleets in management of their electric demand and storage of power as an additional actor in power transmission. Smart grid is crucial to attain this goal as communication between vehicles, chargers and the grid will allow to better use and optimize the resources by sending signals when there is a surplus generation of renewable energy or, on the contrary, when there is a shortage of supply of energy to the grid and vehicles can avoid consuming energy at that time. This can be regulated through economic incentives for example. An example of this is a tariff scheme for EV charging such as differential tariffs to encourage electric charging of vehicles during valley periods in power demand. Any reductions in costs could potentially be partially offset by improved operation costs of baseload capacity or other measures as the stakeholder sees fit. EPEC utility in Argentina has set differential electricity tariff schemes available for EV owners to incentivize charging EVs during valley periods (See Inspiring example 24).

Cybersecurity policies

With digitalization comes new security and privacy risks that have to be addressed through the development of policies to guarantee security, stability and reliability of an integrated system. US National Laboratory on Renewable Energy (NREL) is developing a low-cost option for encrypting distributed energy resources, which will protect command and control messages over communication channels.

Just transition policies

With the transition, many sectors related to fossil fuel activities will face job losses and therefore, the nations should start preparing by setting sound policies to address this affected communities. Countries can offer retraining programs to reallocate these workers in other segments of the economy. For example, employment in Poland coal mining sector shrunk by 75% in a decade, which drove the government to work with labor unions to create a mining social package and set privileges for mining communities in order to adapt to the change. Policies in this area must be inclusive, incorporating gender aspects and reducing as much as possible social existing inequalities.

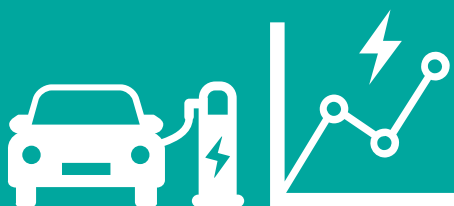
Grants for R&D and innovation

Clean energy technology research is critical for achieving the transition goals. Policies in this regard are necessary early on to drive innovation while other policies may take over once a market is developed.

24 INSPIRING EXAMPLE

• EV charging to boost grid flexibility through an electric tariff scheme

The Provincial Energy Company of Córdoba (EPEC), Argentina presented on July 4, 2019 in Public Hearing a special rate chart (RC) for users of the Distributor who own electric vehicles (VE) and are registered in the National Directorate of Automotive Registration and Pledge Credits (DNRPA).



This RC allows a residential or commercial customer, up to 40kW of contracted power, access a billing scheme divided by time bands: peak, valley and the time in between, while receiving a discount for charging their EVs during valley period.

For a distributor, the energy purchase cost is an exogenous and non-modifiable amount, which is transferred to the user by a pass-through mechanism. The Distributor's own costs, investments and profitability make up the Added Value of Distribution (VAD). Therefore, the user rate is composed by de energy purchase cost plus the VAD.

End User Rate = Energy Purchase Cost + VAD

The tariff scheme presented by EPEC offers a 50% discount over the VAD during the valley period of the load curve leaving the user rate as follows:

End User Rate = (Purchase Cost in Peak + VAD) + (Purchase Cost in Valley + 0.5 VAD) + (Purchase Cost in Rest + VAD)

The driver behind the creation of this tariff scheme is to regulate user behavior by providing incentives to charge their EVs at a time where the demand of the distribution system is low (from 11:00 pm to 5:00 am), ultimately helping prevent spikes at peak demand time. Additionally, by users selecting this tariff scheme, EPEC is obliged to install smart meter that will allow to build know-how regarding users' consumption patterns. Thus, providing useful information to further develop new tariff mechanisms or other incentives for when penetration of EVs reaches significant levels. This tariff scheme can be replicated by other Distributors in Argentina, given they share the same regulations of the Wholesale Electricity Market. and it can also be adapted by other nations to incentivize adoption of EVs while providing flexibility to the grid.

CONCLUSIONS



We are on the brink of missing the opportunity to limit global warming to 1.5°C.

It is imperative to act now while we still have the chance. While there will still be climate impacts at 1.5°C, this is the level scientists say is associated with less devastating impacts than higher levels of global warming (IPCC, 2018). Countries need to take a quantum leap in reducing emissions— globally a 7.6% reduction every year from 2020 to 2030 (UNEP Emissions Gap Report, 2019). Scientists have spoken, now is the time for governments and industries to take the lead and assure a transition path consistent with the 1.5 °C track. Economies must shift to a decarbonization pathway now.

Under a 1.1°C increase in temperature, climate change has become a national security threat to the LAC region.

Climate impacts have affected not only the ecology of the systems impacted but also the livelihoods and sustenance of millions in the region, even forcing migrations from affected areas.



Climate is already starting to threaten the foundations of the region's economy, with droughts, hurricanes and/or floods. If the global temperature continues to rise, climate impacts will be increasingly severe and expensive.

The entire LAC region does have a relatively small contribution in the global carbon footprint (9.5%) with approximately the same amount of global population. However, the regional average GHG emissions per capita (7tons of CO₂-eq) is greater than the global figure (5 tons of CO₂-eq). The region has a significant and growing carbon footprint in its transport sector, as well as a comparable emissions footprint from the power generation sector that together are responsible for 25% of GHG emissions in 2019. According to this report, under the BAU scenario, emissions from both sectors are expected to double by 2050. This will place the region further away from the 1.5°C pathway.



Transformational change needed to meet the Paris Agreement and to reach zero emissions by mid-century can be critically supported by coupling the power and transport sectors.

LAC is the most urbanized region on the planet - 80% of its population lives in cities. Consequently, most of the energy consumption and road activity are concentrated in urban areas. This current situation of the region's urban world opens opportunities for rapid and far-reaching environmentally sound and financially attractive actions in both sectors; making cities a key part of the solution.



A coupled transition has the potential to grow the region's economy while improving public health.



Therefore, it is critical that decision-makers overcome silos and consider public policies that address these two sectors in a coupled manner.

The policy environment has evolved throughout the region in support of a cleaner power matrix, low carbon resilient development, and a cleaner transport system. The trends in technology and economics have contributed to the growth in the use of renewables, utility scale and DG, and are beginning to make a difference in the emergence of electric vehicles. Several new business models are being developed in the region boosting the transition of the power and transport sectors towards decarbonization, decentralization and digitalization, showing that the couple decarbonization has already started and is picking up fast following global patterns. Nonetheless, the degree and speed of change required to a coupled transition by mid-century makes leadership critical through a clear, consistent and robust policy agenda. A well-constructed enabling environment will be critical to attract investment flows towards a coupled transition.

Embarking on the road to electrify the transport sector coupled with the transition towards a fully renewable power sector could contribute to cost-efficient decarbonization. Promoting synergies and interlinkages between sectors of the economy derives in potentially higher economic benefits and greater mitigation impact.



The pathway to decarbonization must be planned to deliver a just transition and leave no one behind.

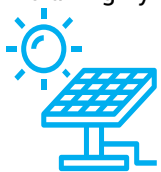
Therefore, it is imperative the integration of social and labor policies in climate objectives to provide retraining, skills development and education in new fields while reducing social and economic inequalities. Gender inequalities are socially constructed and therefore can be and are modified over time. The transition to decarbonization comes with the unique chance to balance the gender scale resulting in better economic outcomes for the whole society.





Decarbonization of the power sector

The first steps of this transition are already in place in the region. Latin America has one of the cleanest power sectors worldwide. In LAC, renewables already account for 58% of the total installed capacity, including hydropower (46%).



Non-conventional renewables have doubled their installed capacity since 2012, now accounting for 12% of the total.

The hydropower capacity installed in the region and the non-conventional renewable potential supports a decarbonization pathway taking advantage of the complementarity of the baseload and intermittent renewable resources. Additionally, cost reductions in solar PV and wind energy power generation reaching, and surpassing cost parity with hydrocarbons-based generation in the major regional economies, makes the renewable energy pathway a no regret option for some countries in the region. These technologies are winning the race to be the cheapest sources of new generation, showing that, based on purely economic

grounds, it will be increasingly difficult to justify investments for power generation using fossil fuels in some countries.

While acknowledging the challenges and differences between national circumstances, a full decarbonization of the power sector is technically and economically feasible as well as financially attractive, given the substantial resource endowment, well-structured policy framework, technological improvements, cost reductions, and strong institutional capacities. Initial efforts in several countries in the region to decarbonize their electric system while providing an enabling environment have resulted in more than USD\$35 billion in investment (44% of global direct foreign investment flows) in non-conventional renewable energy during the last 5 years.



The fact that 7 countries in the region have been named as attractive markets for clean energy investments is indicative of the opportunities in LAC to achieve the decarbonization of the power sector by 2050.

Specifically, Chile, Brazil, Argentina and Peru are in the Top 10 and Colombia, Panama and Uruguay made it to the Top20 most attractive countries for clean energy investments out of 104 nations. However, despite these improvements, the region is currently at a crossroads to make strategic decisions that will define the future of its power system in conditions of efficiency, quality, reliability, safety and sustainability. According to UNEP and OLADE 2017 report, the changes on the duration and intensity of rainfall patterns and drought periods will affect firm capacity of hydropower. At current pace, gas will overcome hydro as the main source of electricity production in about 10 years, by 2030. Besides the increase in GHG emissions, deployment of fossil fuel plants will create a technology lock-in for many years ahead and likely deviate the region from the Paris Agreement goals.



LAC nations should include the highest share of non-conventional renewables in their power matrix, discouraging technologies that contribute to climate change and that pose future economic uncertainties.

By 2050, electricity demand is anticipated to almost triple (16.7 EJ) - which does not include the future power demand caused by an electrified transport sector - requiring substantial additional installed capacity. Meeting the 2050 electricity demand under a fossil fuel-based generation matrix (BAU scenario) would increase 2.4 times CO₂ emissions to 1,200 million tons. This would place the region further away from the 2°C pathway. Additionally, the investment volume required in installed capacity is estimated at US\$ 1,083 billion (2018). A fully renewable energy power matrix will deliver zero CO₂ emissions and require substantially lower capital investment than a fossil fuel-based generation, resulting in US\$ 283 billion in CAPEX reductions by 2050. Clearly, a pathway that takes advantage of the competitiveness of renewables in the region is less capital intensive.

Many countries are developing legal and regulatory frameworks that create the enabling conditions for distributed solar PV deployment. In some nations, distributed PV is already an important market (Mexico, Brazil, Chile and Dominican Republic), in others are rapidly

growing (Colombia, Argentina and Honduras). In this sense, if current trends continue, under the intervention scenario, it is estimated that the distributed solar PV will reach a great percentage of the total solar PV installed capacity by 2050 – penetration of decentralization is growing. Just as in the case of large-scale, to unlock solar PV distributed potential is critical to implement robust legal and regulatory frameworks adapted to small-scale installations that tackle main market barriers, such as generation permitting procedures, technical standards, grid connection rules, among others. The renewable DG sector is a strategic market to foster innovation and promote new business and job creation. This could be achieved through the development of installer training programs, certification of technology standards and eligibility criteria for installation companies. Developing the local distributed PV industry will help create new sources of employment and increase the countries' competitiveness in an evolving global industry.

Competitive renewables will pave the road to decarbonization. LCOE for solar, wind and hydro technologies continues to drop, reaching and surpassing cost parity with hydrocarbons-based generation by 2050. Thus, the decarbonization scenario estimates a lower LCOE associated with the power matrix.



The projected composite LCOE will be 50% lower than in the BAU scenario, resulting in an overall savings in electricity costs of US\$ 222.7 billion by 2050.

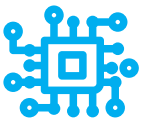
The reductions in generation costs would be directly accrued by electricity consumers making manufacture more competitive and delivering savings to households.

A fully renewable power scenario considers that installed fossil fuel power plants will be decommissioned before the depreciation schedule is completed. The not-depreciated value was estimated at US\$ 80 billion (2018) by 2050. The cost to the economy of these stranded assets are compensated by the CAPEX savings under the intervention scenario. The projected loss of competitiveness represents a clear cautionary signal for fossil fuel investors.



In addition to the economic and environmental benefits, the decarbonization scenario opens new avenues of economic activity in the power sector, resulting in the creation of over 7 million new permanent jobs and about 30 million jobs in construction and manufacturing by 2050.

The analysis also finds that, following current trends, DER will play a major role in the future power system by taking advantage of efficient use of local renewable resources and capital costs reduction to strengthen resilience of supply and allowing the entrance of new players to the market like the prosumers. The transition to a decarbonized and decentralized market will require of digital services to coordinate all the different resources that integrates this new market.



Digitalization is the enabler for a coupled transition of the power and transport sectors towards decarbonization.

A diversified, decentralized and digitalized renewable power matrix in the region will improve security of supply and contribute to avoid expensive interruptions in service. Such a matrix would reduce dependence on energy imports and eliminate reliance on fossil fuels.

Electrification of the transport sector

Although electric transport has evidenced a slow-paced adoption in the region, the electricity demand in the sector has multiplied by 10-fold in the last 6 years. The decarbonization of the transport sector has evolved through improving energy efficiency and carbon emissions standards. Diesel fuel and gasoline continue to be the most used fuels in transport, accounting for 83% of the total in terms of energy use. The characteristics of the transport sector of having most road passenger activity concentrated in cities, high bus utilization rate per capita, and well-known patterns of cargo transport are crucial elements to vouch its electrification and develop ancillary industry tailored to regional needs.



Battery prices fell nearly 50% in 3 years, the cost of electric vehicles is rapidly decreasing, and new technologies are entering the market, supported also by increased concern on air quality and congestion, make possible to consider faster market entry of electric transport options.

Common actions were identified for the promotion of electric mobility among countries in the region. One of them is the electrification of public transport systems. Policy makers continue to push toward zero

emissions public transport. Improving economics, while complying with KPIs, and growing concern about health and environmental impacts of emissions from ICE buses in cities are the two main drivers. In this respect, momentum for electric buses is beginning to be built regionally, The TCO of electric buses is reaching price parity with ICE buses in some cities of the region. This is mainly due to the development of new business models through tendering process for public bus system that are boosting electric buses adoption, such as in Santiago de Chile and Bogota.



Policy and regulation will play a critical role to decarbonize public transport systems fully.

Clear targets and roadmap are a must for the development of this brand-new market structure. This entails policies supporting deployment of public electric transport systems and the entrance of new players in the electric market. The promotion of electric mobility implies a cross-cutting coordination between sectors. Although it is seen as a transport issue, it involves the energy sector and all its actors in the electricity subsector, from generators to electricity retailers.



Decisions taken today in the transport sector will define the climate future.

Many cities are renewing large fleets of buses with dirty technologies (ICE vehicles), which will be in the market for at least 15 years creating stranded assets. The renewal of fleets is an excellent opportunity to transition to electric vehicles. In 2019, the electrification of other transport segments, such as official fleets, delivery and cargo fleets, as well as public sanitation, has become more evident. Mostly, consisting of pilot projects to evaluate the performance of the technology for later scale up. The road cargo transport offers opportunities for electrification at the point of use, which is particularly attractive for cities (about 70% of cargo transport in the region is carried by trucks).

Even though the deployment of public charging infrastructure is in an incipient phase in the region there are many initiatives addressing this issue by

creating EV corridors within countries as well as in between nations. These initiatives are being led by strategic investors, mainly oil and gas companies, as well as utilities and automakers.



As electric vehicle fleets and associated charging infrastructure increases, it becomes highly important to foster interoperability, infrastructure standardization and management and recharge commercialization systems.

A vital aspect that still has the possibility of being explored more deeply is the integration of the national and local electricity network (distribution) with the necessary recharging infrastructure to allow the development of large-scale electric mobility.



On the other hand, consumer interest in electric vehicles is growing as car manufacturers launch more electric car models. This context signals a promising transition in the transport sector.

Energy demand for transport services under a BAU scenario is projected to double its current energy use with an annual emission of 1.2 GT CO₂ by mid-century, doubling current levels.



As the energy efficiency of electric drives is 3 times higher than that of ICE vehicles, the energy demand of the transport sector under the intervention scenario is much lower compared to the BAU scenario.

The transition to electric transport has the net effect of reducing total energy demand in the region while increasing future power requirements. A 100% electrification scenario - all modes for cargo and passenger transport, except air travel - by mid-century would have the net effect of reducing the total energy demand by almost 2,000 million barrels of oil (12 EJ), equivalent to the Canada's annual consumption, while increasing electricity demand by 33% more than the BAU scenario (totaling 22.2 EJ).

The installed capacity needed to meet the additional power demand is 327 GW mostly required by 2040 and afterwards. If the electrification of transport is coupled to a fully renewable power matrix, the investment associated with the additional power demand is estimated at US\$ 214 billion by 2050. Otherwise, if the electrification of transport occurs

under a BAU power sector scenario, the investment associated with the remainder of the additional power demand is estimated at US\$ 317 billion. The cost of the additional capacity to meet this power demand is lower under the coupled transition because the capital investment associated with power generation under a fully renewable power matrix is lower. The difference in costs is estimated to be US\$ 103 billion. This is an additional benefit of coupling the transition of both sectors.

Under the intervention scenario, most of the service is projected to be delivered through road transport. For passenger road transport, big reductions in LCOTs are anticipated for electric light vehicles while electric buses will at most have the same costs of the diesel options. The intervention scenario assumes that the car fleet will not increase more than 30% its current size by 2050, while the bus fleet will more than double its size to compensate the reduction in light vehicles transport measured in passenger kilometers.



Under these assumptions, it is estimated that the overall savings in passenger transport costs to the economy would be of the order of US\$ 328 billion in passenger transport.

No estimates were made for passenger transport in other modes (rail, vessels). For cargo transport, the calculated LCOTs for electric light trucks (90% of the road cargo fleet) are also lower while heavy duty vehicles continue to be more expensive by mid-century. The composition of the fleet (90% light trucks; 10% heavy trucks) is kept constant. Under



San Pedro, Belize

Photo by Fermin Rodriguez, Unsplash

these conditions, it is estimated that the overall savings in capital costs to the economy would be of the order of US\$ 41 billion in cargo road transport. No estimates were made for cargo transport in other modes (rail, vessels). The reduced cost of rolling stock and electricity will provide savings in road transport at US\$ 369 billion by 2050. Electrification of passenger and light cargo vehicles in urban areas will result in a major reduction of exposures to particulate matter and yield avoided health costs to the order of US\$ 30 billion by mid-century. In addition, electrifying the entire vehicle fleet of five Latin American cities – Buenos Aires, Santiago, San Jose, Mexico City and Cali– would result in avoided early deaths of 435,378 people due to reduced air pollutants by 2050.

Electrification of transport will also eliminate the need for imports of middle distillates and eventually cause the early retirement of refinery capacity resulting in a loss of non-depreciated value to the order of US\$ 10.2 billion by 2050. Like in the case of power plants, impending market changes in transport should

back a cautionary warning against longer-term additional capital investment in refinery processes for middle distillates. In addition to the economic and environmental benefits, the electrification scenario opens new avenues of economic activity in the transport sector, resulting in the creation of over 5.3 million new jobs by 2050.

Moreover, with demand-side management measures in place, steering electric charging toward periods of lower load in the daily demand curve (valley filling) might improve operational parameters of the electric sector by flattening the demand curves and generating additional income per MW installed.

Conversely, electric transport, in particular, the fleet of heavy vehicles, could store significant energy, to the order of 10 GW by mid-century that could be used to meet periods of high load by delivering vehicle-to-grid transfers, contributing to avoid the use of peak-demand capacity.

Benefits from a coupled transition by 2050

The coupled transition toward full decarbonization, the report concludes, would generate the following benefits by mid-century:

1. 1,100 million tons
Total CO₂ emission reduction



2. US\$ 621 billion/year
Economic gains in the region derived from reduced power and transport costs.



3. US\$ 30 billion
Annual avoided cost of illness from the elimination of particulate matter in urban areas.



4. US\$ 386 million by 2050
Capital investment reductions derived from anticipated lower capital requirements from renewable energy sources. But, it will trigger the stranding of assets valued at US\$ 90 billion, for a net savings in capital outlays of U.S. \$296 billion.



5. 7.7 million permanent jobs and 28 million job years of temporary jobs on the use of renewables for all power generation, grid modernization and electrification of the fleets.



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ANNEX 1

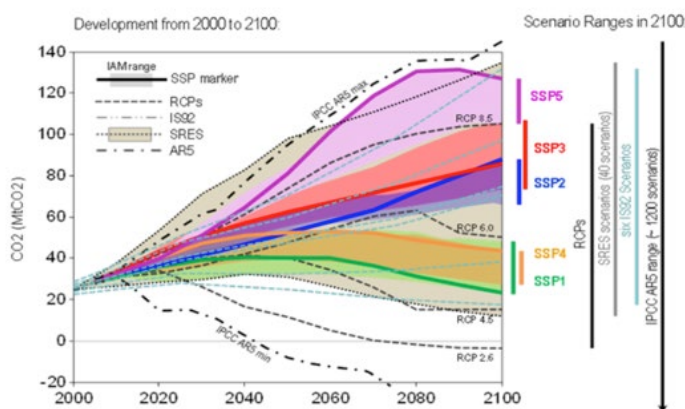
Global Change Assessment Model (GCAM0029)

For purposes of the report, the GCAM version 5.1.3 (LAC version) has been used for the reference scenario (Calvin K et. al, 2018). GCAM is an open source integrated assessment model that represents the linkages between energy, water, land, climate, and economic systems. GCAM is a market equilibrium model, is global in scope, and operates from 2010 (calibration year) to 2100 in five-year time steps. It can be used to examine, for example, how changes in technology cost might alter energy demand and associated emissions. In terms of solution algorithm, GCAM is a dynamic-recursive model, which solves each period sequentially (based on existing information for the period being solved) through the establishment of market-clearing prices for all existing markets (energy, agriculture, land and GHG emissions). This means that, for each model period, an iterative scheme ensures convergence to final equilibrium prices such that supplies, and demands are equal in all markets.

In GCAM's reference scenario, socioeconomics are consistent with the Shared Socioeconomic Pathway 2 (SSP2) "middle of the road" scenario (Fricko et al. 2017).¹⁹⁶ The SSP2 scenario as described by Fricko et al. results in a global final energy demand of 640 EJ/yr by 2050 and leads to 6.7 W/m² of radiative forcing and 3.9 °C of anthropogenic warming. However, socioeconomics assumptions in some LAC countries (e.g., Argentina, Colombia and Uruguay) were refined in closer consultation with local experts from academia and governmental agencies.

The GCAM RCP 2.6 scenario provides a pathway consistent with global decarbonization by 2100, and a temperature anomaly below 2°C.¹⁹⁷ To reach this level of emissions, the power sector relies heavily on carbon capture and storage. The total capital outlay for this scenario is calculated at US\$ 1.8 Trillion (2010) (US\$ 2.1 Trillion (2018)).¹⁹⁸

Figure 1. SSP Land Use-Energy-Economy-Emissions Scenarios (Riahi K., et al, 2018)



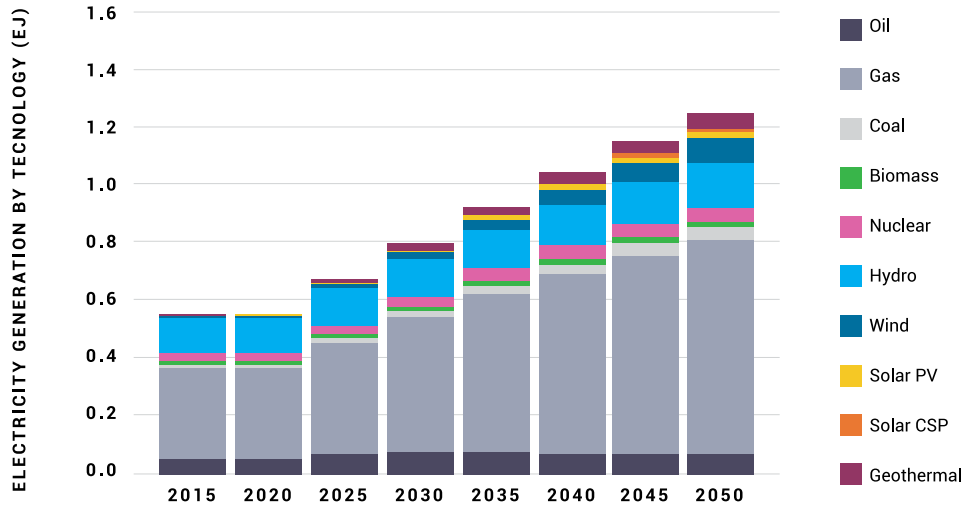
196. <https://www.sciencedirect.com/science/article/pii/S0959378016300784>

197. In fact, 2100 temperature anomaly in GCAM RCP2.6 reaches about 1.7C.

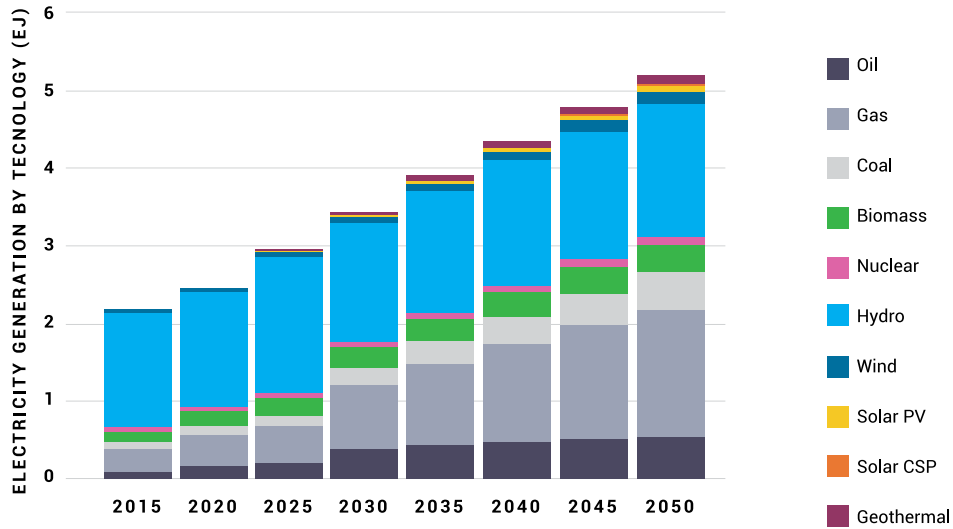
198. For conversion to US\$ 2018, an inflation factor of 1.15 was used.

Projected electricity generation under GCAM by country and subregion:

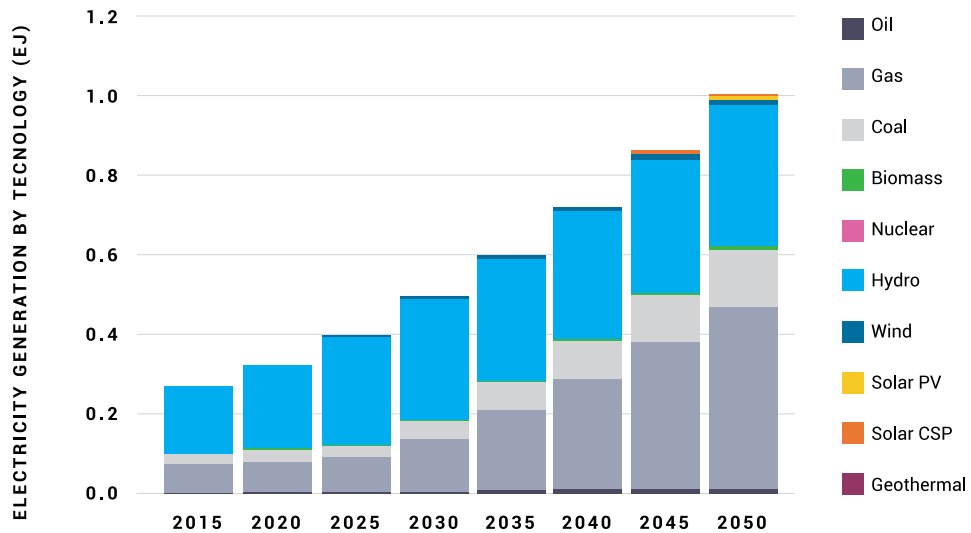
Reference: Argentina



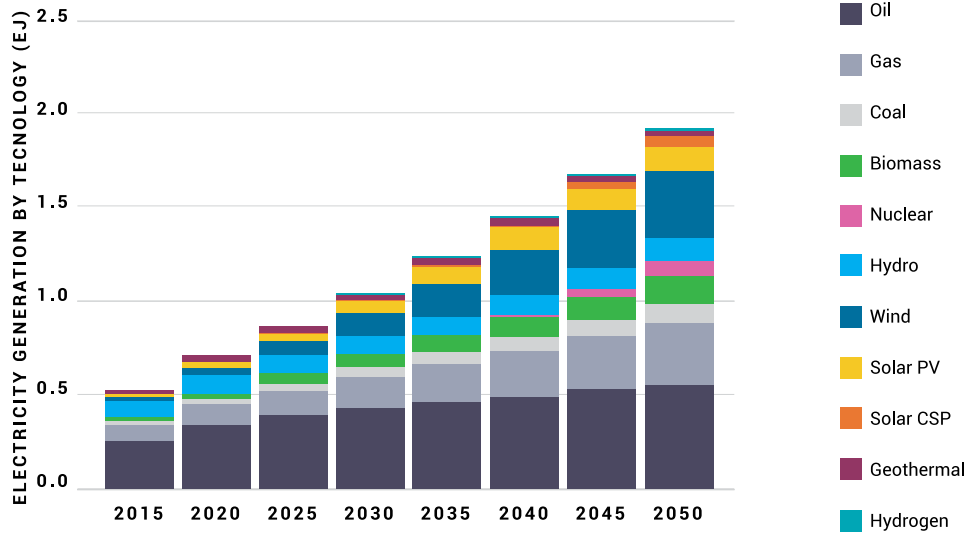
Reference scenario: Brazil



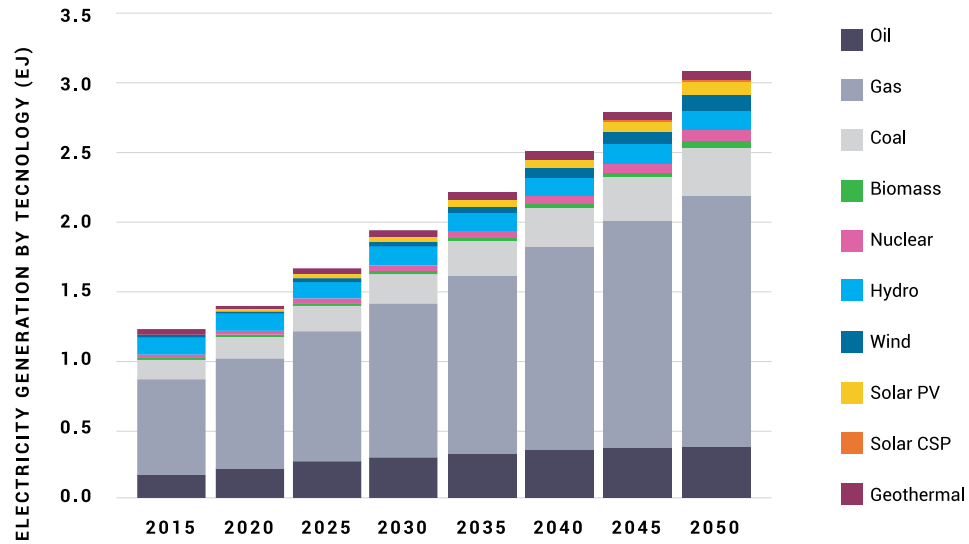
Reference: Colombia



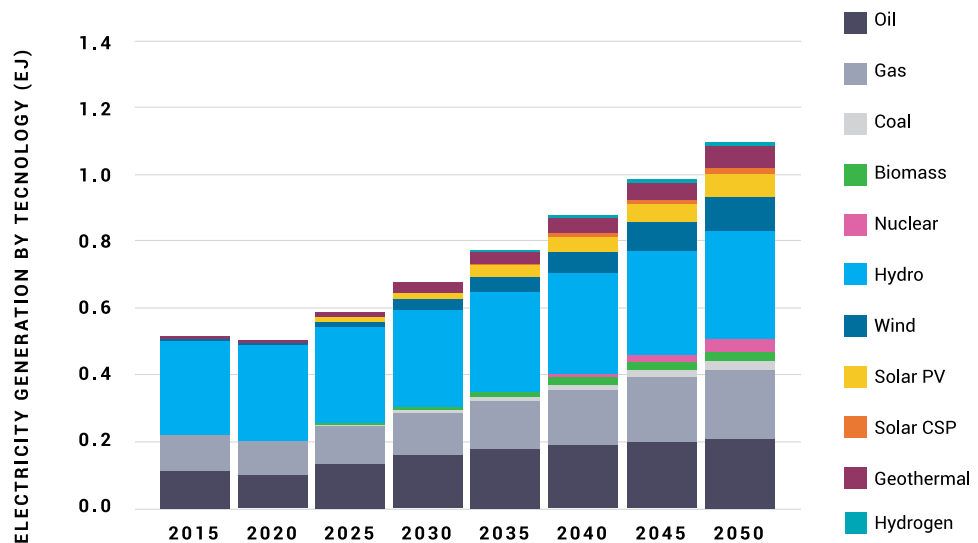
Reference: Central America and the Caribbean



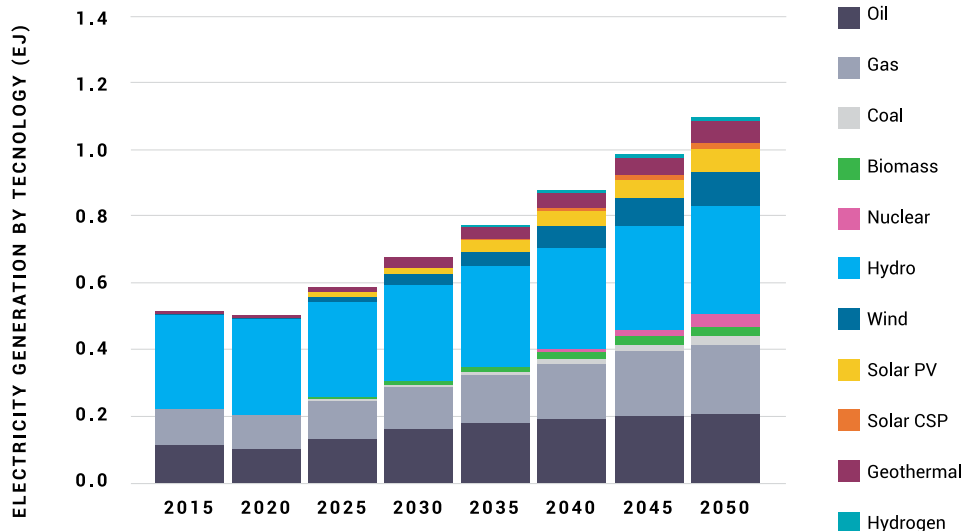
Reference: Mexico



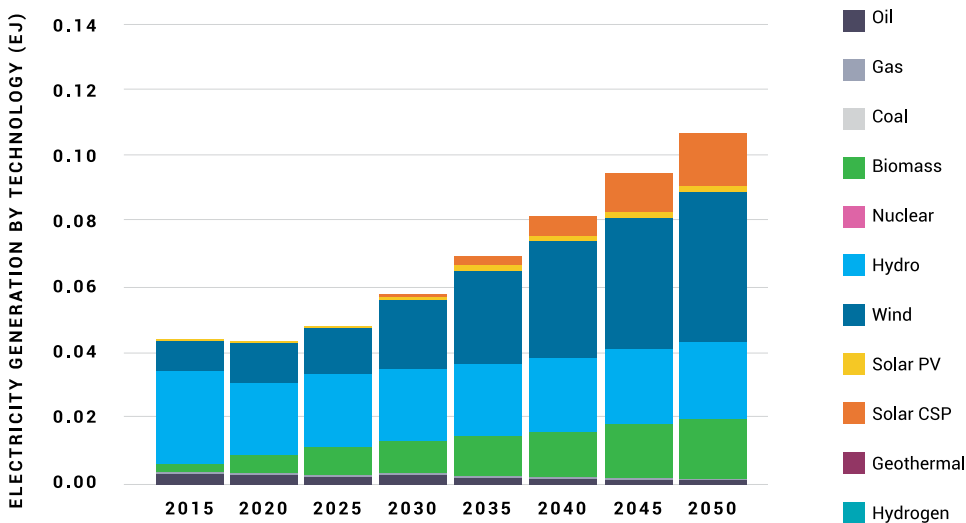
Reference: South America_Northern



Reference: South America_Southern



Reference: Uruguay

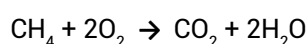


ANNEX 2

Carbon footprint of natural gas

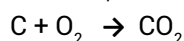
Natural gas is essentially methane (CH₄). Typically, in natural gas there will be minor amounts of heavier weight hydrocarbons like ethane (C₂H₆), but for the purposes of this calculation, and because these other compounds are present in minor amounts (if not, they are typically separated) and would emit more CO₂ per unit of carbon, their contribution will be ignored. Coal is just C.

Upon total combustion, natural gas emits less CO₂ than coal per unit of weight. This is the result of its molecular composition. This is known as the stoichiometry equation.



For each 16 tons (considering the respective molecular weights) of CH₄, 44 tons of CO₂ are released.

For coal, the stoichiometry equation is:



For each 12 tons of coal, 44 tons of CO₂ are released.

That is one ton of carbon emits 33% more CO₂ than one ton of natural gas.

Nevertheless, methane has a much greater warming potential than CO₂. That is, if methane is released to the atmosphere, it would have a greater warming effect per unit of molecular weight than CO₂. Considering the residence time in the atmosphere, the IPCC¹⁹⁹ has estimated the relative warming potential of different greenhouse gases. The values are reproduced in Table 1. The fifth (latest) assessment report indicates that methane has 28 times the warming potential of CO₂.

Table 1. Global warming potential of some greenhouse gases

Industrial designation or common name	Chemical formula	GWP values for 100 year time horizon		
		Second Assessment Report (SAR)	Fourth Assessment Report (AR4)	Fifth Assessment Report (AR5)
Carbon Dioxide	CO ₂	1	1	1
Methane	CH ₄	21	25	28
Nitrous oxide	N ₂ O	310	298	265

Source: http://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf

199. www.ipcc.ch

If methane extracted from the ground is tightly controlled during its processing cycle, that is if there are no leaks or fugitive emissions, there would be a net reduction of 33% in CO₂ emissions when coal is replaced by methane, on a weight basis. But this is not the case. In an assessment of leaks from the natural gas pipeline and distribution system in the United States, it was found that 2.3% of methane is leaked to the atmosphere.²⁰⁰

There is reason to assume that the natural gas emissions during the entire processing cycle command a higher percentage in LAC. In Mexico, an estimate places fugitive emission from natural gas at 8% of total GHG emissions from the oil and gas industry.²⁰¹ In Argentina, Codeseira estimated that between 2002 and 2014 the distribution system for natural gas to the end users lost between 2 and 10% in weight.²⁰²

If one assumes fugitive emissions, losses, of just over 3.3% by weight during the distribution of gas, the emissions from natural gas would about equal those of coal per unit of weight:

Combustion of methane, 1 ton yielding 2.75 tons of CO₂

CH₄ (0.33% x 28 CO₂) = 0.92 tons of CO₂ equivalent.

Total = 3.67 tons of CO₂ equivalent.

Per ton of C:

Combustion of C, 1 ton yielding 3.67 tons of CO₂

200. <https://science.sciencemag.org/content/361/6398/186>

201. <https://imco.org.mx/wp-content/uploads/2018/02/AFB-Emissiones-de-metano-en-el-sector-petr%C3%B3leo-y-gas.pdf>

202. <http://www.ceare.org/tesis/2017/tes18.pdf>

ANNEX 3

Estimate of comparative electricity generation potential of energy hotspots in LAC.

Efficiency of thermal power plants. To calculate the comparative potential in terms of electricity generation potential, the annual production of oil was converted into electricity using the estimated efficiency of modern thermal power plants (Table 1). For purposes of the estimate, it is assumed that all generation will have a 50% efficiency.

Intensity of energy fields. For the Atacama Desert, a solar irradiance of 265 W/m² was considered. For Sonora/Chihuahua it was 190 W/m². For the wind field in Brazil a generation potential of 500 GW was used. The equivalent annual production of electricity from different producers is presented in Table 2 together with the parameters of relevance to calculate the equivalence.

The equivalence was estimated as follows: Years of equivalence in generation = AOP x conversion efficiency / Area of annual production x irradiance x efficiency of conversion.

Table 1. Estimate of efficiency of thermal power plants

Technology	Range of efficiency of energy conversion to electricity (%)
Gas turbine	20-35
Coal Power Plant	35-46
Oil fired power plant	38-45
Combined cycle gas best of class	62
Assumed average efficiency	50

Source: <https://geospatial.blogs.com/geospatial/2010/01/energy-efficiency-of-fossil-fuel-power-generation.html>

Table 2. Estimate of the equivalent electricity potential of large oil producers

Oil Producing Country	Annual oil production (MMBBL) (AOP)	Estimated annual electricity production at site (P _{WH})	Renewable Energy Area	Energy intensity	Total area (km ²)	Efficiency of conversion to power	Months of generation of 10% of area with PV technology to equal use of equivalent annual oil production.
Saudi Arabia	4.53	3.85	Atacama	265 W/m ²	102,000	20% in PV	8
Iran	1.63	1.1	Sonora Chihuahua	190 W/m ²	260,000	20% in PV	1
Brazil	1.27	1.0	On shore wind in Brazil	500 GW	7,500 km	20% on line factor for wind plants	14

Source: Author's estimates; assume 10% of area, PV efficiency of 20% wind energy production at 20% of potential. Uses average efficiency of power thermal plants at 50%. For wind in Brazil, it uses a 500 GW potential.



ANNEX 4

Estimated equivalent potential energy of large hydropower reservoirs

The total hydropower nominal capacity in the region is estimated at 155 GW. Of these about 100 GW are in reservoirs exceeding 1 GW in nominal capacity, judged to be more capable of maintaining a storage capacity.

For illustration purposes, it is estimated that only 25% of the reservoir capacity could function as storage capacity available to dispatch in a regionally connected system.

The estimated equivalent energy storage available would then be:

Equivalent regional annual storage capacity of large reservoirs in the region=

$100 \text{ GW} \times 0.25 \times 8,760 \text{ hours of operation/year} = 0.22 \text{ TWh}$

ANNEX 5

Road Transport fleet in some countries in the region

The road transport fleet in some countries is described in Table 1.

For the purposes of the report, it has been assumed that the motorization rate in the region will slow down gradually, remaining constant from 2030 to mid-century. The reduction in growth of the car fleet is anticipated based on concerns over congestion, effects on productivity and an increase in the use of public passenger and non-motorized transport. The growth rate until 2030 was assumed to be a compounded 2% per year. Under this assumption the car fleet would grow by about 30% to 140 million cars by 2030 and thereafter remains flat. Contributing to a reduction in the rate of growth of the car fleet is the anticipated increase in shared mobility. It is entirely possible, however, that despite efforts, the motorization rate continues to grow at an unsustainable rate. Consistent with a stagnant growth of vehicle passengers, the bus fleet is assumed to double in size by 2050. The truck fleet would double as well.

Table 1. Size of the road transport fleet in some countries (in thousands of units)

Country	Cars	Buses	Trucks
Argentina	13,330	84	680
Brazil	62,200	1,026	4,308
Chile	3,560	129	206
Colombia	3,370	197	325
Costa Rica	850	17	213
Mexico	30,700	400	10,800
Panama	610	33	144
Peru	2,780	83	266
Uruguay	1,035	70	70
Total	118,435	2,039	17,012

ANNEX 6

Some fossil fuel assets subject to decommissioning under the intervention scenario

Power plants. The intervention scenario assumes that no fossil fuel plants will be in operation by 2050. To estimate the value of the capital lost through the mothballing of plants, the installation costs and year of commissioning were compiled. The value of the demobilized capital was estimated using a straight depreciation schedule with a useful period of operation of 60 years. In order to be conservative, the year of the most recent commissioning was used as the starting point of the depreciation schedule. The residual value is the value left to be depreciated in the estimated year of decommissioning as per the intervention scenario.

Table 1. List of power plants using fossil fuels subject to decommissioning under the intervention scenario.

Country	Country	Number of Units	Capacity MW	Primary Fuel	Most Recent Commissioning Year	Cummulative Installation Cost (US\$ billion)
ARG	Argentina	8	4,844.2	Coal	1993	3.63
BRA	Brazil	9	2,584.9	Coal	2013	1.94
CHL	Chile	12	4,794.3	Coal	2012	3.60
COL	Colombia	5	1,393.0	Coal	2016	1.04
MEX	Mexico	3	5,378.4	Coal	2015	4.04
PAN	Panama	1	120.0	Coal	2015	0.09
PER	Peru	1	132.0	Coal	2015	0.10
ARG	Argentina	32	13,335.1	Gas	2013	10.67
BRA	Brazil	28	10,454.7	Gas	2016	8.63
CHL	Chile	6	2,926.2	Gas	2015	2.34
COL	Colombia	5	2,553.0	Gas	2015	2.04
JAM	Jamaica	1	120.0	Gas	2015	0.10
MEX	Mexico	61	25,674.2	Gas	2015	20.5
PAN	Panama	1	160.0	Gas	2015	0.13
PER	Peru	9	4,187.2	Gas	2013	3.35
URY	Uruguay	1	212.0	Gas	2015	0.17
BRA	Brazil	27	5,164.5	Oil	2015	4.65
CHL	Chile	12	1,879.8	Oil	2015	1.69
COL	Colombia	1	188.0	Oil	2015	0.17
CRI	Costa Rica	2	434.5	Oil	2015	0.39
JAM	Jamaica	2	470.0	Oil	1992	0.42
MEX	Mexico	23	11,522.4	Oil	2015	10.37
PAN	Panama	1	96.0	Oil	2015	0.09
URY	Uruguay	1	300.0	Oil	2015	0.27
BRA	Brazil	1	147.3	Other	2007	n.a.

Refineries. A similar procedure was employed to estimate the value of refineries decommissioned before the end of their useful period of operation. The refineries used in the estimate are listed in Table 2.

Table 2. List of refineries subject to decommissioning under the intervention scenario.

Country	Capacity (Thousands of Barrels per Day)	Most Recent Commissioning Year	Installation Cost (US\$ billion)
Argentina	580	2010	2.32
Brazil	2,285	2010	9.14
Chile	258	2010	1.03
Colombia	421	2010	1.68
Curacao	320	2010	1.28
Ecuador	175	2010	0.70
Mexico	1,546	2010	6.18
Peru	253	2010	1.01
Trinidad & Tobago	165	2010	0.66
Venezuela	1,303	2010	5.21
Other S. & Cent. America	384	2010	1.54
Total Latinamerica	7,690	2010	30.76
Total S. & Cent. America	5,979	2010	23.91

ANNEX 7

Intervention scenario

The intervention scenario was described earlier (Vergara W., et. al., 2015). It consists of measures to decarbonize the economy of the region by mid-century. For the power sector it assumes:

a) Starting around 2020, all new demand will be met by renewables, that is, by a combination of new wind, solar and geothermal facilities, which already have LCOEs below natural gas and coal, supplemented by some expansion of hydro-capacity mostly by small-hydro or run of the river.

b) By 2030, all currently operating fossil-fuel plants other than gas will have been decommissioned, and by 2050 all existing natural gas units will also be mothballed. Demand will be met by corresponding additions in renewables (mostly wind, geothermal and solar supplemented by the expansion of run of the river or small-hydro and large plants already under construction) with increased participation of CSP and distributed power. One should expect the large-scale utilization of hot spots for renewable technology development by then. Examples include the deployment of GW-sized solar PV and CSP in the Atacama Desert and other high irradiance areas, as well as similar use of localized endowments for wind.

For the transport sector the pathway includes:

a) Shift to electric mode for all existing BRTs in the region by 2025, and all new BRTs going electric from the design stage by 2025. While this shift will not produce substantial reductions in fossil fuels, it could be an emblematic change, illustrating the potential of the technology and bringing visible co-benefits in urban areas, as well as stimulating development of the market in electric drives for public transport vehicles.

b) The replacement passenger car fleet becomes 10% electric (adjusted downward from an original estimate of 15%) by 2025, 60% by 2040 and is fully electrified

by 2050. The same conversion rate is experienced by light trucks and all buses. This is predicated based on anticipated gains in competitiveness achieved over a very short period. These segments represent 47% of road emissions in the region.

c) All railroad cargo and passenger transport are electrified by 2040. Again, this is not a major segment of the sector, but conversion of railroads to the power grid is within existing and available technology and will signal the decision to electrify the sector.

d) All marine transport shifts to hybrid engines by 2050.

e) Heavy road cargo transport becomes 5% electric by 2025, 60% electric by 2040 and is fully electrified by 2050.

f) Aviation remains fossil fuel-based until mid-century.

Map of future power generation capacity

Under the intervention scenario no fossil fuel-based power plant is in operation by 2050. These are substituted by a mix of renewable energy technologies. The mix is determined by the recent momentum in expansion of capacity and the forecasted relative competitiveness. The current makeup of renewable energy mix by technology is presented in Table 1.

There are substantial differences between nations but the average distribution for non-hydro is 70:25:5 for wind, solar and geothermal. The projected costs of generation for renewables was presented in Chapter 3 of the report. Wind is projected to continue to be the cheapest alternative regionwide. But solar PV is projected to also become very competitive and close in on onshore wind by mid-century. In addition, the large reservoirs for solar energy in the region and the easy adaptability to disperse applications and deployment through renewable generation will play a role in future share of solar.

Table 1. Makeup of current installed capacity of renewables

Country	Current capacity of renewables (GW)			
	Hydro	Wind	Solar	Geothermal
Argentina	11.28	0.75	9.22	-
Brazil	99.33	14.40	2.23	-
Chile	6.72	1.52	2.27	-
Colombia	11.83	0.02	0.08	-
Costa Rica	2.33	0.45		0.20
Jamaica	0.03	0.10	0.02	-
Mexico	12.11	4.68	2.43	0.95
Panama	1.71	0.27	0.14	-
Peru	5.12	0.37	0.29	-
Uruguay	1.53	1.51	0.25	-
Region	185.54	25.05	9.22	1.59
Share in the region (%) excluding hydro	-	70	25	5

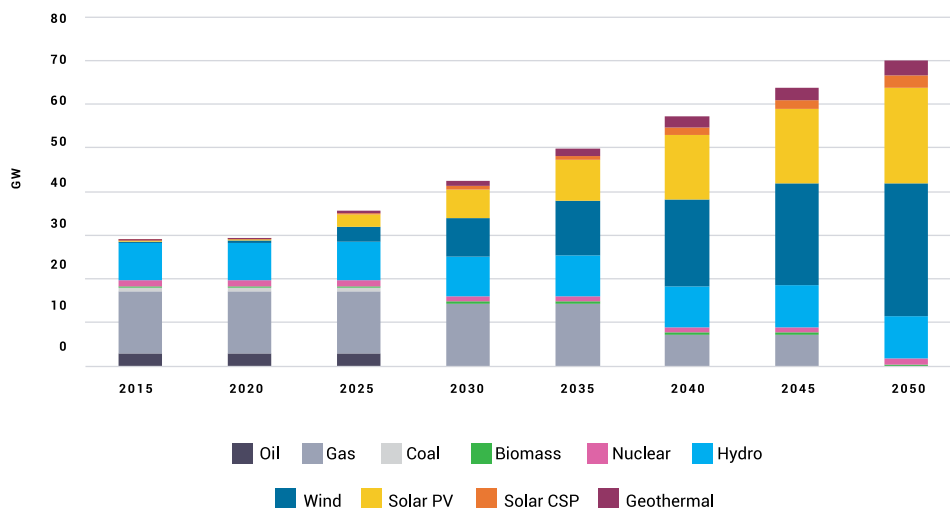
Today, hydro has a commanding lead in total installed nominal capacity. However, some factors weighed against maintain this lead. The first is the improved competitiveness of wind and solar, which will outbid hydro in terms of generation costs. Second is the fact that the best places for cost-competitive large reservoirs are already in use in the region, consistent with a long history of exploitation of the resource. Finally, there are likely to be substantial social and environmental costs associated with any large new reservoirs, high enough to deter many investments in the future.

The report does not consider a major increase in biomass for power generation given the anticipated future demand for land as a carbon sink and for food production. Marine energy is not expected to play a significant role by mid-century. However, it is important to continue to invest in its future development given the potential in the region. Besides the storage capacity in reservoirs there is an expectation for increased competitiveness of storage capacity linked to wind and solar and further in the future in self standing storage facilities.

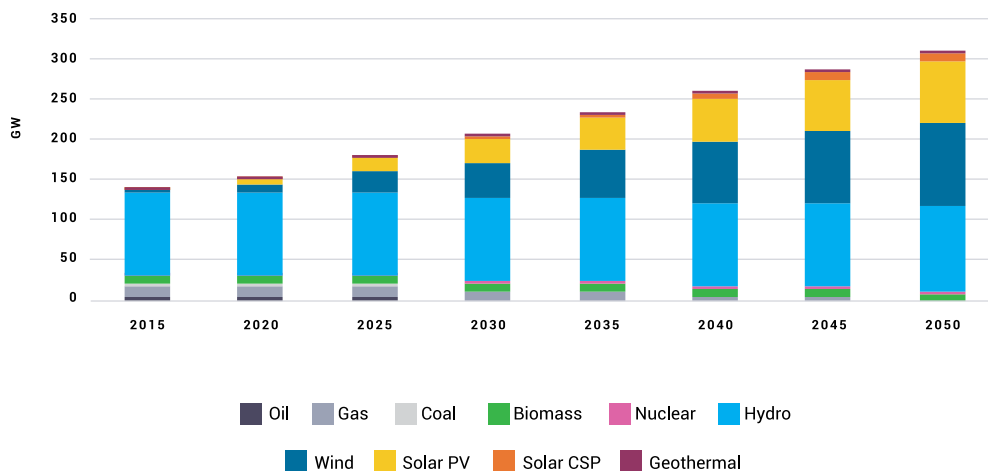
For illustrative purposes, and to facilitate the estimate of capital outlays, the projected future distribution of new capacity renewable energy sources is assumed to be 55:40:3:2 for wind, solar (including distributed which represents a market of emergent importance and utility-size PV) as well as CSP, geothermal, and hydro (mostly reflecting small units, run of river and a few large units already under construction). The system is also assumed to incorporate some utility-size storage by mid-century. This distribution has been applied on a regional basis and for some of the countries in the analysis.

The country-based resulting capacities are summarized below:

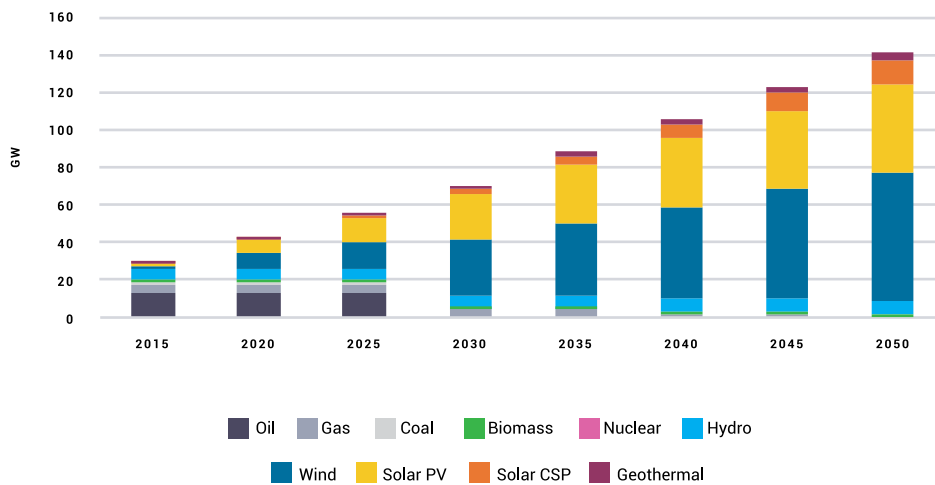
Intervention scenario: Argentina



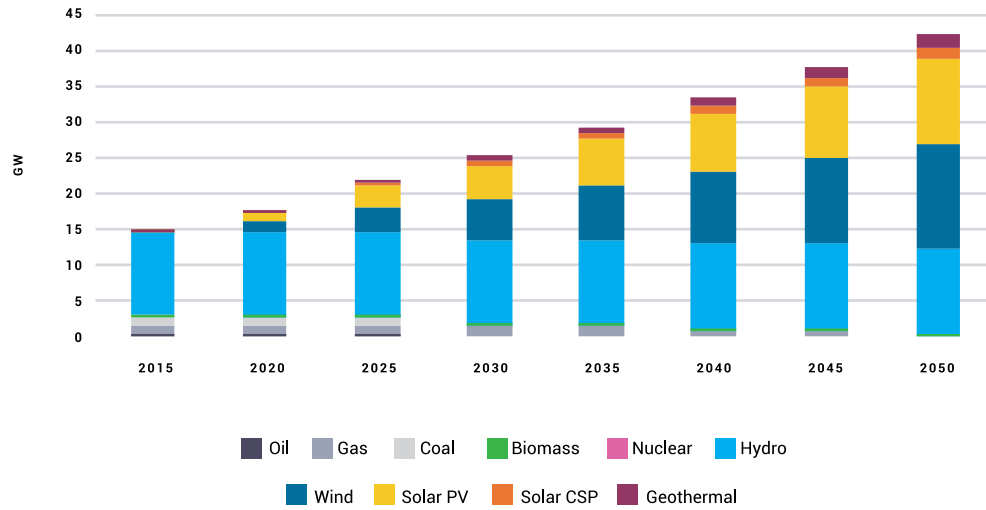
Intervention scenario: Brazil



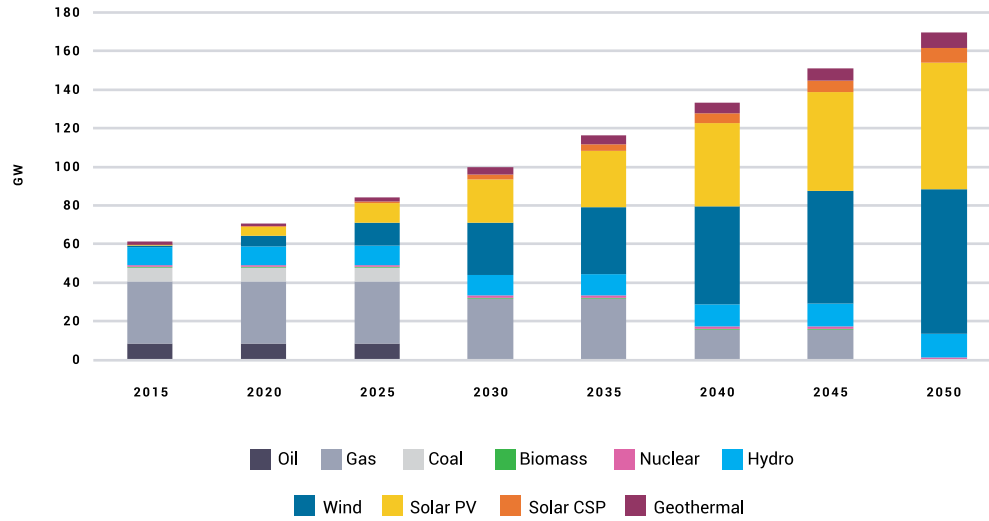
Intervention scenario: Central America



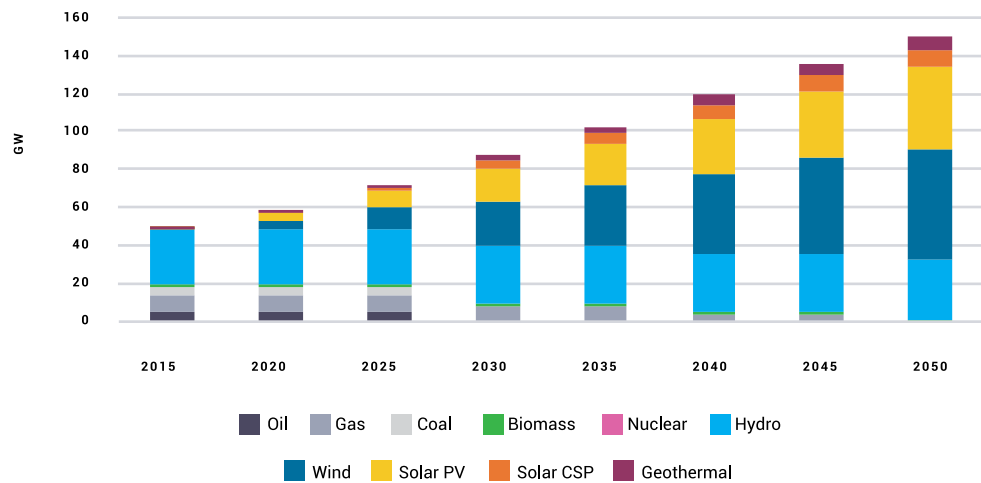
Intervention scenario: Colombia



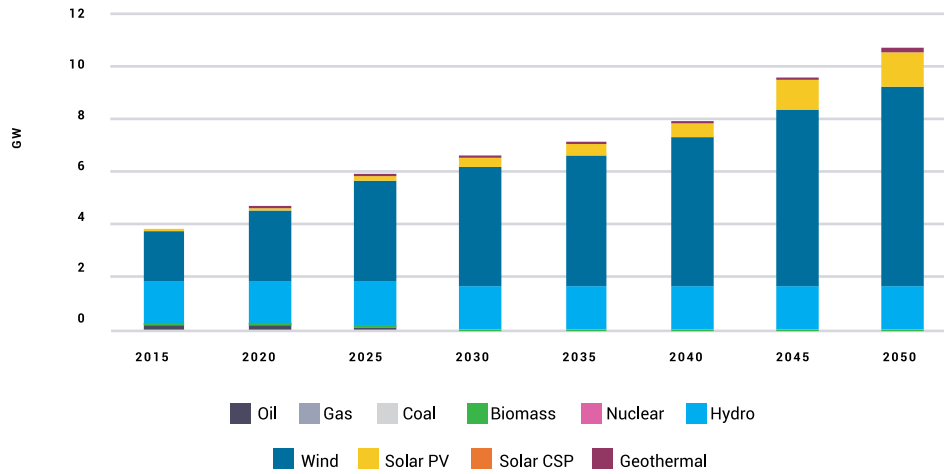
Intervention scenario: Mexico



Intervention scenario: South America southern

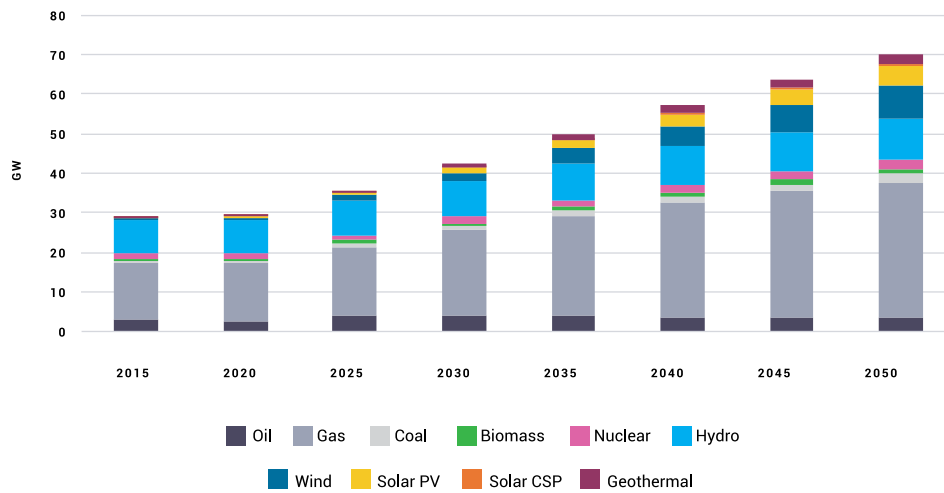


Intervention scenario: Uruguay

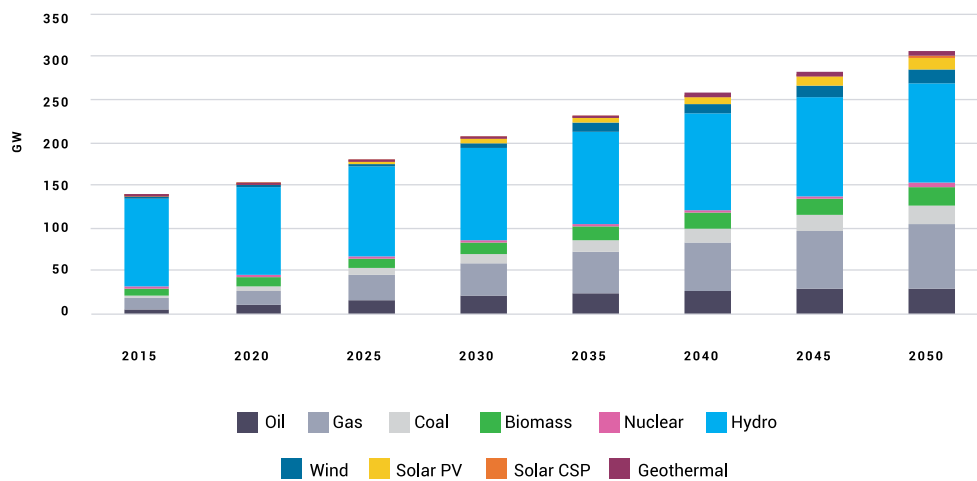


For comparison purposes the capacities under the reference scenario are also included:

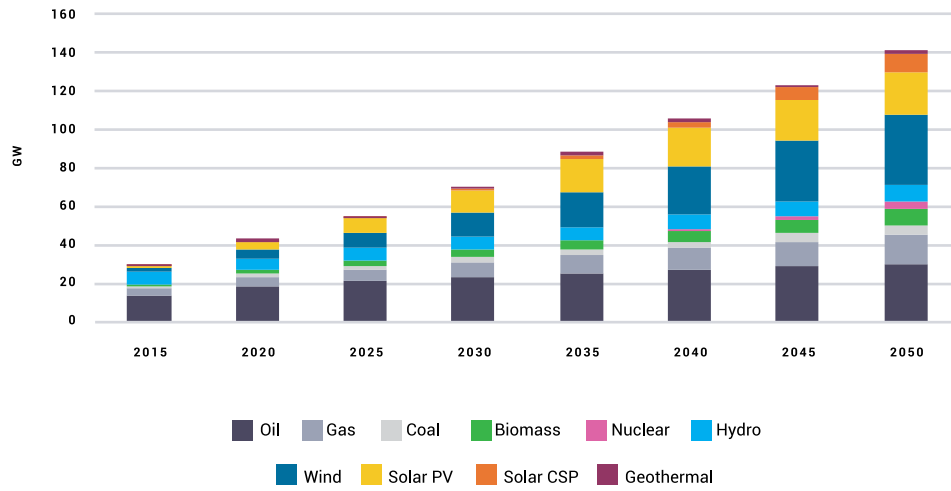
Reference scenario: Argentina



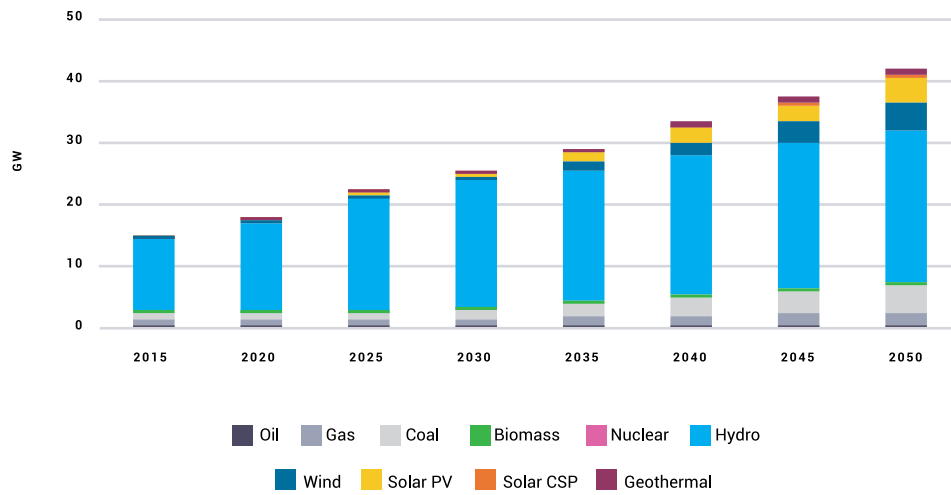
Reference scenario: Brazil



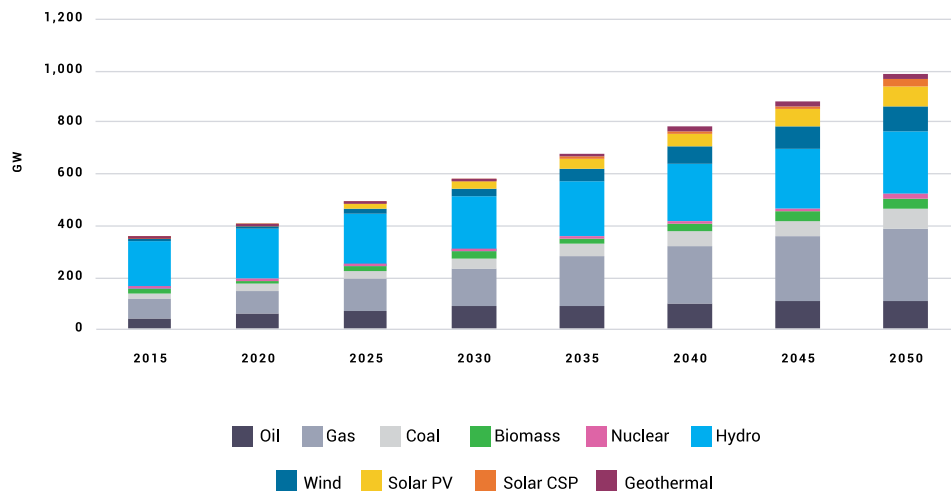
Reference scenario: Central America



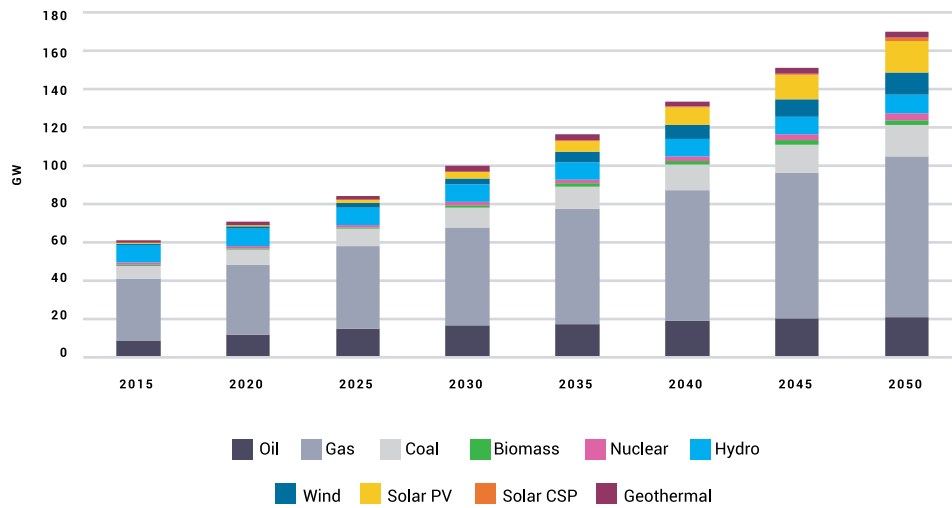
Reference scenario: Colombia



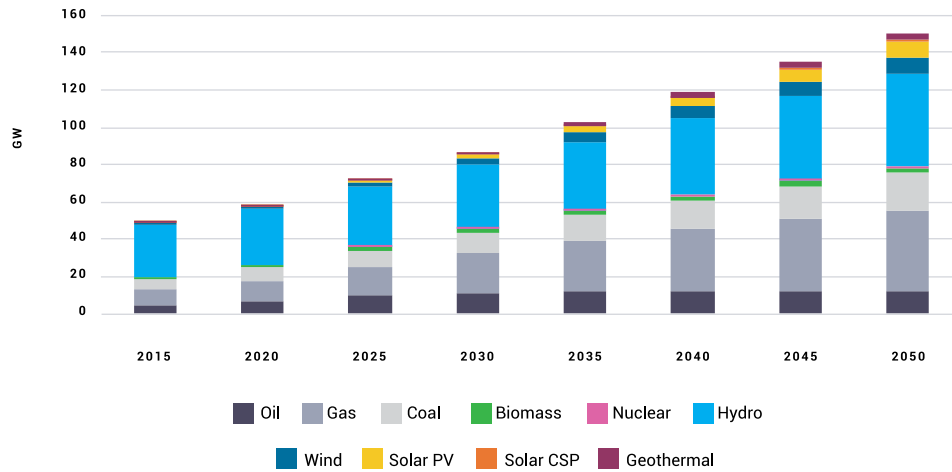
Reference scenario: LAC



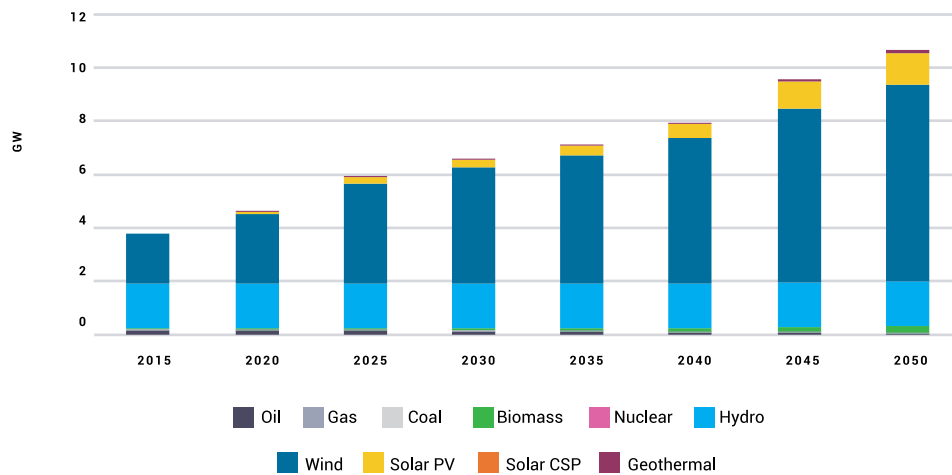
Reference scenario: Mexico



Reference scenario: South America Southern

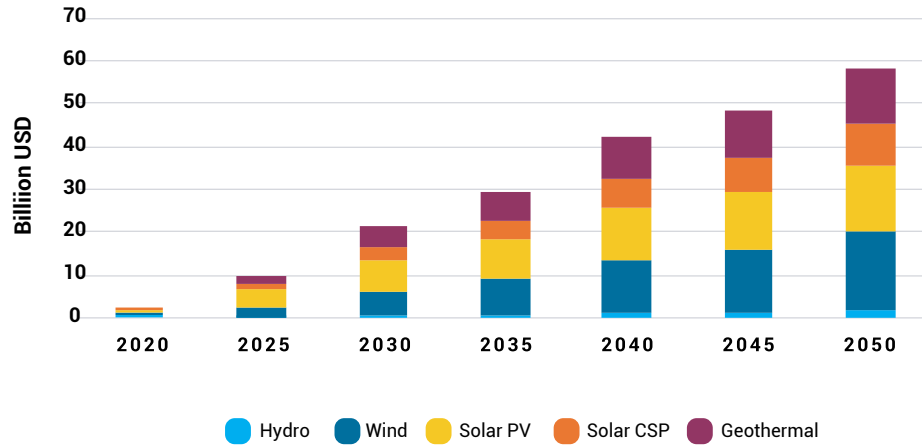


Reference scenario: Uruguay

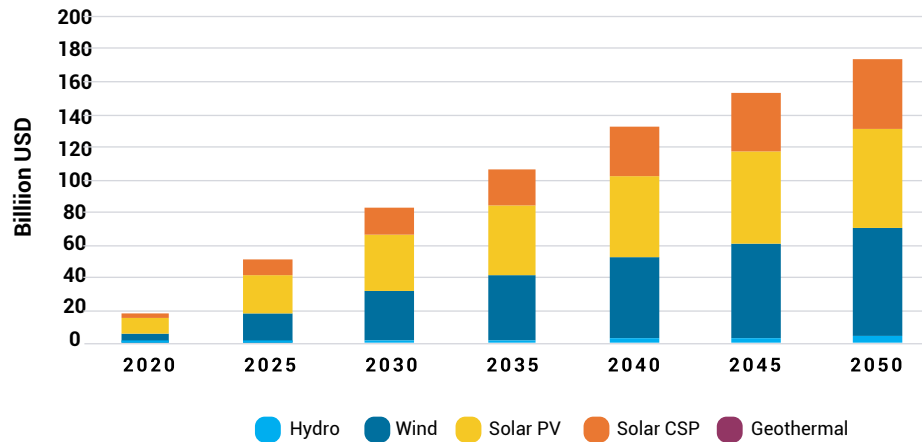


The country-based investments for the intervention scenario are summarized below:

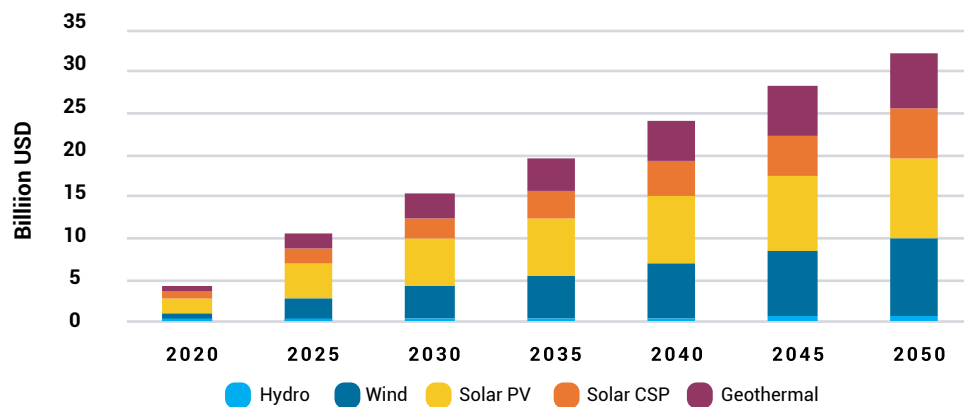
Cumulative Investment: Argentina



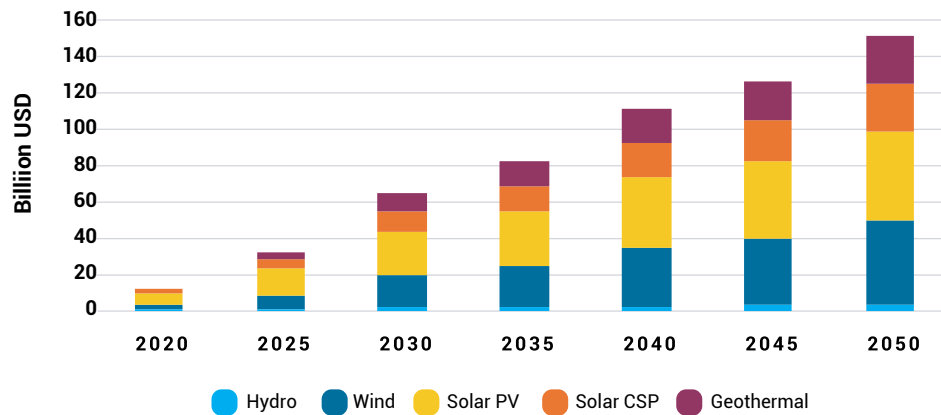
Cumulative Investment: Brazil



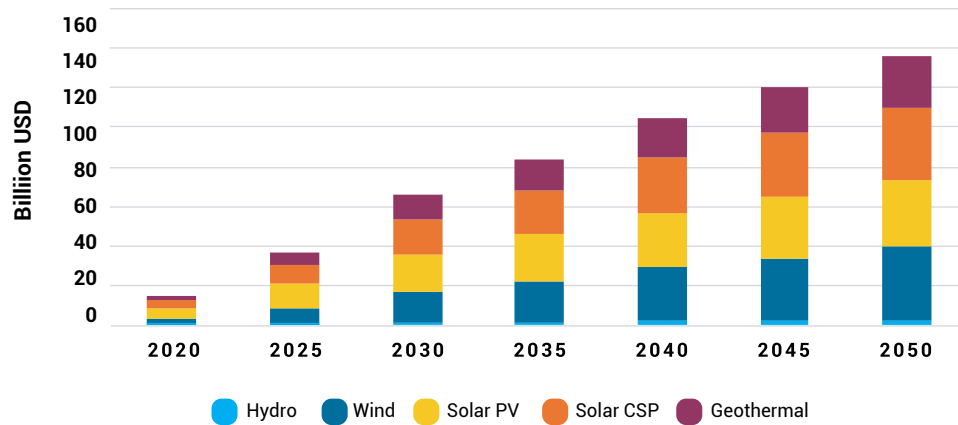
Cumulative Investment: Colombia



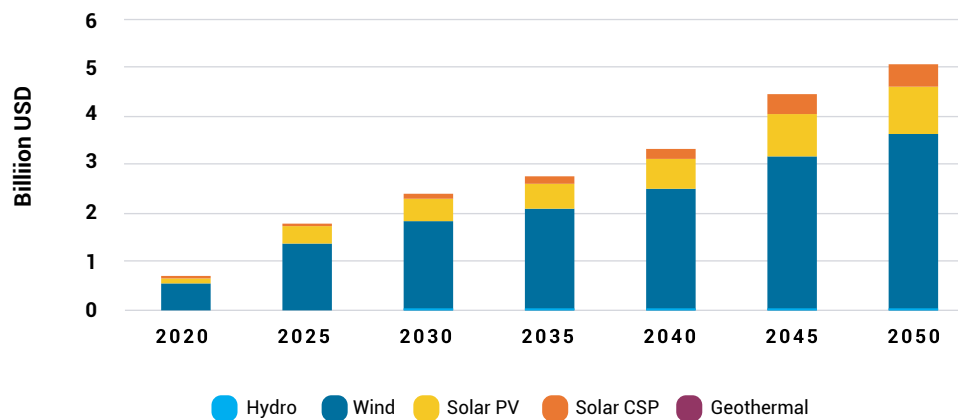
Cumulative Investment: Mexico



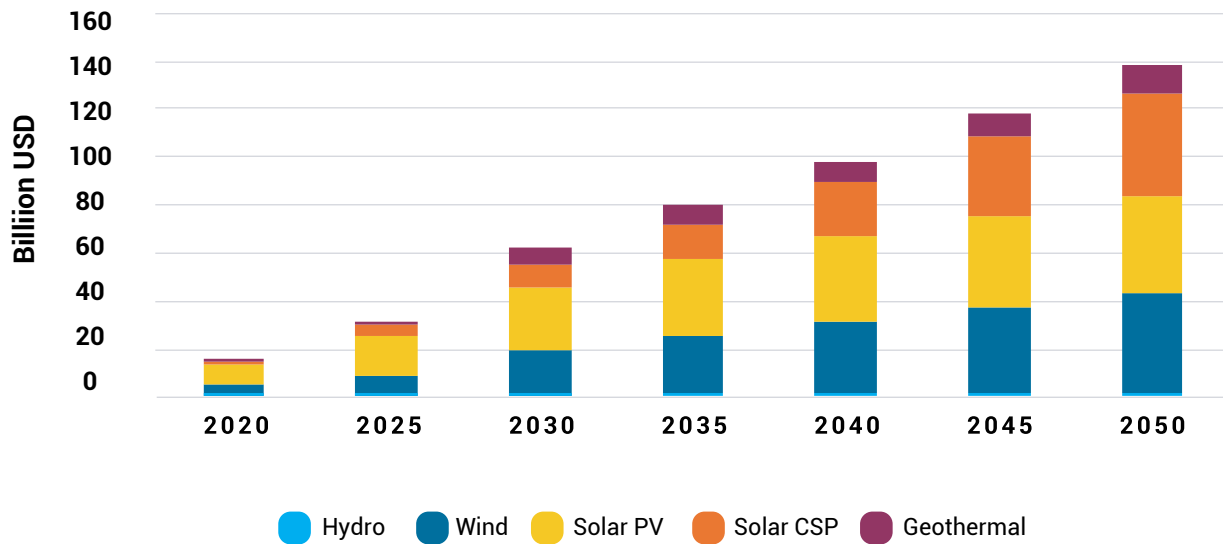
Cumulative Investment: South America southern



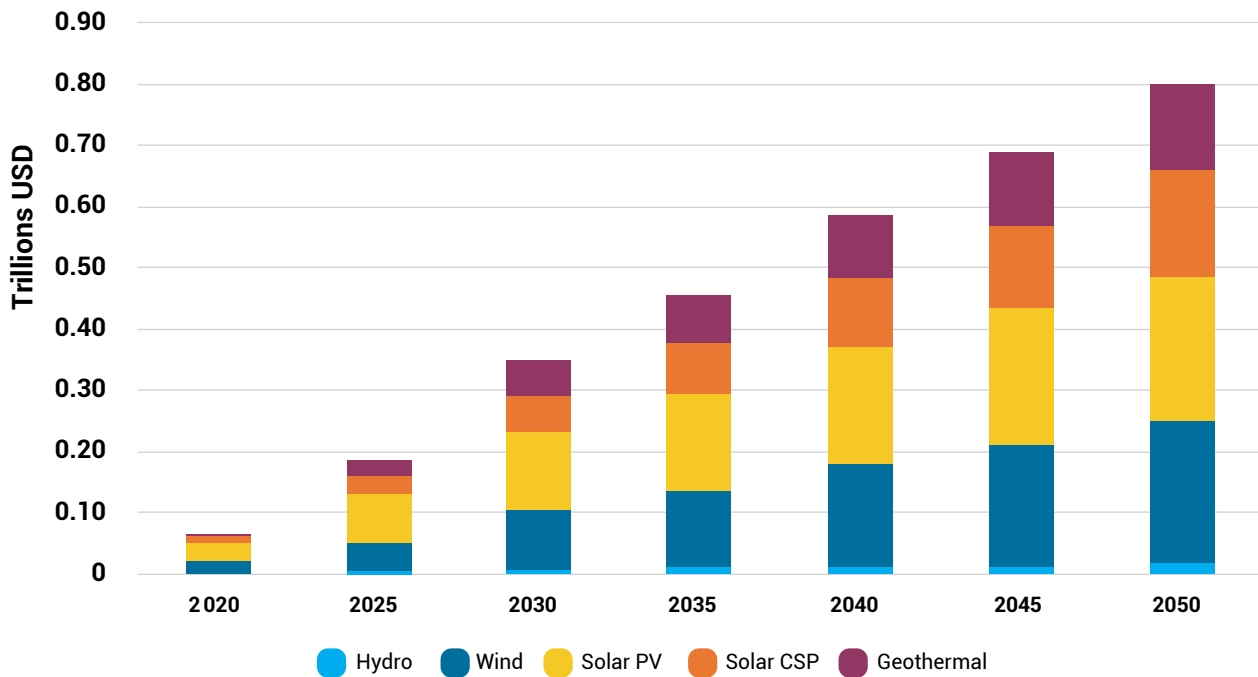
Cumulative Investment: Uruguay



Cumulative Investment: Central America and the Caribbean



Cumulative Investment: Latin America and the Caribbean



ANNEX 8

Estimate of Costs of Transport under the Intervention Scenario

The size of the transport service for passenger and cargo transport by midcentury was estimated by GCAM under BAU conditions. This demand is adopted for the Intervention Scenario. The results are summarized in Table 1.

Table 1. Estimated level of service in the road transport sector

Year\Mode	Passenger (billion km-passenger)			Cargo (billion km-ton)		
	Rail	Bus	Car	Truck total	Light	Heavy
2020	41	1559	2,771	4,595	4,135	460
2030	56	1571	3,772	5,643	5,079	564
2050	84	1456	5,814	7,584	6,826	758

Source: GCAM outputs.²⁰³

The BAU scenario projects a continuous increase in car transportation, almost doubling the service by 2050 in relation to 2020 while bus transport losses share. Under the intervention scenario, the service through light vehicles only increase by 30% compared to 2020 (see also Annex 5), while service by bus increases by 235% to maintain the total level of service projected to 2050. In terms of cargo, the projection has been split between light (average 5 tons) with 90% of the fleet and heavy (average 15 tons) trucks.

The total cost of the service was estimated using the calculated LCOTs for conventional and electrical vehicles (see Figure 2 in Chapter 5), over the period under analysis. The results are presented in table 2 for the year 2050, when the fleet is fully electrified. Only road transport is considered. The LCOT or levelized cost of transport is a concept like LCOE, where the capita, operation and maintenance costs are levelized on an annual basis for the lifespan of the asset.

With a fully electrified fleet for passenger road transport, the total cost of service is higher for buses (in part as a result of the significant increase in the size of the fleet) but much lower for autos where costs for electric options are projected to be considerable lower than for conventional vehicles by midcentury (see LCOT table in Chapter 5), with a net saving for passenger transport of US\$ 328 billion. Similarly, the electrified cargo fleet (just trucks) has a combined savings of US\$ 41 billion. The total annual savings are estimated at US\$ 369 billion.

203. The approach to modeling transportation in GCAM has been documented in Kim et al. 2006, Kyle and Kim 2011, and the dataset in the current version of GCAM is documented in Mishra et al. 2013. The modeling approach is consistent with the other sectors in the model.

Table 2. Projected annual cost of transport service in 2050 under BAU and the Intervention scenario.

	Passenger LCOT (\$/km)		Cargo by truck LCOT (\$/km)		
	Bus	Auto	Light	Heavy	
Conventional	0.45	0.23	0.91	0.77	
Electric	0.58	0.18	0.85	1.59	
Passenger/vehicle	80	2	5	15	Tons cargo/vehicle
Total Cost of Service in US\$ billion ²⁰²					
Conventional	8.2	668.6	1,242	39	
Electric	26.6	324.2	1,160	80	
Difference	+16.4	-344.4	-82	+41	

Estimated capital requirements to meet additional power demand from electrification of transport

Electrification of the transport sector will create an additional demand of electricity estimated at 5.5 EJ by 2050. The estimated additional capacity to meet this demand is 327 GW (at a rate under the BAU scenario of 59.5 GW/EJ). The cost of the additional capacity under BAU conditions in the power sector has been taken to be proportional to the cost of the entire power matrix:

Cost of new capacity = Cost of BAU capacity by mid-century x 5.5 EJ/16.7 EJ = US\$ 317 billion.

Table 3 illustrates the case where a power sector that is transitioning toward full use of renewables, provides the additional power requirements. The distribution of new capacity under installation has been assumed to be 55:40:3:2 for wind : solar : geothermal : hydro. The cost is estimated at US\$ 214 billion for savings of US\$ 103 billion.

Table 3. Estimated capacity required to meet electricity demand by the power sector by mid-century (GW)

	Share of new capacity online (%)	Wind	Solar	Geothermal	Hydro
Capacity installed by 2040	40	71.9	52.3	3.9	2.1
Investment per MW by 2040 (US\$ million)		600	600	3,764	1,138
Total Investment by 2040 (US\$ billion)		43.2	31.4	14.8	3.00
Capacity installed by 2050	60	107.9	98.1	6.1	3.9
Investment per MW by 2050 (US\$ million)		550	400	3,262	1,138
Investment by 2050 (US\$ billion)		59.3	39.2	19.2	6.1

202. Total cost of service=Level of service x LCOT/passenger or ton

ANNEX 9

Valuation of avoided health impacts

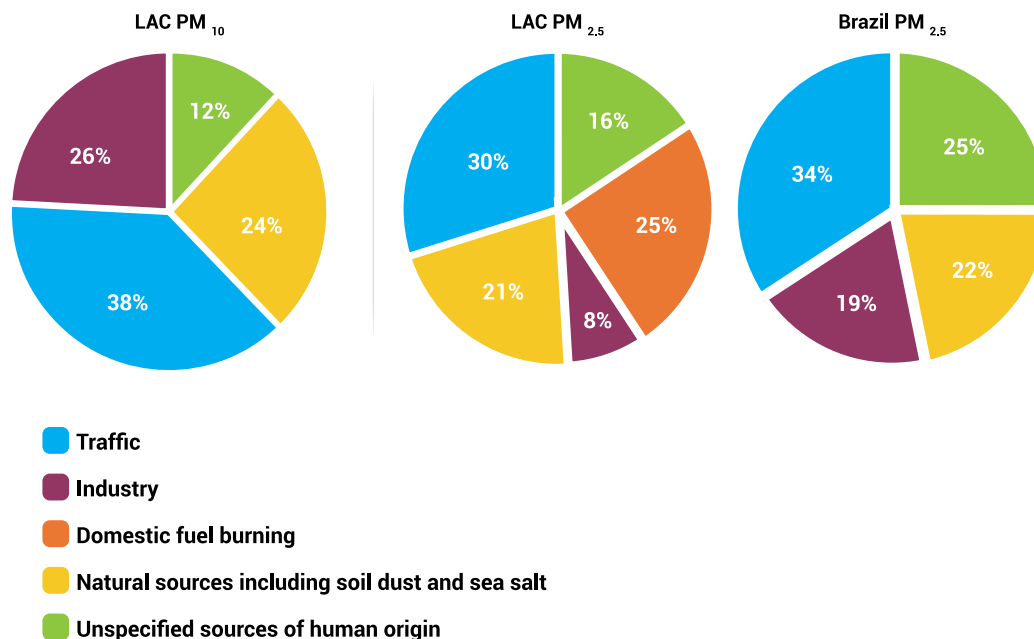
The following studies were analyzed to determine avoided health impacts:

a) OECD (OECD, 2014) which found that In OECD countries the cost of air pollution including death and illnesses was about 1.7 trillion US\$, with Mexico accounting for 39 billion US\$. The study also found that 50% of PM is caused by the transport sector.

b) The review of contributions to cities' ambient particulate matter (PM) by Karagulian and coworkers (<https://www.sciencedirect.com/science/article/pii/S1352231015303320>) which attributed 38% of PM₁₀ emissions and between 30 % to 34% of PM_{2.5} to traffic in LAC cities (see Figure 1). For purposes of the analysis it is assumed, by the authors, that most of the attribution is derived from diesel combustion.

c) The analysis of urban air quality and human health by Cifuentes L and coworkers (2003) estimated regional economic benefits in terms of avoided costs of illnesses of the order of 3 to 8 \$/person year

Figure 1. Attribution of emissions of PM₁₀ and PM_{2.5} by source in cities in the region



Source: Adapted from Karagulian F. et al 2015

The estimates made by each method above is summarized in Table 1.

Table 1. Valuation of health benefits from elimination of exposure to PM by alternative methods

Method	Value of health benefits (Billion US\$ 2018 /year)
Avoided exposure resulting from a 10% reduction of PM to urban populations (Cifuentes et al, 2005)	30-68
Elimination of PM from diesel combustion in transport (based on estimates for Mexico; OEC D, 2014)	113
Elimination of PM from diesel combustion in transport in urban areas (based on region-wide estimates; Karagulian et. al., 2015)	32

The avoided exposure uses the per capita WTP factors by Cifuentes and coworkers and multiplies by the estimate of urban population in the region in 2018 (80% of 642 million). The impacts of elimination of PM from transport uses the value of attribution of 90% by OECD and 30% of attribution of PM for traffic found by Karagulian and coworkers in the region. For the purposes of this report, the most conservative value of the different studies was used as the avoided costs from the elimination of PM emitted by transport, which lies in US\$ 30 billion per year (2018).

ANNEX 10

Assumptions Made on the Cost of Electric Vehicles

The cost of electric vehicles in GACMO is projected using the current trends in capital and O&M costs. The assumptions used are summarized in Tables 1.

Table 1. Annual distances used in the estimate of levelized cost of operation for road transport

Annual distance	km
Gasoline cars	12,000
Electric cars	12,000
Diesel buses (18m)	100,000
Electric buses (18m)	100,000
Diesel buses (12m)	40,000
Electric buses (12m)	40,000
Diesel light trucks	12,000
Electric light trucks	12,000
Diesel heavy trucks	37,500
Electric heavy trucks	37,500

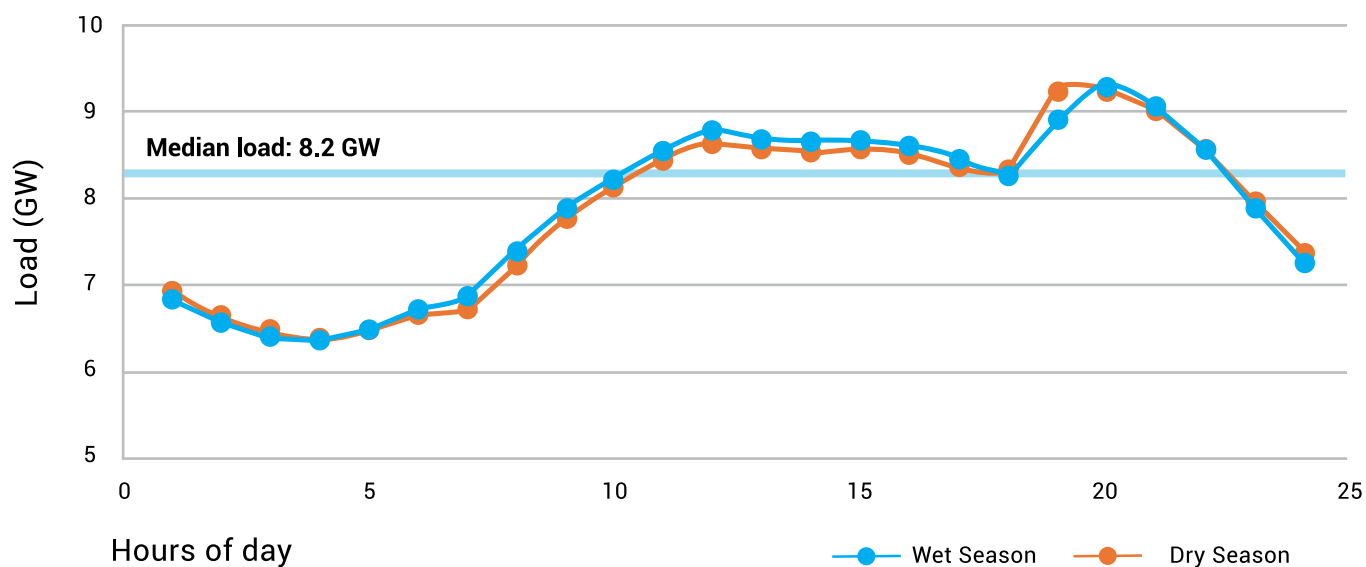
Table 2. Future capital cost of road transport fleet (U.S. \$ in 2018)

Type of vehicle\year	2020	2030	2050
Light vehicles	25,000	17,500	15,000
Bus 18 m	550,000	450,000	350,000
Bus 12 m	300,000	250,000	150,000
Heavy trucks	550,000	500,000	400,000
Light trucks	97,500	68,250	48,750

ANNEX 11

Example of valley filling to accommodate demand from transport in daily loads.

The daily load curve for Colombia is shown below:



The median of load is estimated at 8.1 GW. The valley under the median was estimated at 12.1 GWh per day or (12.1x365) 4,416 GWh/year.

The annual diesel use by transport in Colombia is reported at 11,812 kTOE (DNP, 2017) or 137,000 GWh. If it is assumed that only one third of the energy content of diesel is delivered as work, the electric equivalent is 45,700 GWh, or 50,800 GWh used by electric engines with 90% efficiency.

This corresponds to about 9% of the equivalent diesel demand.

For the regional daily load curve, the median was estimated at about 112 GW (between 115 and 109 for days in December and in June). The area under the median is measured at about 40,000 GWh/year which for a 4000 h/year online factor would equal about 10 GW.

ANNEX 12

Job estimates

For the purposes of estimating job creation in renewable energy, the job generation factors reported by Dominich and colleagues (Dominich et al, 2018) were used. Employment losses caused by the retreat of the fossil fuel industry were also calculated using the same source. The generation factors are summarized in Table 1.

Table 1. Employment factors (jobs/GW) in the energy industry and estimated new capacity by 2050

Industry	Construction (Job years/GW)	Manufacturing (Job years/GW)	Operation and Maintenance (permanent jobs/GW)	New installed capacity by mid-century (GW)
Geothermal	6,800	3,900	400	34
CSP	8,900	4,000	700	51
PV	13,000	6,700	700	296
Wind	3,000	3,400	300	373
Hydro	7,500	3,900	200	14

The employment factors were adjusted by a factor of three to correspond to labor practices and productivity in the region. The results are summarized in Table 2.

Table 2. Estimated job generation in the energy industry (millions of jobs)

Industry	Construction	Manufacturing	Operation and maintenance
Geothermal	0.69	0.39	0.03
CSP	1.35	0.60	0.09
PV	11.43	5.88	0.60
Wind	3.36	3.81	0.33
Hydro	0.30	0.15	0.01
Total	17.13	10.83	1.03

To estimate the jobs generated by electric transport, industry data was used (AIE, 2018). For electric buses a factor of 0.1 jobs for heavy vehicle and 0.01 jobs for light vehicle were used.

Jobs related to smart grid construction, operation and maintenance it was estimated that 52,500 jobs would be generated for each US\$ 1 billion investment.



"The report identifies significant economic advantages in the parallel decarbonization of both sectors of the economy, which according to the report is becoming technical feasible and financially attractive. It also identifies priority policy actions to facilitate the required investments and transformations. This is a welcome addition to the body of work just becoming available on the costs and benefits of delinking economic activities from fossil carbon emissions."

Luis A. Moreno President of IADB



"This publication points out the exciting potential that the Latin American and Caribbean Region can move greatly toward a stabilization of greenhouse emissions by mid-century through coupling electric grid transformation with a large-scale electrification of the transport sector. The Climate Institute has for several years explored and championed the idea of a North American Supergrid to reduce U.S. power sector emissions by creating high voltage direct current links to the major alternating current-based grids. This transformation would also reduce vulnerability of the grid to devastation from solar storms, EMP attacks and extreme weather events. In the U.S., Canada and Mexico that would likely be encompassed in a full blown North American Supergrid, this transformation would enable large-scale decarbonization of the economy if it was accompanied by a wide array of measures to promote electrification of vehicles, such as improving charging facilities. I am heartened that Walter Vergara and his team have shown that in the Latin American and Caribbean Region such a coupling of power sector changes is feasible. It is our hope that someone in North America will undertake an equivalent analysis."

John C. Topping, Jr.
President
Climate Institute

UN 
environment
programme

