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Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Vergara, W., Fenhann, J. V., & da Silva, S. R. S. (2021). *The Opportunity, Cost, and Benefits of the Coupled Decarbonization of the Power and Transport Sectors in Latin America and the Carribean*.

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February 2021

ISBN 978-163795970-1

Published by

Climate Institute

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Climate Institute

ISBN 9781637959701

The Opportunity, Cost, and Benefits of the Coupled Decarbonization of the Power and Transport Sectors in Latin America and the Caribbean

by
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Published by
Climate Institute

1 Walter Vergara is a senior fellow with WRI, and was under a sabbatical sponsored by UNEP for the purposes of report analysis and preparation.

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ACKNOWLEDGEMENTS

The authors wish to acknowledge the support received from the UNEP regional climate change team in Panama, led by Gustavo Manez; the UNEP/DTU partnership team in Copenhagen, led by its Director, John Christensen; the Cooperative Institute for Climate and Satellites and the Earth System Science Interdisciplinary Center at the University of Maryland, led by its Director Fernando Miralles, and the Joint Global Change Research Institute, through its Director Leon Clarke, during the preparation of the analysis and finalization of this report.

Thanks are also due to Jennifer Layke, Alex Perera and Katie Pastor at WRI, Elizabeth Font, Maria Garcia and Esteban Bermudez at UNEP regional office in Panama for their suggestions to an earlier draft. Special thanks are due to Johannes Friedrich and Mengpin Ge at WRI for their help with information from and access to the CAIT database, to Sergio Avelleda for information from the BRT database, to Tina Huang and Emily Nilson for assistance with retrieval of information from Resource Watch, to Katherine Segura and Byron Chiliquinga for their assistance n collection of the load curves of power demand in the region and to Tulio Alves Executive Director of the Commission for Regional Energy Integration.

A word of immense gratitude as well to John Topping, Brian Fowler and Kathleen Hollister for their help in getting the report published and to Luciana Gallardo, from WRI for her assistance in editing key messages and supporting the art work.

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To our grandchildren, Gabriel Elias, Sami Aurelio, Asta Iben, Agnes, Rose Mai, while wishing their generation the opportunity of a wholesome planet.

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 IPCCC special report on Global Warming of 1.5 ºC 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. 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 out-weight 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-regret 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.

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Ministro de Medio Ambiente y Energia
Costa Rica

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Chile

January 2020

*currently, Chief Executive Officer and Chairperson of the Global Environment Facility

EXECUTIVE SUMMARY

The objective of this report[2] is to illustrate the opportunity, costs, and benefits of the coupled decarbonization of the power and transport sectors in the Latin America and Caribbean (LAC), which together account for two-thirds of fossil CO2 emissions, and about one-quarter of the total greenhouse gas (GHG) emissions in the region. These sectors are expected to more than double their emissions under business as usual conditions by mid-century. The intention is to promote awareness on the advantages of a coupled transition and in support of improvements in the Nationally Determined Contributions to the Paris Agreement (NDC ambitions).

This analysis has been conducted in the context of calls for immediate and drastic action to arrest the continuing increase of CO_2 concentration in the atmosphere, which by 2019 reached 409 parts per million (ppm) (NOAA, 2020). Global temperatures have now reached 1°C above pre-industrial levels, and at current trends, will result in a 2.5-3.2°C increase or more by the end of the 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)[3] and requests for decarbonization of economic activities.

Coupling the decarbonization process of power and transport can contribute to cost efficiency, enable synergies and interlinkages, and deliver higher economic benefits and greater mitigation impacts than through a sector by sector approach. Embarking on the road to carbon emissions-free power and transport simultaneously could also provide greater flexibility to the region's efforts to decarbonize. The report identifies policies and practical approaches and provides data to support the process.

The measures proposed in this report fit into the mold of bold climate action, as called for by the UN Secretary General and the Global Commission on the Environment and Climate (New Climate Economy[4]), 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 UN 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 transition pathway (the proposed intervention scenario) consists of actions to decarbonize both sectors by mid-century.[5] For the power sector, it assumes that all new demand will be met by a combination of renewables and, that over the course of the next few decades, all fossil fuel plants will be decommissioned and replaced by corresponding additions in renewables (mostly wind, solar, and geothermal supplemented by some

2 This report is a follow-up to the analysis released at COP 21 (November 2015) on a pathway for full decarbonization of the regional economy in Latin America and the Caribbean (Vergara, W. et. al, 2015).

3 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).

4 https://newclimateeconomy.report/

5 This scenario was first described by Vergara and coworkers in the Zero Carbon Latin America report, 2015

hydro[6]) with increased participation of distributed power and storage facilities. It also assumes regional grid integration and local decentralized energy resource deployment during the period.

For the transport sector, the pathway includes a shift to electric mode for all existing and new Bus Rapid Transit (BRT) systems in the region by 2025.[7] 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.

Even if financially attractive, transitions of this sort would face substantial policy, regulatory, and market barriers. For example, the rules for electricity generation, grid delivery, and use have been defined with fossil fuel resources in mind. The infrastructure was developed under different circumstances, without allowances for the participation of novel, intermittent sources. The marketing, 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, including from fossil fuel producers and users that would represent obstacles to otherwise desirable sector transformations.

Adding to all this, the global health emergency caused by the novel coronavirus (COVID 19) does have an important, immediate and may be lasting effect on the economy of the region. It is however quite speculative to project what long-term effects will be experienced. [8]

1. UPDATE ON THE DYNAMICS OF CHANGE

Power sector. In many respects, electricity generation in the region is already transitioning toward full decarbonization. Since 2012, the capacity for non-conventional renewables has doubled its participation in the regional matrix, and together with hydropower, accounted for almost 54% of the total in 2018. Renewables are increasingly displacing coal and other fossil fuels in the share of electricity sources. Even the growth in capacity of natural gas is slowing down.[9] 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.

The increase in participation of renewables has clipped the carbon intensity of the sector (Figure 1) from an already low value of 285 tCO2/GWh in 2015 to 243 tCO2/GWh in 2018,[10] one of the lowest worldwide. The region's power sector has a good launching pad toward full decarbonization. The energy transition is firmly in place, but it is still a long way from achieving carbon neutrality. This will require additional policy and regulatory actions, investments, technology deployment, and market developments to make it happen.

While apparently daunting, the prospects for the transition by mid-century toward a fully decarbonized sector are aided by several factors, favoring renewables as the "technologies of choice" for the region. These include:

- **a.** Installed hydropower, which can provide a baseload capacity in many of the countries, enabling an increased level of intermittent sources to participate in the power matrix; and regional, but currently disconnected, hydro-storage capacity bordering on 0.22 TWh. The firm capacity of hydropower, however,

6 Past rapid deployment of hydro is anticipated to be tempered by the limited availability of new sites and escalating environmental and social concerns.

7 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.

8 Also, while there is no direct evidence that climate change is facilitating the rate of infections of the spread of COVID-19, there is sufficient information on how changes induced by climate change alters exposure to disease. Many of the drivers of climate change may increase the risk of wide spread of diseases, for example through vectors affecting the spread of tropical disease (Zell, R., 2004).

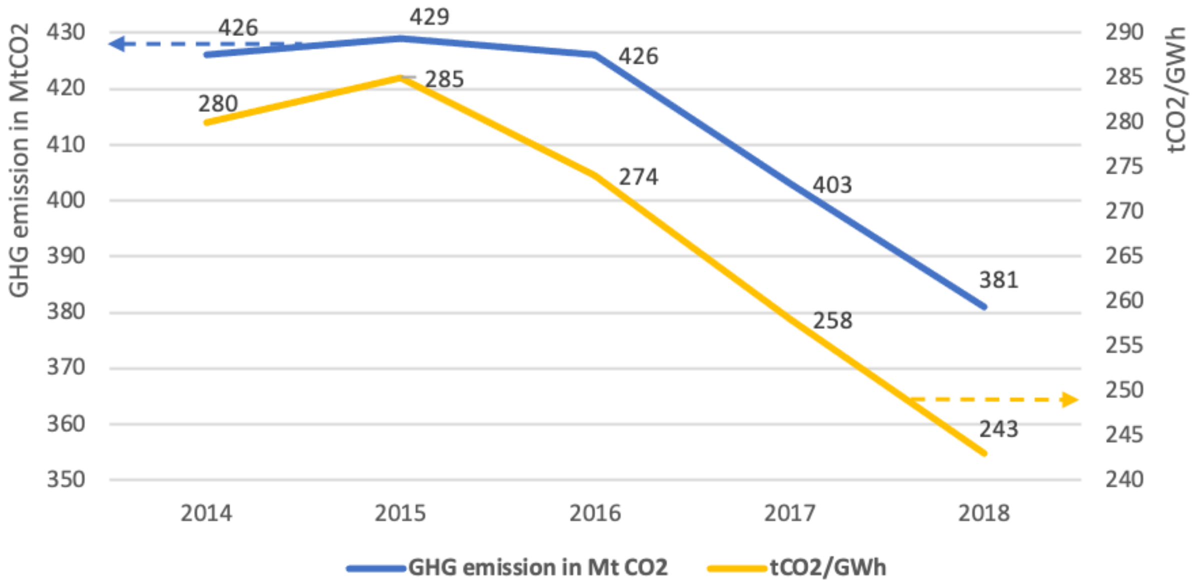
9 In the region, use of natural gas decreased by 0.4% in 2018, down from a compounded growth of 1.0 % since 2012.

10 GACMO database accessed July, 2019.

is being affected by changes in rainfall patterns,[11] raising some doubt the ability to continue to deliver the nominal installed power in the future (UNEP, 2019);

b. the global-size assets of renewable energy resources, represented by large endowments in wind fields, solar irradiance, geothermal, marine potential, and hydropower;
c. the rapid decline in installed and generation costs for most intermittent and new baseload technologies;
d. the potential for increased use of electricity from other sectors of the economy that would become viable through trends in generation costs from renewable resources and improved security of supply;
e. the potential for distributed generation in the region; and
f. improving support through ongoing policy and regulatory reform favoring entry and access of renewables to the electricity market.

Figure 1. Recent evolution of sector emissions in power generation



Source: Based on information provided by ENERDATA, accessed August 2019

Transport sector. Transport has also moved, albeit at a slower pace, toward improved energy and carbon efficiency. It remains, however, the sector of the economy with the highest fossil energy use, therefore leading in terms of fossil fuel-related emissions (15% of all regional GHG emissions in 2018[12]). 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.[13]

Eliminating emissions from this heterogeneous fleet would require enormous effort. Passenger and cargo transport use very different technologies and are driven by a different set of economic factors. Likewise, light

11 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.

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

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

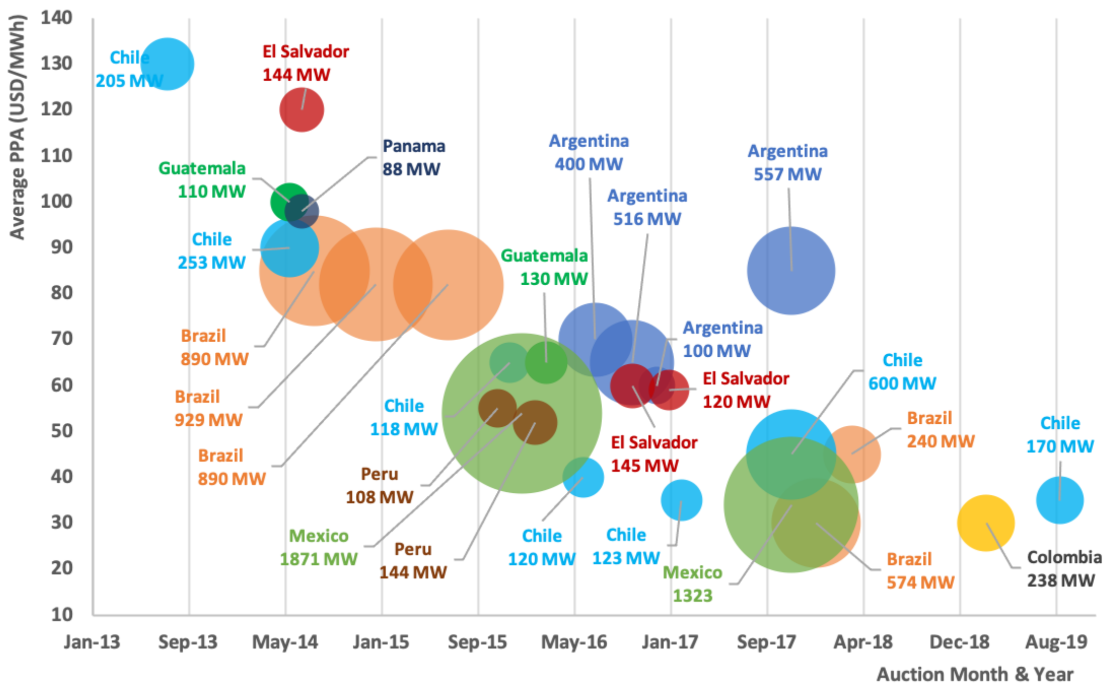
and heavy vehicles present widely different market realities. Rail and vessels operate under very different management and operations. But foremost, there is a large share of the economy that is vested in the current system of transportation and must be included in the process to facilitate the changes required. However, as in the case of electricity generation, there is an ongoing technology and market revolution that may improve the likelihood of the transition rapidly becoming a reality.

2. TECHNOLOGY AND ECONOMIC TRANSITION OF POWER GENERATION

Energy resources, technologies, and economics. Evidence is mounting on the size, quality, and relative competitiveness of the renewable resources available in the region. The potential for generation of electricity using renewable resources is immense. There are 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 in the region. Furthermore, dispersed solar, geothermal, and wind fields favor the utilization of distributed generation.

The efficiency, reliance and cost of renewable options have made some renewable resource technologies already financially attractive. The report reviews prices under recent auctions and power purchase agreements (PPAs) in the region (Figure 2) and projects current dynamics up to 2050, making use of current trends. Bids for new power generation capacity have been suspended or postponed recently by the impacts on demand caused by the health emergency. However, the assessment makes the judgment that in the longer term both increases in demand and a continuation of reduction in bid prices will resume.

Figure 2. Evolution of bid prices for utility-size PV projects in the region



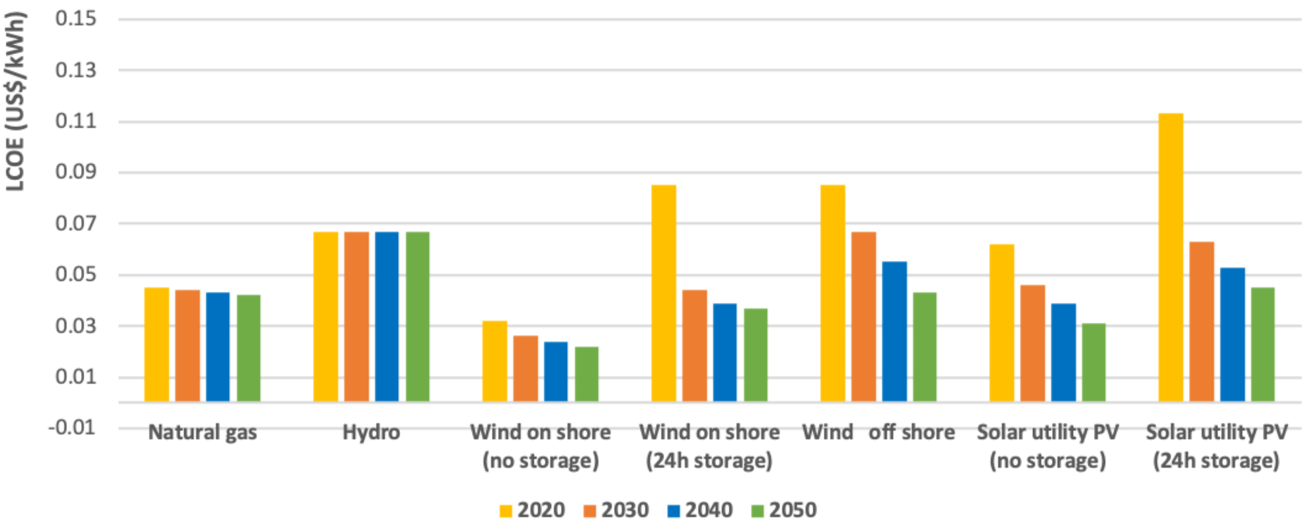
Source: Based on compilation by Nagendran S., 2017 and recent industry data.

The report finds that the costs of power generation from onshore wind and solar photovoltaic (PV) already outperform natural gas and coal, while offshore wind and PV with storage are expected to do so before 2030.

Hydropower and geothermal generation 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 Levelized Costs of Electricity generation (LCOEs; Figure 3) 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 for new coal plants to 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, and even if the differences today are small, investments in natural gas capacity already appear not to be competitive. The deployment of PV and wind with storage capacity is anticipated to also become competitive with natural gas and provide firm capacity to these technologies. New advances have the potential to accelerate the competitiveness gaps.

Figure 3. Projected LCOEs of renewables vs. natural gas (US$/kWh)



Source: Author's estimates using GACMO outputs

3. TRANSMISSION AND DISTRIBUTION

Transmission infrastructure is a critical element of the transition process. The report finds that the management, structural, and resource elements to support a smart regional grid are already present in Latin America. The market operates in a relatively efficient manner, under a competitive environment. Also, the region already possesses key elements of an integrated grid, a substantial hydropower storage capacity, renewable resources, and complementary conditions between hydro, solar, and wind. There are still gaps, elements, and policy instruments missing that could be used to accelerate the transition toward a smart regional grid.

It 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:

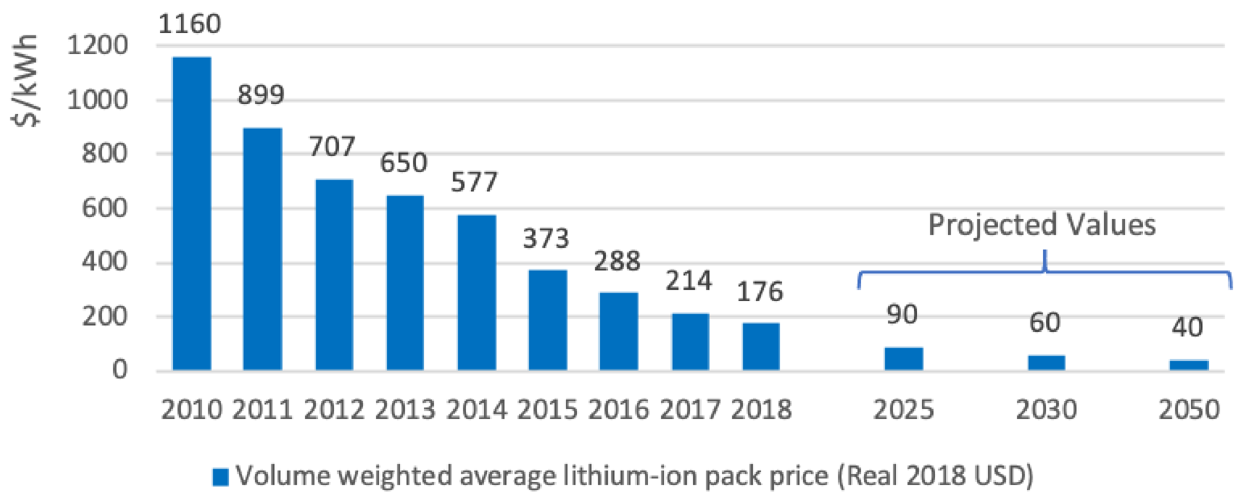
- **a.** be able to accept large shares of intermittent or variable renewable energy sources to dampen fluctuations and take advantage of existing complementarities between energy endowments;
- **b.** provide a link between major reservoirs in different climatic zones (areas with complementary pluviometry), 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 distributive 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; and
g. enable a high level of market transparency with clear rules of access and open competition.

4. ELECTRIC TRANSPORT

Substantial and continuing decreases in energy storage (Figure 4) and electric vehicle costs make it 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; and e) on the software side, demand management of transport fleets.

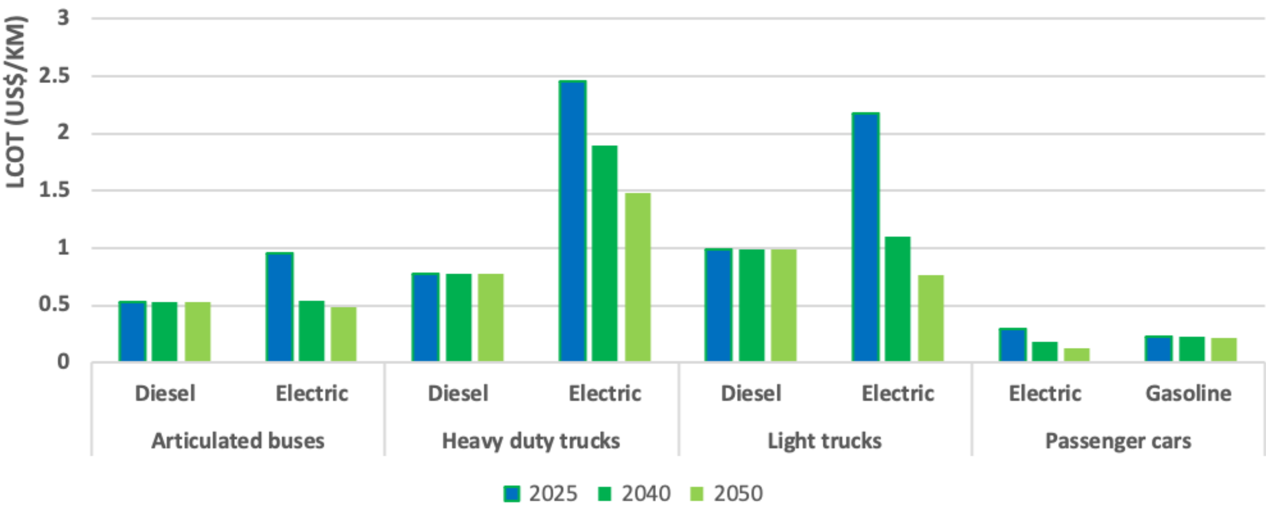
Figure 4. Recent and projected costs for battery packs for electric vehicles (US$/kWh)



Source BNEF, 2019; and author's estimates.

Future costs of electric transport, measured through Levelized Cost of Transport (LCOT; Figure 5) have been projected, based on recent developments, to quickly outperform internal combustion (IC) vehicles. These developments 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 cost of electric truck maintenance has also been incorporated. Assumptions for internal combustion vehicles have been revised to account for new projections in the price of liquid fossil fuels. A summary of the assumptions used in the analysis is described in Annex 10. It is now widely anticipated that some electric vehicles will reach cost parity and, in some cases, outperform internal combustion vehicles between 2025 and 2030 further increasing their economic advantage by 2050.

Figure 5. Projected LCOTs for electric vs internal combustion vehicles (US$/km)



Source: Author's estimates based on GACMO outputs

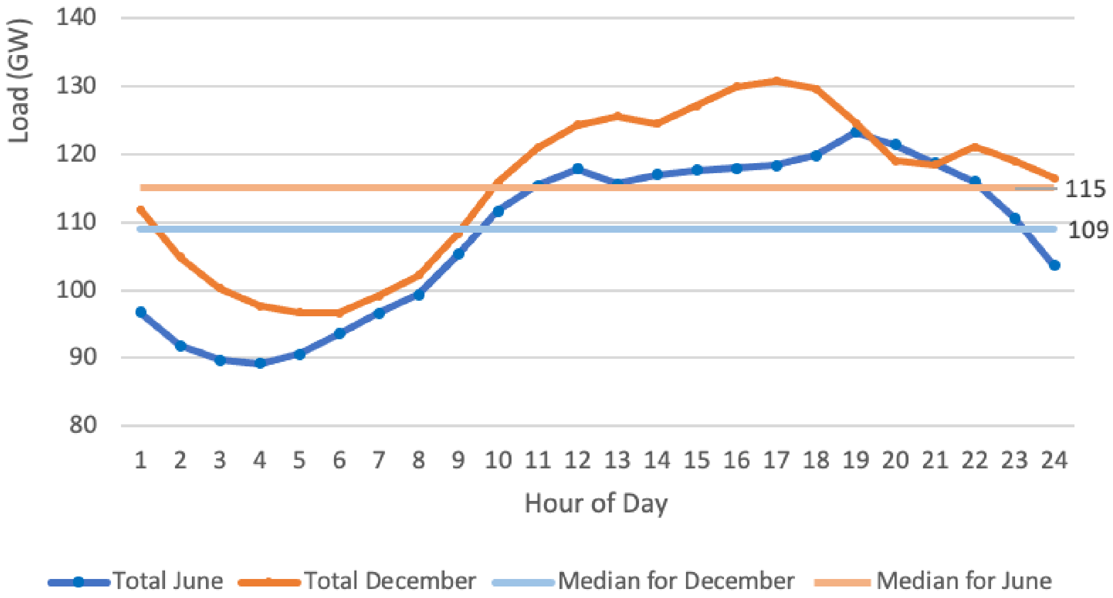
5. CHALLENGES AND OPPORTUNITIES FOR A COUPLED TRANSITION

Energy security. A secure energy system can be characterized as having a diverse blend of energy sources; a reduced carbon footprint; access to local or domestic supply; resiliency to external impacts; and capacity to respond to emergencies. While it is difficult to monetize all these aspects, it is clear, however, that failure to ensure adequate electricity supply can result in serious disruptions to the economy. It has happened in the past.[14] The intervention scenario relies on a diverse renewable power matrix that distributes and reduces risks of disruption, for example, in hydropower supply. It also minimizes the energy imports other than through an integrated grid and eliminates fossil fuel use for power generation and transport.

Impact on power sector loads and size. The entry of a large electric fleet in the region would add additional power demand. The power requirements of electric transport have the potential to destabilize the grid. The additional load, if not properly managed, will require additional expensive capacity to meet peak demand or large storage options. The problem can also be appreciated by examining the aggregated load curve for the electricity system in Latin America, prepared assuming full integration at a regional level (Figure 6). Similar conditions prevail at a national level.

14 For example, in Colombia, serious shortages of energy were caused by an intense ENSO during 1992-1993, resulting in the depletion of hydropower reservoirs and triggering major losses for the economy for an extended period of time. 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.

Figure 6. 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.

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. 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. The use of the valleys in the load curve (demand flexibility) has been estimated to equal about 10 GW of equivalent capacity. Some of the demand will be conveyed through the commercial and residential sectors for light vehicles and through the industrial and commercial sector for heavier and cargo vehicles, increasing the electricity demand in those sectors.

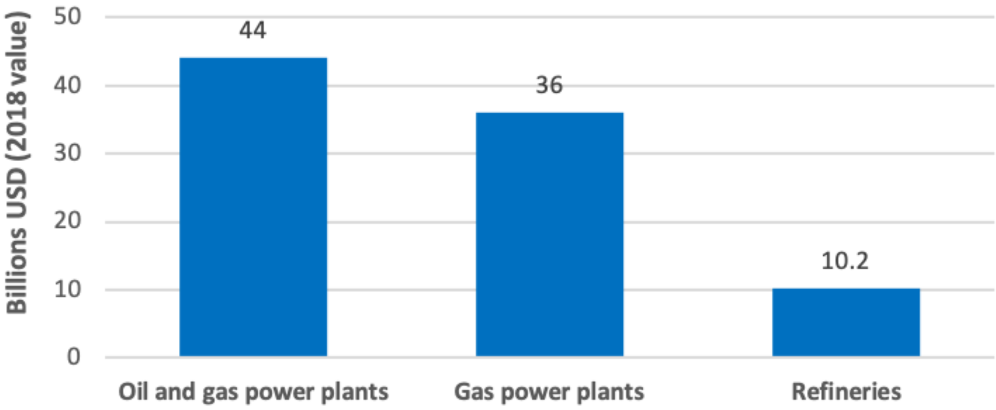
Health benefits. The mass electrification of transport in urban areas would eliminate the emissions of particulate matter (PM), a proven human health risk factor, from mobile sources, mainly by eliminating diesel fuel in transport. It would also lower ozone formation by eliminating emissions of volatile organic compounds and NO_x. These reductions in emissions and exposure translate into avoided cost of illnesses and overall reductions in morbidity and mortality.

Impact on refining operations. The projected decrease in the demand for gasoline and diesel will reduce the need for most refinery operations. 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.

Stranding of capital assets. 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. Consequently, there would be an impact on the use and value of associated production, refining, transportation, and distribution infrastruc-

ture. The report estimates the economic consequences of the transition caused by displacement of some of these capital assets in the region. This is done by estimating the value lost in capital assets made obsolete (Figure 7).

Figure 7. Estimated residual value of assets in power generation and refining at projected time of retirement (in billion US$ 2018)



Source: Author's estimates

Net oil, gas, and coal exporters would also incur a loss in the value of reserves. But 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. Whether decarbonization takes place at a pace consistent with the urgency of the climate crisis, or on a slower timetable, there is consensus that most of the existing fuel reserves for gas, oil, and coal will not be developed. It is therefore important for countries in the region with large fossil fuel reserves to start developing and implementing divestment and alternative development policies.

6. ECONOMIC COSTS AND BENEFITS OF A COUPLED DECARBONIZATION

Reduced capital requirements. Converting to a fully renewable system under the assumptions indicated above are estimated to require cumulative investments to the order of U.S. $800 billion (2018) and deliver zero CO_2 emissions. This is lower than the investment required to meet the projected demand of energy under a business as usual reference scenario by mid-century (US $962 billion (2018)). The investment associated with a scenario that instead includes heavy reliance on carbon capture and storage to achieve carbon neutrality would be considerably higher (U.S. $2,100 billion (2018)). Clearly a pathway that takes advantage of the competitiveness of renewables in the region is less capital-intensive.

Lower electricity costs. The lower capital and operational costs associated with wind, solar, geothermal, and hydropower are anticipated to result in lower electricity generation costs. The projected LCOE under the intervention scenario by 2050 is estimated to be $0.048/kWh.[15] The estimated cost of generation under the baseline scenario is $0.097/kWh. Shifting to a renewable energy matrix would result in significant savings in electricity costs to the regional economy. The reductions in generation costs would be directly eventually accrued by all consumers of electricity, making manufacture more competitive and delivering savings to households.

Combined lower energy demand. As the energy efficiency of electric drives is three times higher than for

15 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.

internal combustion (IC) engines, the energy demand of the transport sector under the intervention scenario is much lower compared to the BAU scenario. Transitioning the transport sector to electric drives is calculated to represent savings of the order of 11 EJ by mid-century. On the other hand, electrification will add to the capacity and investment requirements of the power sector. The transition to electric transport has the net effect of reducing total energy demand in the region while increasing future power requirements. Meeting the additional power requirements from a fully electrified transport sector by a fully renewable power sector, as opposed to the BAU power sector, would also yield additional savings estimated at U.S. $ 103 billion.

Avoided cost of illness. The elimination of diesel use in urban areas, where exposure is concentrated, is conservatively estimated to trigger annual avoided health costs at U.S. $30 billion (2018) by mid-century.

The combined costs, benefits, and avoided costs of the coupled transition are summarized in Figure 8.

Figure 8. Combined costs, benefits, and avoided costs by mid-century under a coupled power and transport zero emissions pathway (in US billion dollars, 2018).[16] Cumulative impact on capital assets

Reduction in capital investments in the power sector:	162 billion
Reduction in capital investment to meet power demand by electric transport :	103 billion
Value of stranded assets in the power sector:	80 billion
Value of stranded assets in the refinery sector:	10 billion
ANNUAL SAVINGS IN 2050	
Savings in electricity cost :	222 billion
Reduction in annual costs of passenger road transport :	328 billion
Reduction in annual costs of cargo road transport:	41 billion
Avoided cost of illness:	30 billion

Source: Author's estimates Source: Author's estimates

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 $175 billion. The savings represent a reduction in the costs of products and services (a reduction in GNP) that results in a net increase in economic efficiency and welfare.

7. JOBS, EDUCATION, 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. Public and private educational institutions will need to develop specific courses, in a wide range of disciplinary backgrounds, including engineering, energy analysts, economics, and planning for the new industries. 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.

16 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.

The gains in employment resulting from the transition in the power sector is estimated at 28 million job-years during construction of new facilities and 1.0 million of permanent maintenance and operation jobs. The loss of jobs in the fossil fuel industry are estimated at 3.0 million job-years from the avoided construction of fossil fuel facilities and 0.04 million permanent jobs associated with their operation and maintenance. While the net gains are clear, there is a need to re-train those fossil fuel industry workers in skills relevant to new job opportunities that will arise with the transition.

Grid modernization activities are estimated to result in the creation of 3.4 million jobs while the assemblage, maintenance, and ancillary services linked to the electric fleet would result in 2.9 million jobs, for a partial total of 7.7 million jobs resulting from the coupled transition of power and transport.

8. POLICY OPTIONS FOR AN ACCELERATED TRANSITION

Generally, the policy environment has evolved throughout the region in support of a cleaner power matrix, low carbon resilient development, and a cleaner transport system. There is also an overall positive posture in support of climate mitigation and adaptation action in most countries, and widespread public support for measures addressing climate change. The trends in technology and economics have contributed to the growth in the use of renewables 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 necessary a strong, bold policy agenda. The policy goals and the elements of such agenda are summarized below.

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

Goal	Policy	Instruments
Reduce the cost of stranded assets in the power generation and refinery sector.	Discourage capital investments in the fossil industry.	Clear energy and transport policy adopting zero emission goals by mid-century. Enact sunset provisions to encourage early retirement of assets.
Promote more flexibility, storage capacity, and integration of distributed options to ensure that variable resources can operate in a cost-effective manner.	Promote investments in a modern, smart transmission and distribution infrastructure.	Clear regulations on demand management and the use of storage, net metering and distributed options.
Optimize allocation of generation and transmission infrastructure to meet demand.	Promote regional grid integration	Market-based power exchange with neighboring countries. Eliminate regulatory barriers to grid integration.
Internalize health and climate costs in transport emissions.	Develop fiscal measures that enable allocation of the costs of health and climate impacts to those generating emissions.	Fiscal measures to pass costs to emitters of airborne pollutants and GHGs. Use revenues to promote public investments in enabling infrastructure
Encourage level playing field for use of renewables and electric transport	Promote economic competition of new technologies with fossil fuels.	Eliminate subsidies for use of fossil fuels
Facilitate market entry of electric transport.	Direct the removal of regulatory and policy barriers	Adopt standards for charging. Review/modify road standards. Enact transit and parking preferences. Regulate composite fleet emissions.
Promote technology and business development in support of the transition.	Promote investments in R&D and technology development in zero carbon technologies	Technology and science policy in favor of zero emission goals by mid-century. Fiscal measures to support investments in R&D.

There is an opportunity for sizable economic and climate benefits in the coupled decarbonization of its power and transport sectors. It can lend support to strengthened NDC ambitions. It represents a pathway that would deliver climate goals and sustainable development goals at net economic benefits without negatively affecting access to, or quality of, services.

CHAPTER 1

Introduction

Despite the signing of the Paris Agreement by most nations, in late 2015, global emissions of greenhouse gases have continued to increase. At the start of 2019, CO_2 concentration in the atmosphere reached 409 ppm (NOAA, 2019) with emissions sized at 53 GT CO_2e per year (Mc Cracken, 2019). This level of CO_2 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 now reached 1°C above pre-industrial levels and at current trends, will result in a 2.5 to 3.2 °C rise or more, by the end of the century (IPCCC, 2018; W. Steffen et al, 2018, UNEP Emissions Gap Report, 2018). 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).[17]

Also, additional evidence has become available on the changes and disruption in the global climate system affecting the Latin America and Caribbean 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

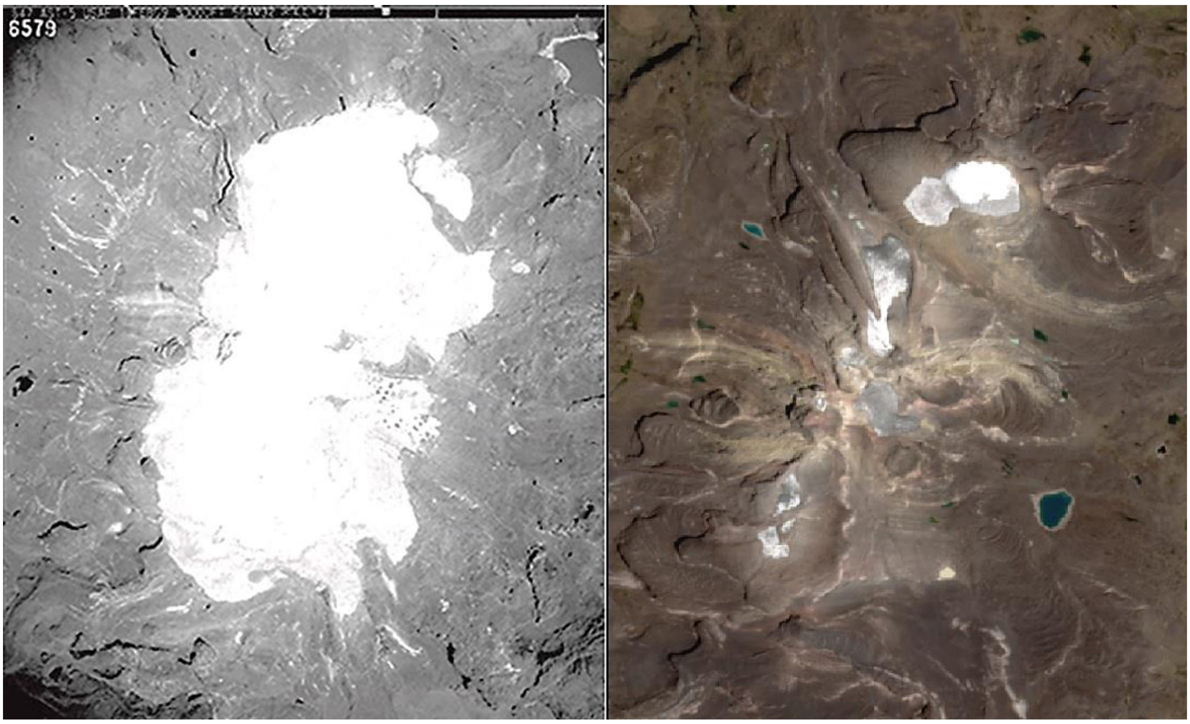
17 Global peaking of emissions by 2020 is crucial for achieving the temperature targets of the Paris Agreement, but the scale and pace of current mitigation action remains insufficient. (Emissions Gap Report 2018, UNEP).

at under 5000 m (Figure 1). Also, there is increasing awareness of the impacts of the intensification of extreme weather events over the coasts of Central America, Mexico and the Caribbean nations. 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.

Adding to all this, the global health emergency caused by the novel coronavirus (COVID 19) does have an important, immediate and may be lasting effect on the economy of the region. It is however quite speculative to project what long-term effects will be experienced. [18]

The Intergovernmental Panel on Climate Change (IPCC; Allen et al 2018) and others (McCracken, 2019) have concluded that only forceful and immediate actions to stop emissions will now 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[19]) and are being embraced by a growing number of nations in Latin America.[20] 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.

Figure 1: Satellite photos of Santa Isabel Glacier in the central range of the Colombian Andes (1958 and 2018)



Source: Ceballos, J.L., 2019

18 Also, while there is no direct evidence that climate change is facilitating the rate of infections of the spread of COVID-19, there is sufficient information on how changes induced by climate change alters exposure to disease. Many of the drivers of climate change may increase the risk of wide spread of diseases, for example through vectors affecting the spread of tropical disease (Zell, R., 2004).

19 https://initiative20x20.org/news/buenos-aires-declaration-restoration

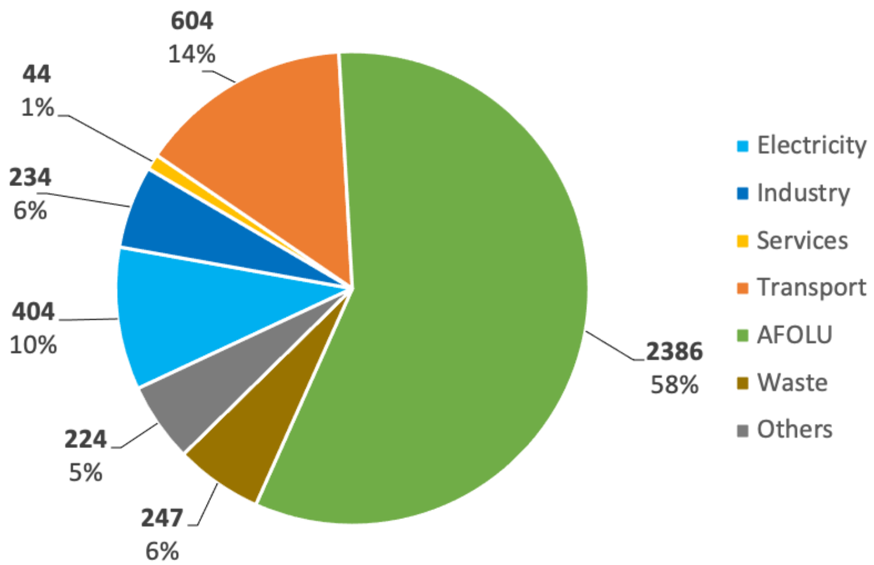
20 For example, Costa Rica, Uruguay, Chile, and Colombia have all announced steps toward complete decarbonization.

The objective of this report is to illustrate the advantages, costs, and benefits of the coupled transition of the power and transport sectors, which together account for two-thirds of fossil CO2 emissions, and about one-quarter of the total GHG emissions in the region. The intention is to promote awareness on the opportunity of a coupled transition that could be of support for improvements in the Nationally Determined Contributions to the Paris Agreement (NDC ambitions).

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 does have a relatively small contribution in the global carbon footprint. Since 2012, the regional emissions have decreased from 4.6 GT CO_2e to 4.3 GT CO_2e by 2017, despite an upsurge in deforestation.[21] Land use and land use change continue to command the largest and growing fraction of its emissions, only made bigger with the contribution from recent forest fires and thus this sector demands priority attention in efforts to decarbonize the economy. Still, the region has a significant and growing carbon footprint in its transport sector (Figure 2), as well as a comparable emissions footprint from the power generation sector that together account for two-thirds of emissions of fossil CO_2. Both sectors present opportunities for rapid, environmentally sound and financially attractive action.

Figure 2. GHG emissions in LAC (2017) in MT CO_2 e



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

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

21 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.

would necessitate their import or production even if the power sector were to completely transition to renewable sources. Therefore, decarbonizing the power sector today is not sufficient to move the economies much closer toward zero fossil CO_2 emission status. If other sectors of the economy, could simultaneously transition to electricity as this sector is decarbonized, the process could advance much further.

The region has an expanding power sector, which added about 80 gigawatts (GW) of installed capacity between 2012 and 2018. It 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. 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 activity concentrated in cities and well-known patterns of cargo transport, also provide initial conditions for an alike evolution of the sector. Both sectors account for almost a quarter of the region's total GHG emissions. In the short-term the demand for services in both sectors will be affected by the reduction on economic activity induced by the global health emergency and this may reduce emissions in the region for a while[22]. While this is no indication of a lasting change, the recovery response of the region could offer an opportunity to change directions toward less-carbon dependent economies.

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.[23]

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, and renewable energy technologies. The marketing, 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 indus-

22 But, sulfur emissions are also being reduced which could offset the net effect. Also, any drop in emissions, even in a scenario in which the pandemic lasts through 2021, won't have much of a lasting effect on climate change.

23 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.

trial 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.

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. Some have included in their Nationally Determined Commitments (NDCs),[24] concrete goals in emissions reductions of GHGs, including goals in renewable energy and electric transport (see full NDC list at https://www4.unfccc.int/sites/NDCStaging/Pages/Search.aspx?k=latin%20america).

Further, experiences in a few countries may be seen as 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. A more granular analysis of these country situations would provide additional data on the potential to reach the zero-carbon emission goals and the actions required to get there.

This is the rationale for the current report. The goal is to increase awareness on this opportunity 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 seen as a continuation of the previous document, published in 2015 (Vergara W. et al, 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.

24 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 2

Context

The Status of the Power and Transport Sectors

This chapter summarizes the dynamics of energy supply and demand in these sectors of the economy. It also looks at the carbon intensity of power generation and for transport, the carbon emissions by mode. It concludes with a summary of expectations of future demand and projected carbon emissions, under a BAU scenario, as defined under the GCAM modeling framework.

2.1 POWER SECTOR

a. Recent trends in the region

Demand for electricity is growing at a moderate pace, driven by demographics, improved access, and increases in the overall standard of living. LAC's Power generation in 2018 is estimated at 1.57 PWh,[25] which represents a 7% increase since 2012. This level of generation is equivalent to about 6% of global electricity generation (26.6 PWh),[26] for a region with 8.5 % of the global population.

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

25 Data from GACMO, accessed July 29, 2019. The demand seems to have increased to 1.69 PWh by 2019 (https://www.statista.com/statistics/985064/electricity-generation-latin-america-country/)

26 BP Statistics, 2019.

power generation matrix is changing. There has been a substantial increase in installed capacity of non-conventional renewables.[27]

Specifically, the gains for solar and wind have been the result of: a) lower equipment, operation, and management costs (discussed in more detail in Section 4); technological and efficiency improvements, including capacity to store energy; b) awareness of the negative impact of fossil fuel-driven power plants on the environment; and c) more forceful policy commitments, in many of the countries in the region.[28] The net result has been a further reduction in the carbon intensity of the sector, making electricity generation in LAC one the least carbon-intensive worldwide.[29]

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.

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 (tCO2/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.

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

28 A review of policy frameworks can be consulted in Vergara W. et.al., 2015, referred to as Zero Carbon LAC version 1.0).

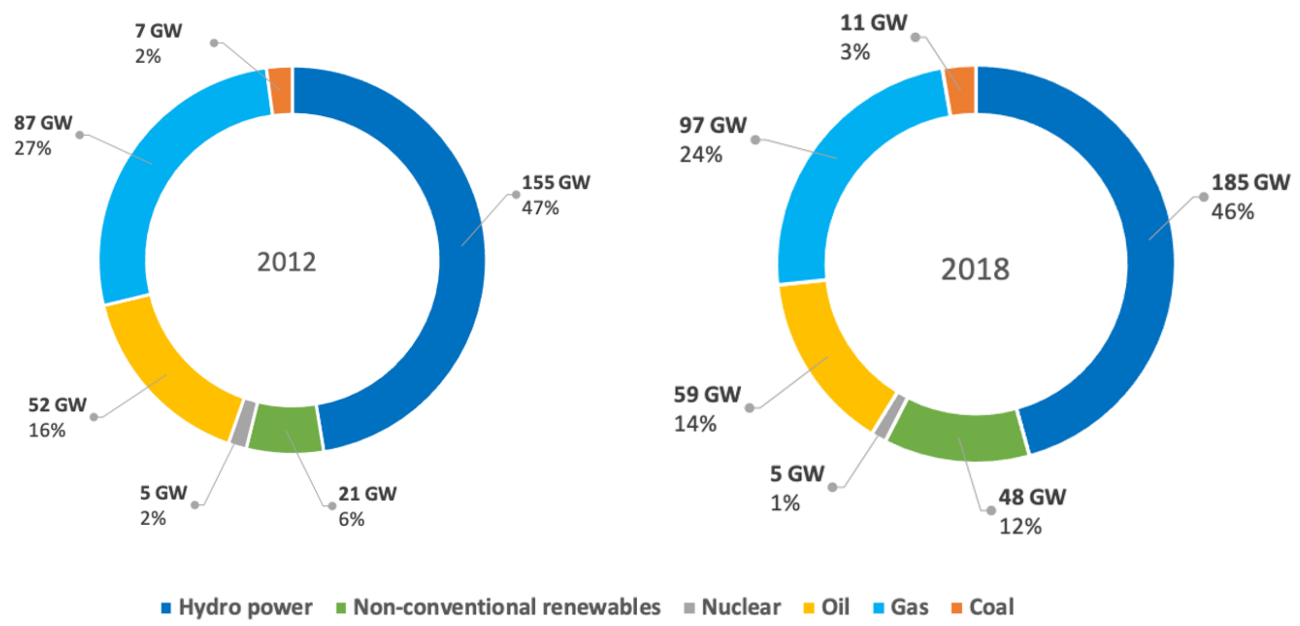
29 A few countries in other regions have lower carbon footprints, but LAC has the lowest footprint worldwide.

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%)[30] and comparatively high with respect to most developing regions.[31]

b. Sources of electricity and carbon footprint of the sector in the region

Currently, most of the installed capacity is in hydropower. But, since 2012 the capacity for non-conventional renewables, has doubled its participation in the regional matrix, and together with hydropower, now account for almost 54% of the total in 2018 (Figure 1). Renewables are increasingly displacing coal and heavy fossil liquid fuels in the share of electricity sources. Even the growth of capacity in natural gas is being checked.[32] In the region, use of natural gas decreased by 0.4% in 2018, down from a growth of 1.0 % since 2012.

Figure 1. Evolution in composition of electricity generation capacity by source (2012 to 2018)



Source: from data in ENERDATA, accessed August 2019

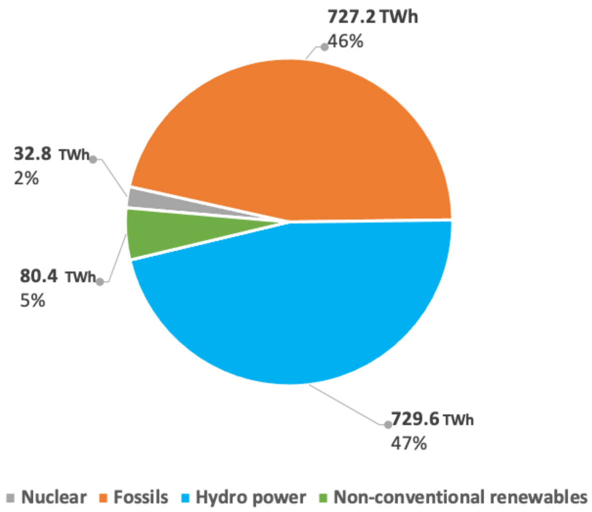
The share in total generation can be seen in Figure 2. Renewables now provide 57.5 % of the total. Some countries in the region have reached or are in the process of attaining 100% renewable power and more are aligning actions and policies toward this goal.

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

31 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/)

32 Worldwide, natural gas production and consumption increased by 5.2% in 2018, double the 10-year average growth. In the region, use of natural gas decreased by 0.4% in 2018, from a growth of 1.0 % during the same period (based on data presented in BP Statistics, 2019).

Figure 2. Composition of electricity generation in 2018 by source

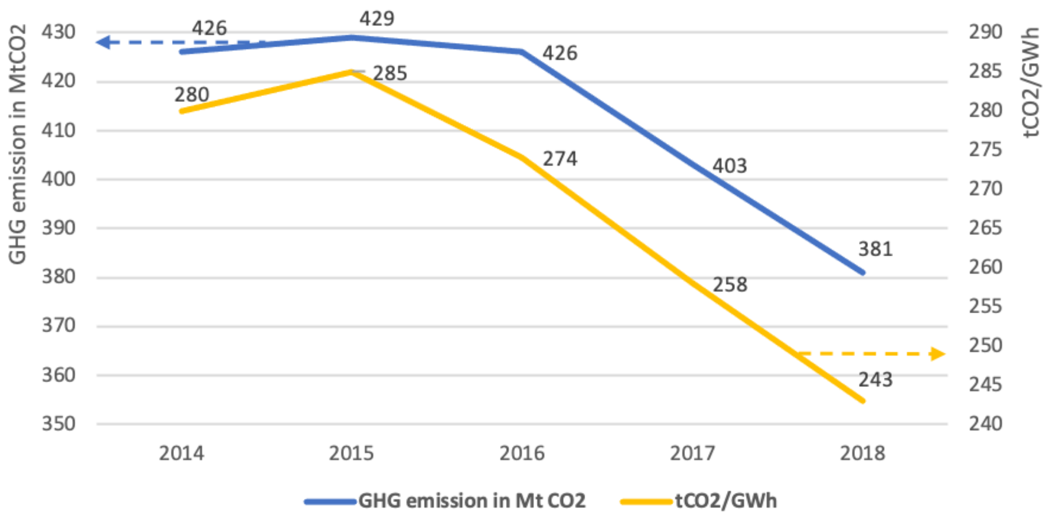


Source: from data in ENERDATA, accessed August 2019

The new capacity structure has led to a reduction in CO_2 emissions. 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 is firmly in place.

The increase in participation of renewables has clipped the carbon intensity of the sector, from an already low starting point of 285 tCO_2/GWh in 2015 to 243 tCO_2/GWh in 2018,[33] making the region a world leader in low-carbon power generation. An efficient and low carbon matrix is a strong argument to electrify other economic activities, like transport. It offers opportunities to couple the transition of other sectors of the economy toward complete decarbonization. The region, in its power sector, has a good launching pad toward full decarbonization.

Figure 3. Recent evolution of sector emissions in power generation



Source: Based on data from ENERDATA, accessed August, 2019

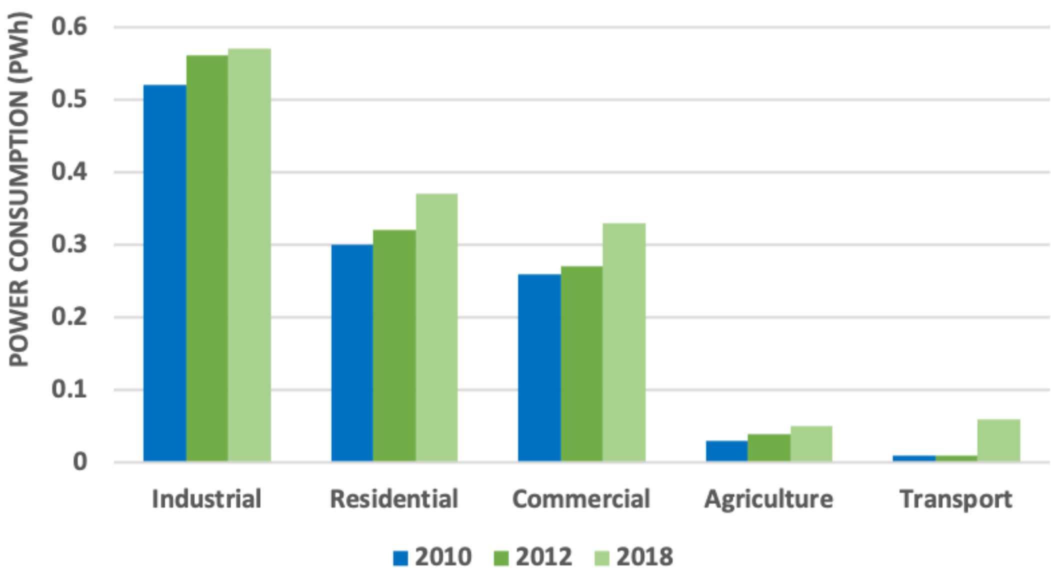
33 GACMO database, accessed July, 2019

However, contrary to the overall regional situation, the Caribbean's main source for electricity continues to be fossil fuels with an 82% share (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.

c. Sector use

Electricity is used in varying 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 light and passenger electric vehicles.

Figure 4. Recent evolution of electricity use by sector (PWh)



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

d. 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 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).

A second subset has a majority of renewables in its power sector, on the basis of 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
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
Jamaica	34	3	9	0	2.0	0.67
Total Region		1570				

Source: 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 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.

e. Future demand

Growth in electricity demand is expected to be driven by increases in standard of living, demographics, 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 (5.0 PWh). This is a substantial increase in demand that will require lasting investments in power infrastructure (generation units, transmission infrastrcucture). For purposes of this analysis, the no-intervention scenario is based on the reference scenario from the Global Change Assessment Model[34] (GCAM 5.1.3: http://www.globalchange.umd.edu/gcam/). 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.[35] A summary description of the model and its capabilities can be found in Calvin et al., 2018. In addition, the GCAM RCP 2.6, which reflects conditions resulting in no more than an end-of-century 2.0 °C temperature anomaly is also used for comparison purposes.

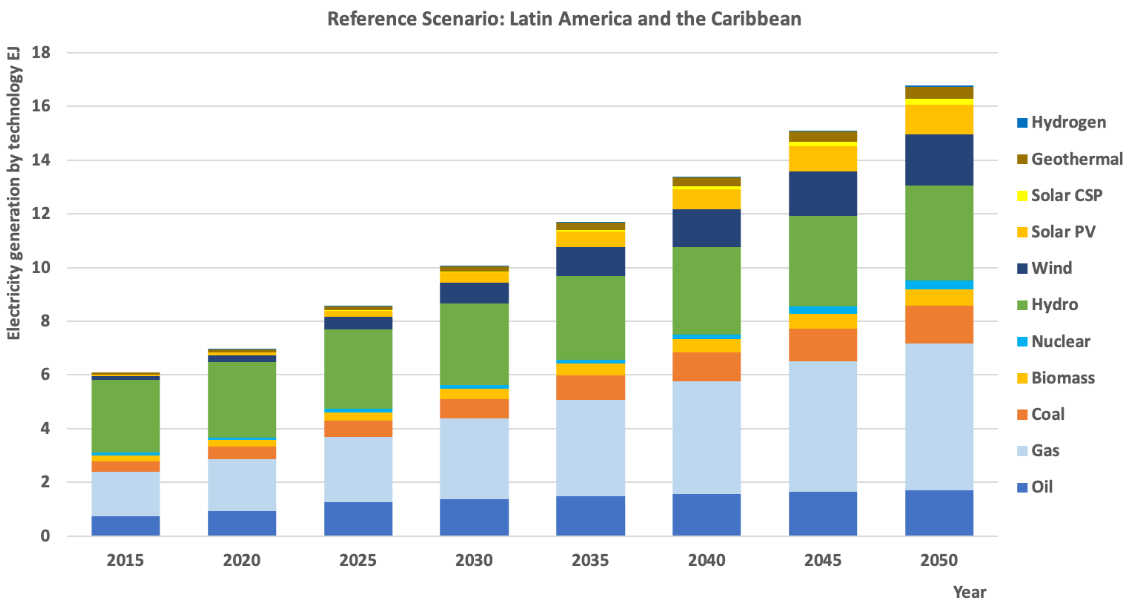
34 A description of the GCAM model and on-line documentation are available at: http://jgcri.github.io/gcam-doc/

35 The reference scenario assumptions for socioeconomic conditions are consistent with the SSP2 pathway.

The projected regional demand reaches 16.7 EJ (4.6 PWh) under the GCAM BAU scenario (Figure 5). 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 as a whole. The projected electricity generation in these geographies under the GCAM BAU scenario is included in Annex 1.

The intervention scenario would lead to zero emissions from the power sector by 2050, while meeting a projected demand of 16. 7 EJ as projected under GCAM BAU. 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 in the region, under an open market environment. It also reflects an expectation for further gains and a reluctance by market actors to invest capital in facilities that would face an uncertain economic future. The scenario assumes that all coal and oil derivative power plants will be mothballed by 2030, as well as all the natural gas plants by 2050. A more detailed description of the intervention scenario is included in Annex 1.

Figure 5. Projected electricity generation by technology under GCAM BAU

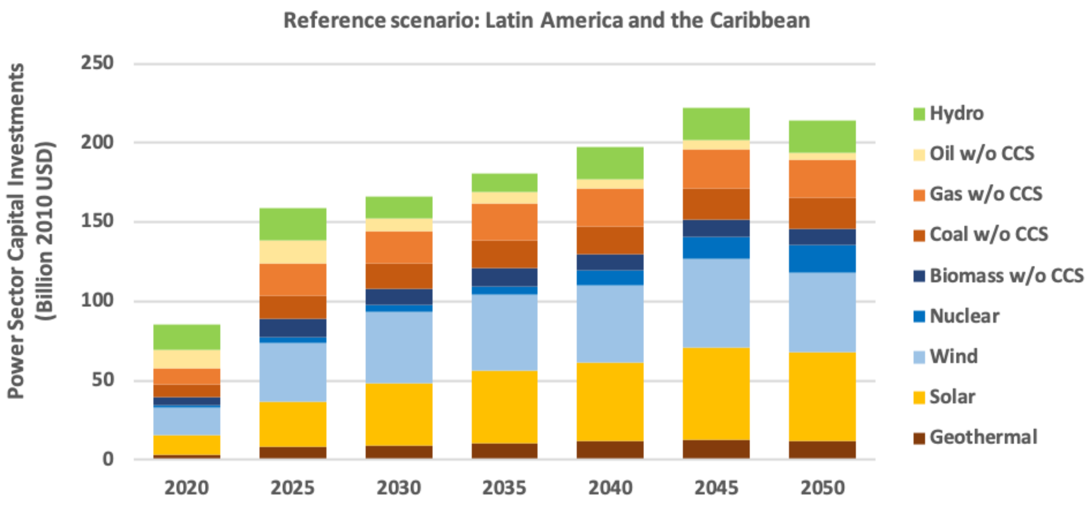


Source: As projected under GCAM BAU outputs, November 2019

The associated investments 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)[36] (in Figure 6, this is equivalent to US $962 billion (2018)). Out of this total, investments in fossil fuel power capacity would total US $365 billion (2010) (US $420 billion (2018)), with about 70% invested into new coal and gas power plants. This would be a major outlay of capital, on a technology that faces strong competition and sunsetting pressure in order to meet climate goals.

36 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.

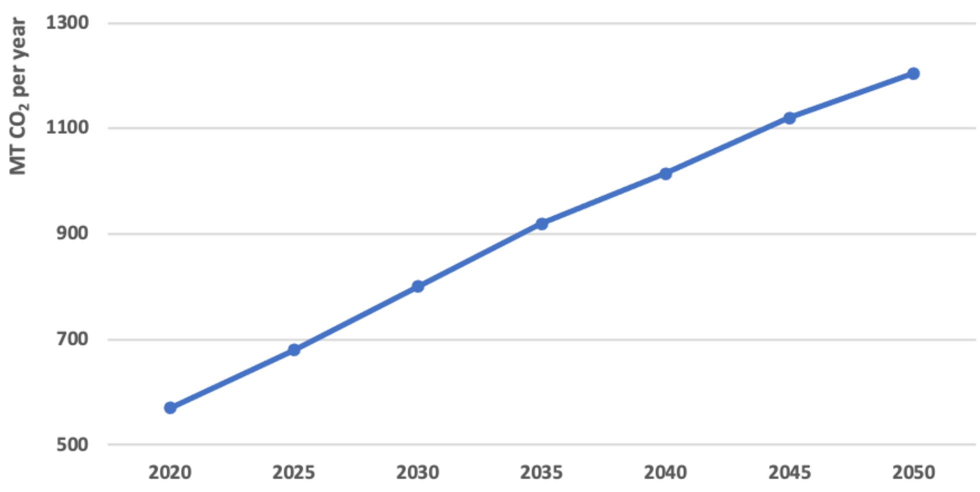
Figure 6. Capital investment in the power sector, by 5-year periods, until 2050 under GCAM-BAU



Source: As projected under GCAM BAU outputs, November 2019

Under the GCAM reference scenario, fossil sources of electricity generation would generate about 60% of the electricity by mid-century, with natural gas tripling the electricity delivered in 2018. Renewable sources and hydro would increase in capacity but only represent 47% of the total capacity installed. Most of the new capacity would still be provided by natural gas. Any climate impacts on Installed hydropower facility are not considered. As a consequence, emissions would increase from about 500 million tons of CO_2 in 2017 to 1200 million tons by mid-century (Figure 7).[37] This is a future that cannot be afforded if the region is to meet the goals of the Paris Agreement.[38]

Figure 7. Projected emissions from the power sector under the GCAM BAU scenario



Source: As projected under GCAM BAU outputs, August 2019

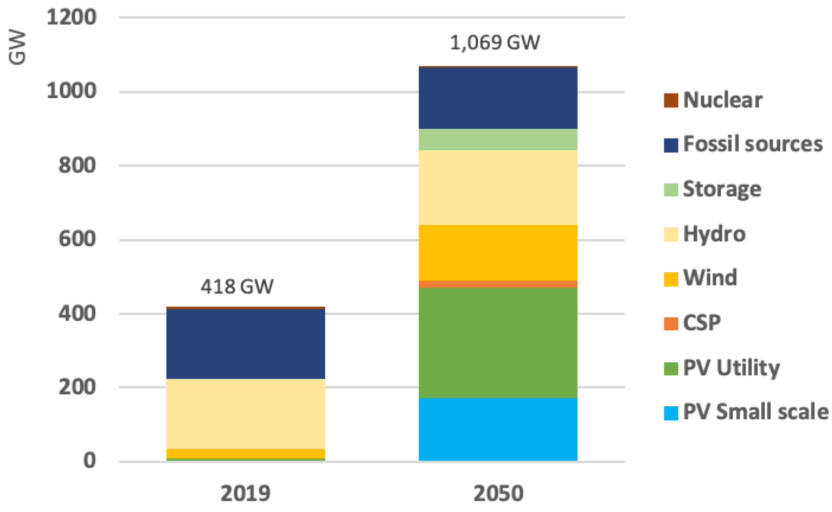
37 GCAM overestimates the 2017 emissions of the power sector by about 20% when compared with data from ENERDATA, compiled through GACMO.

38 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.

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. The investments associated to this pathway were estimated at US $1.9 trillion (2010) (US $2.2 trillion (2018)).

A recent regional projection (BNEF, 2019) that takes into account 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 the demand side flexibility (figure 8). 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.

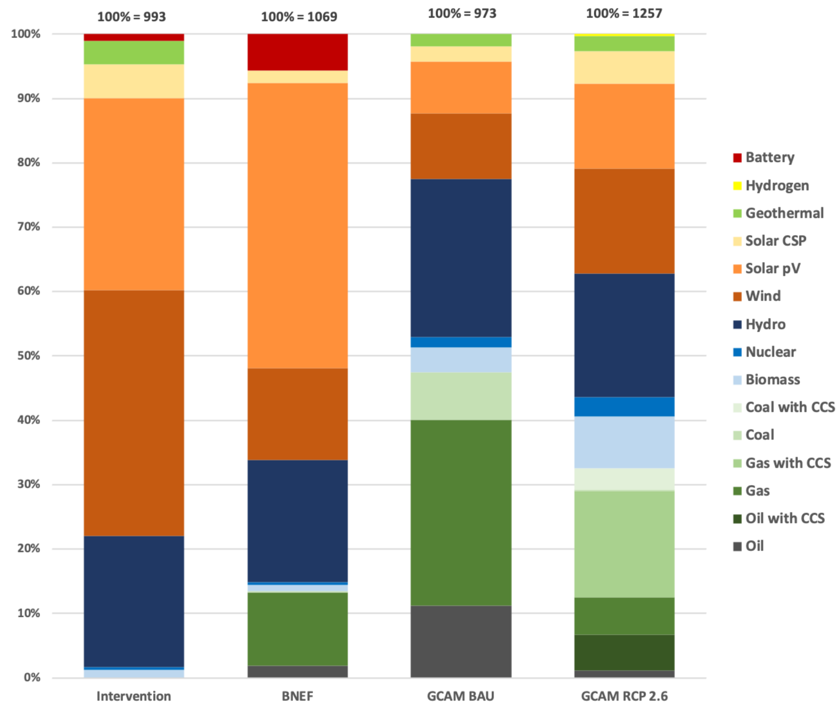
Figure 8. Bloomberg's New Energy Outlook: Total installed capacity in the region by mid-century



Source: Adapted from BNEF, 2019

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 9.

Figure 9. 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.

While apparently daunting, the prospects for the transition by mid-century toward a fully decarbonized sector are aided by a number of factors, which could strengthen 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,[39] raising some doubt the ability to continue to deliver the nominal installed power in the future (UNEP, 2019);
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 and new baseload 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; and
f. improving support through ongoing policy and regulatory reform favoring entry and access of renewables to the electricity market.

39 A UNEP publication (UNEP, 2019) 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.

These aspects will be discussed in subsequent sections of the report.

On the other hand, the fossil fuel industry has considerable assets and investments in the region and an accelerated transition will affect its market share and income, stranding assets of considerable value already in place. Within this context, natural gas, which has abundant reserves in the region, has been proposed by some in the industry[40] 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. On the basis of the warming potential of CO_2 and CH_4 it can be shown that 3.3% by weight of fugitive emissions from gas would make it equal the emissions of CO_2 by coal (Annex 2). There is evidence that fugitive emissions in at least some countries in the region surpass this threshold.

A transition will also require a profound change in how the transmission and distribution of electricity operate. These factors constitute the basis for the discussion on the future of the power sector in the region.

2.2 TRANSPORT SECTOR

a. Recent evolution of the transport sector

Transport is the sector with the highest share of fossil energy use in the region, therefore leading in terms of fossil fuel related emissions. It now accounts for an estimated 9.0 EJ of total primary energy use, as well as for about 15% of all regional GHGs emissions in 2017.[41] Factors contributing to the increase in the use of energy include: a) fast motorization rate; b) an expanding urban population coupled with poor urban planning processes; c) more movement of cargo, for domestic and export markets; and d) improving living standards.

Transport is a complex sector of the economy attending to varied demand for services, with fleets that respond to different drivers.[42] 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, and Mexico), as well as marine (fluvial) and air transport components.[43] 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.

40 https://www.igu.org/natural-gas-cleanest-fossil-fuel

41 Compilation in GACMO, accessed August, 2019, using data from ENERDATA

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

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

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)[44]	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 (MT CO_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).

b. Passenger transport

Light 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.[45] The rise in motorization has been

44 Provincia de Panama: 1992-2005

45 While electrification of transport in urban areas has the potential to displace emissions of GHG and airborne criteria pollutants, it will not 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.

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 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, 2018).

Data in Table 4 illustrates that the largest share of CO2 emissions is linked to light 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.

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 (%)		
				Automobiles and light vehicles	Public transport (Buses, metro, light rail)[46]
Argentina	3.4	93	Buenos Aires	22[47]	50
Brazil	4.2	92	Sao Paulo	46[48]	37
Chile	5.2	83	Santiago	28[49]	30
Colombia	7.9	77	Eleven cities	24[50]	47[51]
Costa Rica	5.3	66		n/a	n/a
Mexico	3.0	91	Mexico D.F.	36[52]	58
Panama	7.6	n/a	Panama City		
Peru	9.5	71	Lima and Callao	22[53]	54
Uruguay	4.5	n/a	Montevideo	26[54]	36

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

46 Estimates of share of passenger-kilometers were 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.
47 Centro Tecnologico del Transporte de Argentina (2013).
48 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
49 2012: https://www.mtt.gob.cl/archivos/10194
50 http://imaginabogota.com/academia/movilidad-en-bogota-bien-en-distribucion-de-modos-nos-falta-mucho-en-satisfaccion/
51 Figure only applies to Bogota.
52 2017: http://giitral.iingen.unam.mx/Estudios/EOD-Estadisticas-03.html
53 WRI internal communication
54 WRI internal communication

The region is the world's leader in Bus Rapid Transit (BRT) systems.[55] There are now BRTs in 54 cities in Latin America.[56] 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). At least three BRTs are now including or are about to commission electric buses (Santiago, Bogota, and Curitiba) in their core or feeder routes. Santiago has launched the first 100% electric-fleet BRT.[57] There are also 21 additional BRT systems in construction and 10 in expansion in the region.[58] 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.

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 1, 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 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

55 BRTs (Bus Rapid Transit) systems make up 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.

56 https://brtdata.org/; consulted August 2019

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

58 https://brtdata.org/; consulted August 2019

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 the region's truck fleet

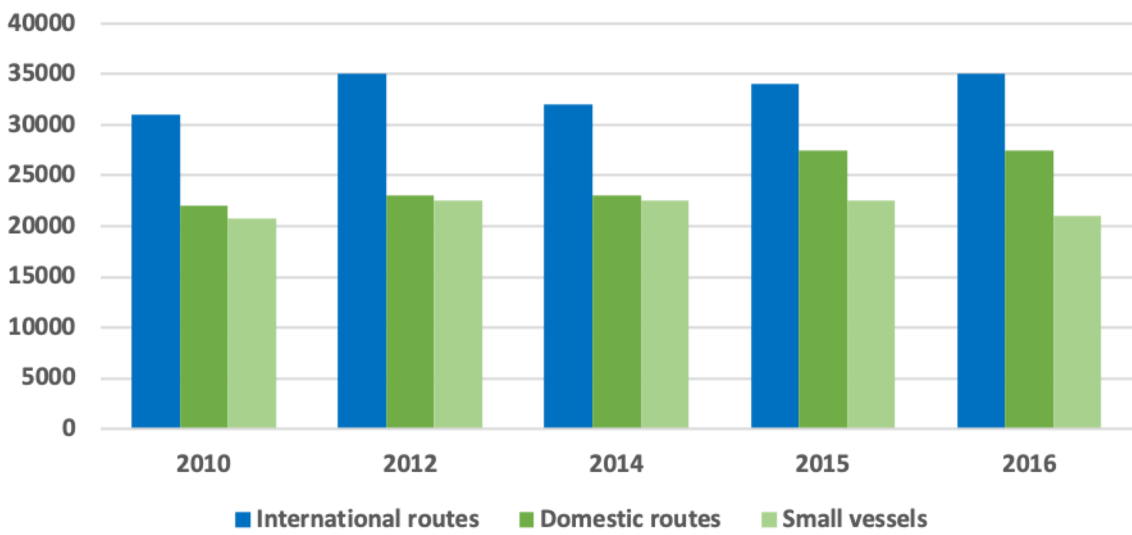
Region	Fleet age (years)	Annual distance travelled (km)	Fuel Efficiency
Central America	Over 20	40,000	Low
Andean Nations	20	60,000	Medium
Southern Cone	13	80,000	High
Brazil	12	80,000	High
Estados Unidos	Under 7	105,000	High

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.[59] In Brazil, fluvial transport accounts for about the same distance travelled as for international transport (Figure 10). In Central America and the Caribbean, ocean transport is the principal mode of commercial trade.[60]

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.

Figure 10. Fluvial transport in Brazil: Annual distance travelled (km) per type of vessel



Source: CEPAL, 2017

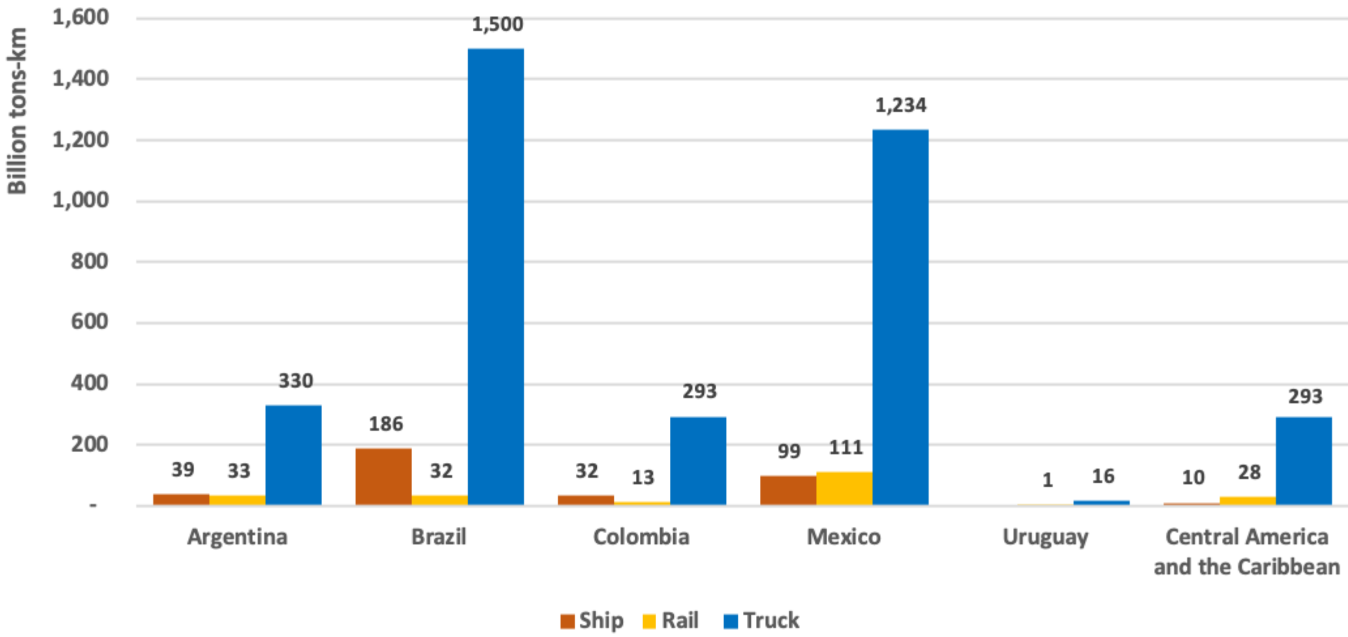
59 Colombia, Peru, Argentina, and Brazil have extensive, yet underutilized fluvial networks (see CEPAL, 2017 for a review of fluvial infrastructure in the region)

60 Estimate from http://thecentralamericangroup.com, consulted September 2019

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 cargo and passenger rail-transport show relative 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 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 Table 7. Trucks are the predominant mode in cargo.

Figure 11. Estimated cargo transported by mode in 2015 in some countries in the region (in billion tons-kilometer)



Source: Data from GCAM for 2015

Energy efficiency and carbon footprint

Rail and ships are considerably more energy-efficient, 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 11). Maximizing both would be the most rational approach, even if all modes move to electricity under a renewable energy matrix.

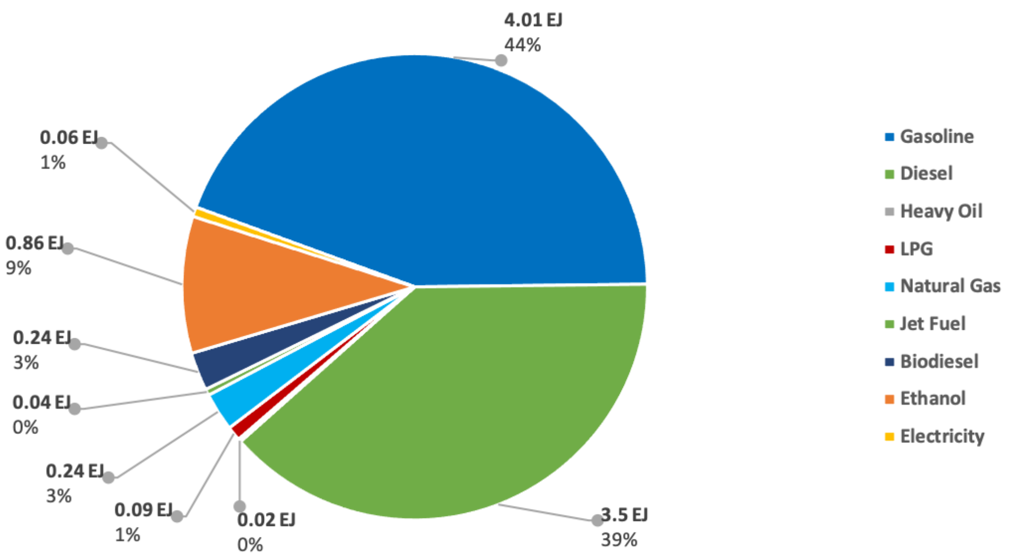
Table 7. Energy efficiency of transport modes for passenger and cargo

Cargo	(PJ/Million tons-km)	Passengers (PJ/Million passengers-km)
Ships	0.12-0.17	
Trucks	0.75-1.59	
Medium Trucks	0.67-2.01	
Rail	0.12-0.72	
Buses		0.05-0.50
Cars		0.18-0.68
Airplanes		0.52-1.88
SUVs		0.65-1.85
		0.63-2.22

Source: adapted from IEA, 2019

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 12 (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.

Figure 12. Fuels used in the transport sector in the region (Total: 9 EJ in 2018)



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.

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.

Table 7. Estimated 2018 carbon footprint in the transport sector by country and by mode (in MT CO_2)

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

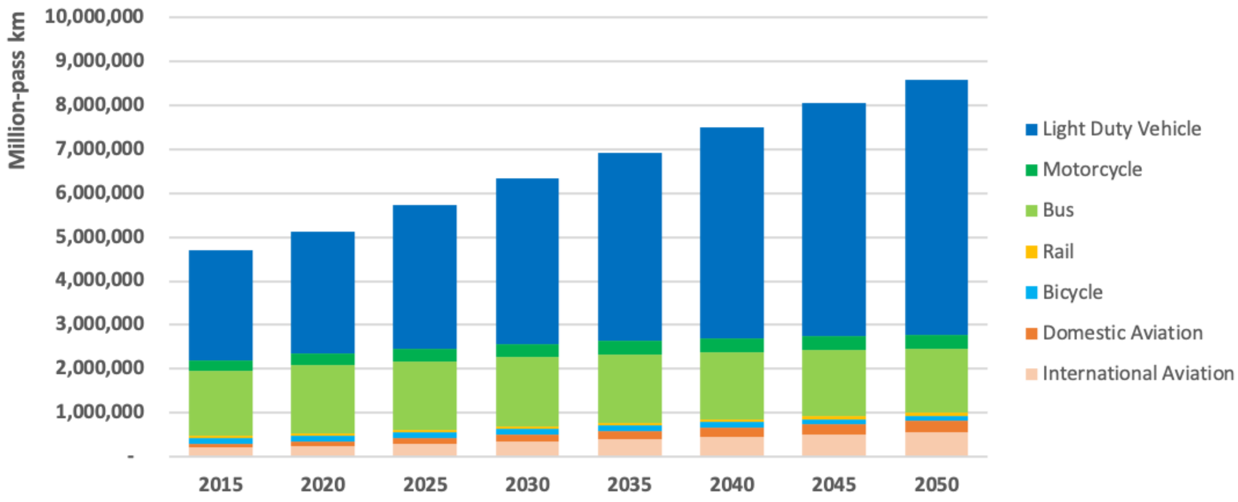
Source: Enerdata compiled through GACMO on the use of fuels. Assumes all light vehicles use gasoline and all buses and trucks use diesel. It considers that the use of ethanol and biodiesel does not result in any direct emissions. Some data not available.

c. Future demand

The IIASA projections place annual energy use by transport growing to 14 EJ by 2050.[61] The GCAM BAU scenario projects an energy demand of 18 EJ by 2050.[62] 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. These projections were made in the absence of the consequences from the COVID-19 pandemic. Clearly, the sector has been impacted. For example, public transport ridership has been negatively affected. Demand for cargo transport, at least intra-city, including delivery services has increased. Cities in Latin America have adopted massive restrictions to limit transmission of the virus. Fare losses have been significant in Brazil and other nations for BRTs and metro systems. Yet, there is no way to estimate to what extend there would be long-lasting changes in mobility and commuting patterns. The effects of the pandemic could be a harbinger of long-term behavioral changes but there is not enough data on which to base a multi decadal prediction.

61 This is the projected increase under GCAM's BAU scenario.
62 Both the energy use in power generation and in transport are above. Data on the current situation is derived from Enerdata.

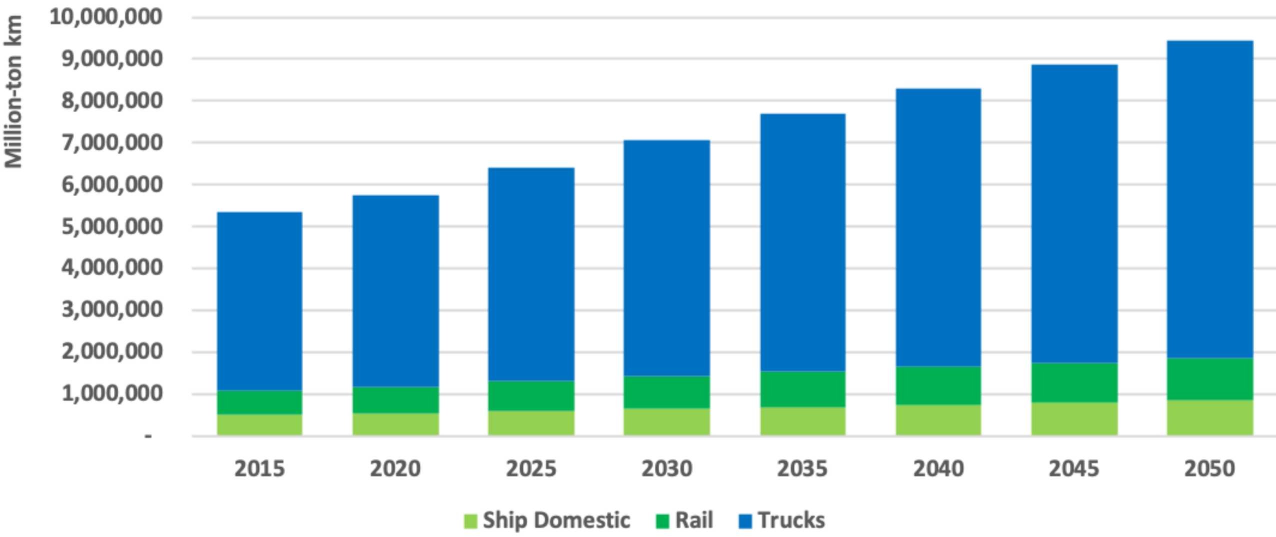
Figure 13. Projected passenger demand under GCAM BAU scenario



Source: As projected under GCAM BAU, August 2019

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.

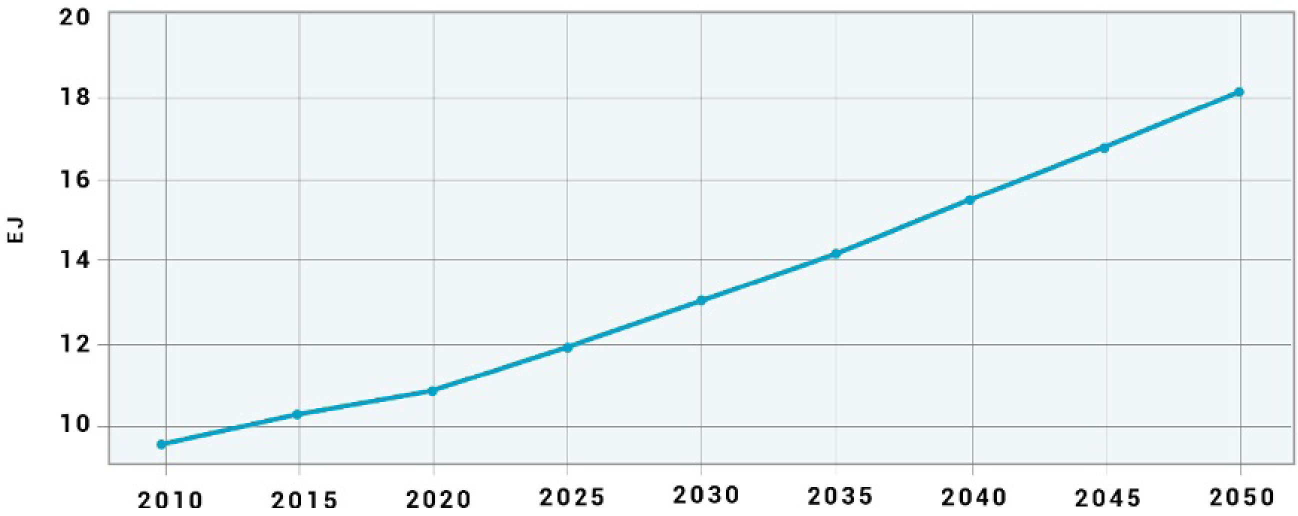
Figure 14. Projected cargo demand under GCAM BAU scenario



Source: As projected under GCAM BAU outputs, August 2019

Eliminating emissions from the transport sector would require under any scenario, of an enormous effort. Also, any displacement of fossil fuels by electricity will add to demand by the power sector. The transformation of transport to electricity 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 3-7.

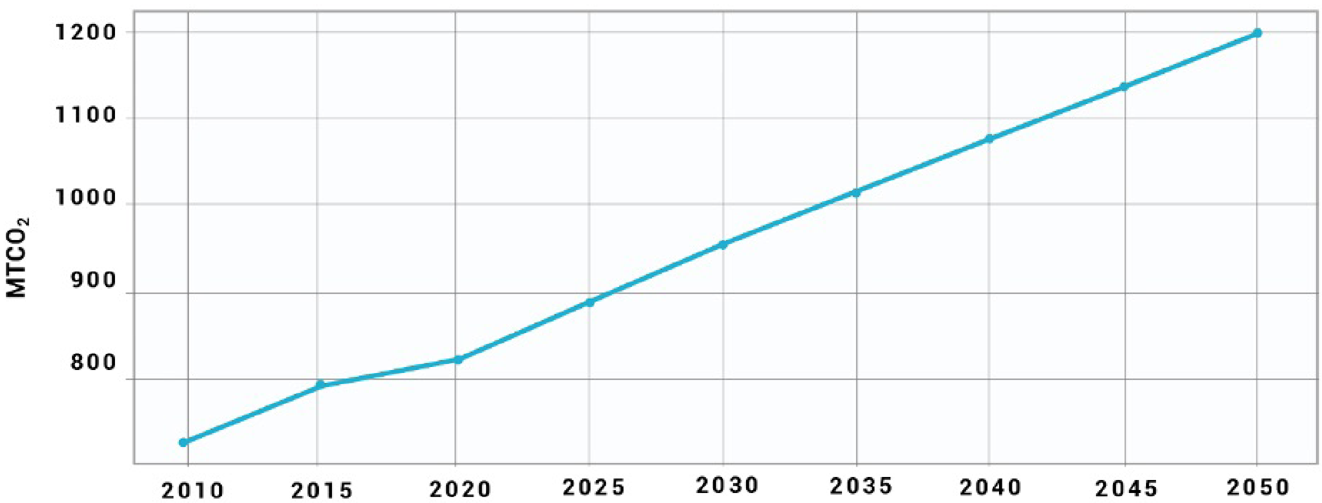
Figure 15. Projected energy demand by the transport sector under GCAM BAU scenario



Source: As projected under GCAM BAU outputs, August 2019

The emissions linked to this future scenario are shown in Figure 16, as calculated through GCAM. The projection calls for emissions to increase to 1200 MT CO_2, from current levels.

Figure 16. Projected associated CO2 emissions from the transport sector under GCAM BAU



Source: As projected under GCAM BAU outputs, August 2019

CHAPTER 3

The Evolving Economics of Renewable Energy in the Region

This section reviews the conditions that could 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 (LCOE)), 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

The Latin America and 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 northeast region 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 docu-

mented off the southern pacific coast. Geothermal fields continue to be assessed over the Andes, the Central American Cordillera, and other areas of interest.[63]

Figure 1 summarizes information on some of these hotspots in terms of location, resource intensity, and size.

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

The annual electricity generation potential of some of these areas is of comparable size to what could be generated through the use of the annual oil extraction in oil-rich nations. For example, in Chile's Atacama region, the potential for solar power using just 10% of the area with commercially available conversion efficiencies of PV systems, during eight months would equal the potential electricity generation from the annual production of oil from Saudi Arabia (Table 1, see details in Annex 3). After eight 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 CO_2 concentration in the atmosphere. The potential of Atacama for power generation is just

63 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

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/Chihuaua 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.

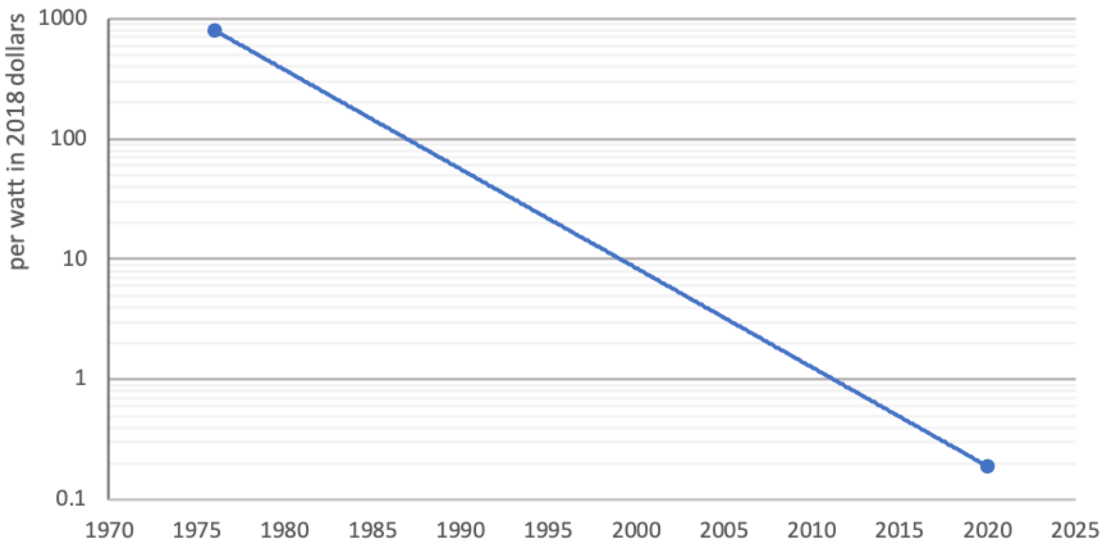
Table 1. Comparison between electric potential of proven oil reserves and renewable energy potential in Latin America

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.

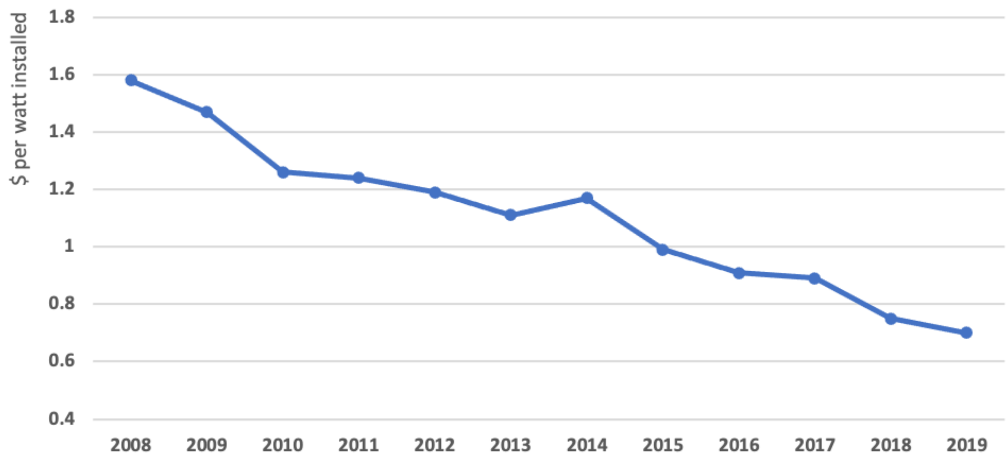
Trends in technology costs. An analysis (BloombergNEF, 2019) of PV modules and wind turbine prices has found that since 2010, costs have fallen by 85% and 45% respectively (Figures 2 & 3). At the same time, the efficiency of conversion of PV modules and the capacity factors of wind projects already in operation have also improved. In the case of wind, the size of turbines has also increased.

Figure 2. Trend in cost of PV modules per watt



Source: Adapted from Bloomberg NEF, 2019.

Figure 3. Trend in cost of wind turbines

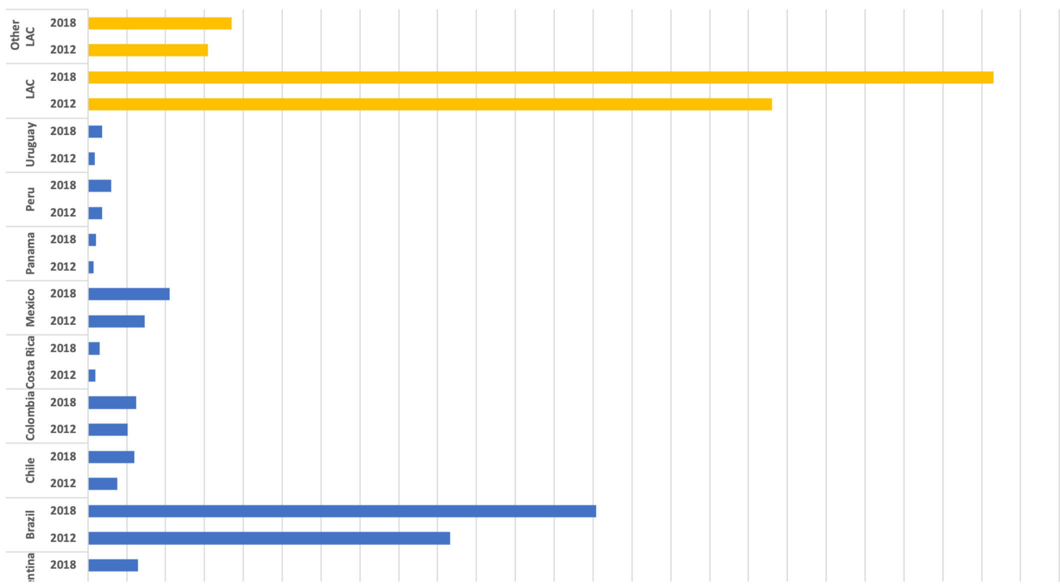


Source: Adapted from Bloomberg NEF, 2019 and Industry data.

3.2 EVOLUTION OF CAPACITY

Installed capacity by country. During the period 2012-2018, installed capacity for wind energy in LAC increased by nearly 400%, and for solar, it increased 29,000%. The total capacity added 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 a 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 4). The rapid development of renewable energy in the region is facilitating gains in knowledge and practical experience that will be helpful in further reducing operation and maintenance costs.

Figure 4. Evolution of share of nominal capacity in renewable energy in LAC (2012-2018)



Source: Based on information from ENERDATA compiled in GACMO, accessed July 31, 2019. For hydro and geothermal, 2017 data was used for some countries where 2018 data was unavailable.

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 Table 2. In some cases, the capacity that is under construction or contracted surpasses the operational capacity by a good margin.

Table 2. Examples of solar and wind capacity under construction and contracted (GW) in some countries

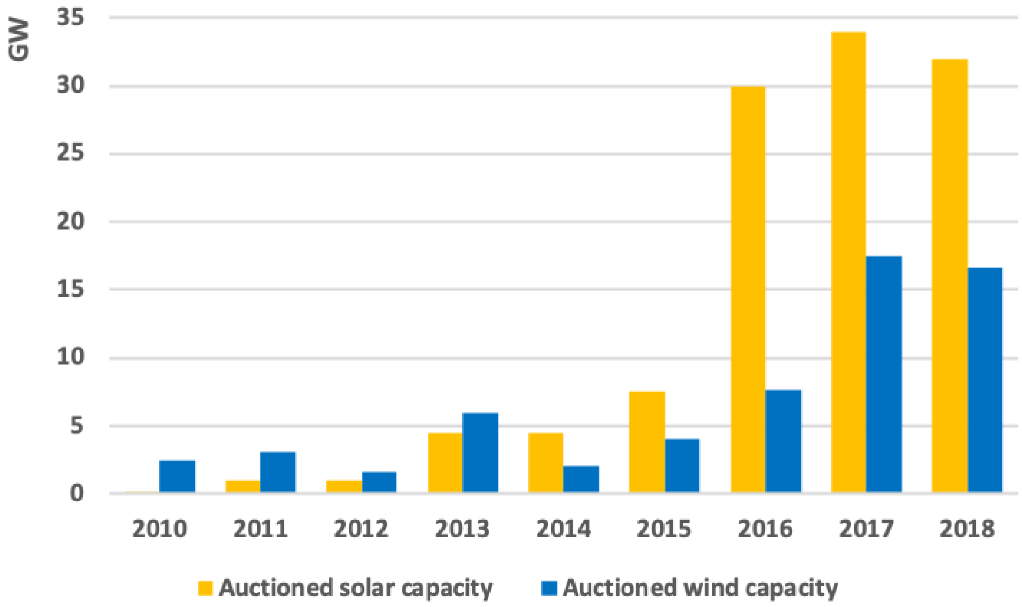
	Operational	Under Construction	Contracted	Upcoming capacity as % of operational
Solar				
Mexico	2.43	1.85	1.50	138
Chile	2.27	0.59		26
Brazil	2.23	1.03	0.44	123
Argentina	0.19	0.46	2.47	489
Rest of South America	0.74		0.24	32
Wind				
	Operational	Under Construction	Contracted	
Mexico	4.68	1.08	1.15	48
Chile	1.52	1.01		67
Brazil	14.40	3.64	0.96	32
Argentina	0.75		0.10	13
Rest of South America	2.16		1.16	54

Source: Industry data as of September 2019

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. However, a pause in demand and new capacity installations was experienced throughout 2020 as a consequence of the impact of COVID-19.

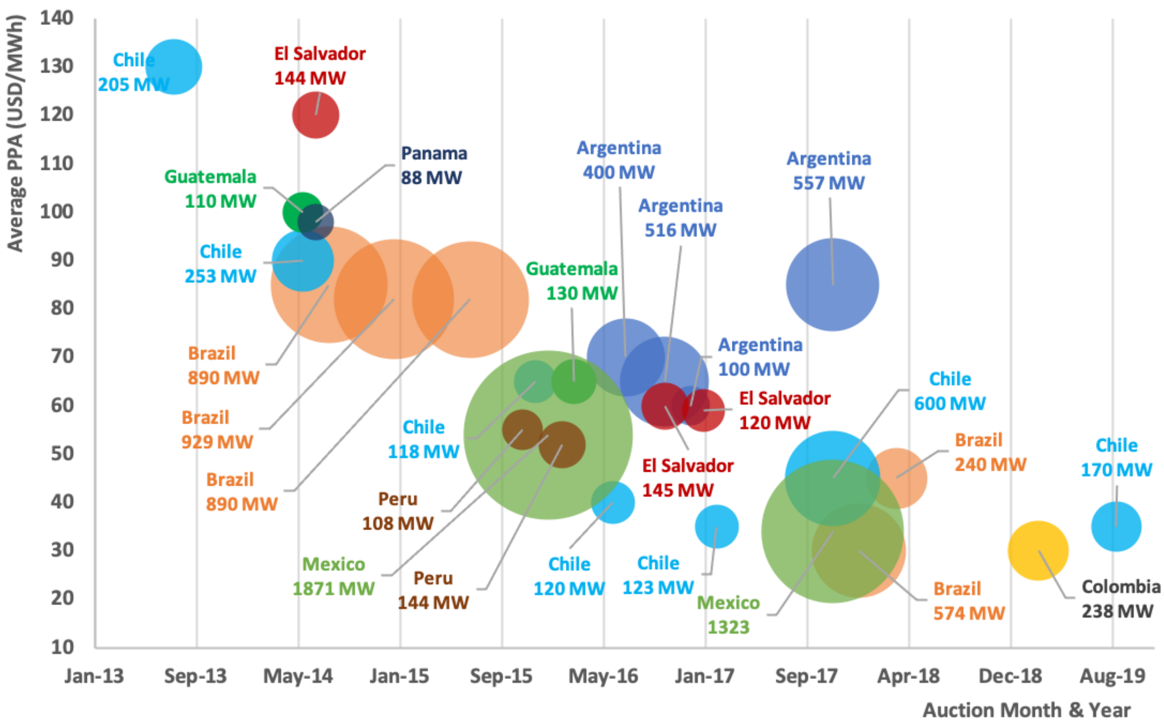
Evolution on the cost of generation using non-hydro renewables. Reductions in the cost of generation for wind and solar projects have continued. A recent analysis by IRENA (IRENA, 2019) indicates that auctioned prices have fallen (between 2010 and 2018) by 75% and 25% respectively for solar- and wind-powered installations (Figure 5).

Figure 5. New global auctioned capacity for solar- and wind-powered plants (2010-2018)



Recent bids for PV and wind energy installations in the region confirm the long-term trend of improved competitiveness. Some recent bid values are presented in Figures 6 and 7. For example, solar power PPAs offered in Chile in 2018 are in the range of 20-30% of the prices offered for similar installation in 2013. The same is true in other countries in the region.

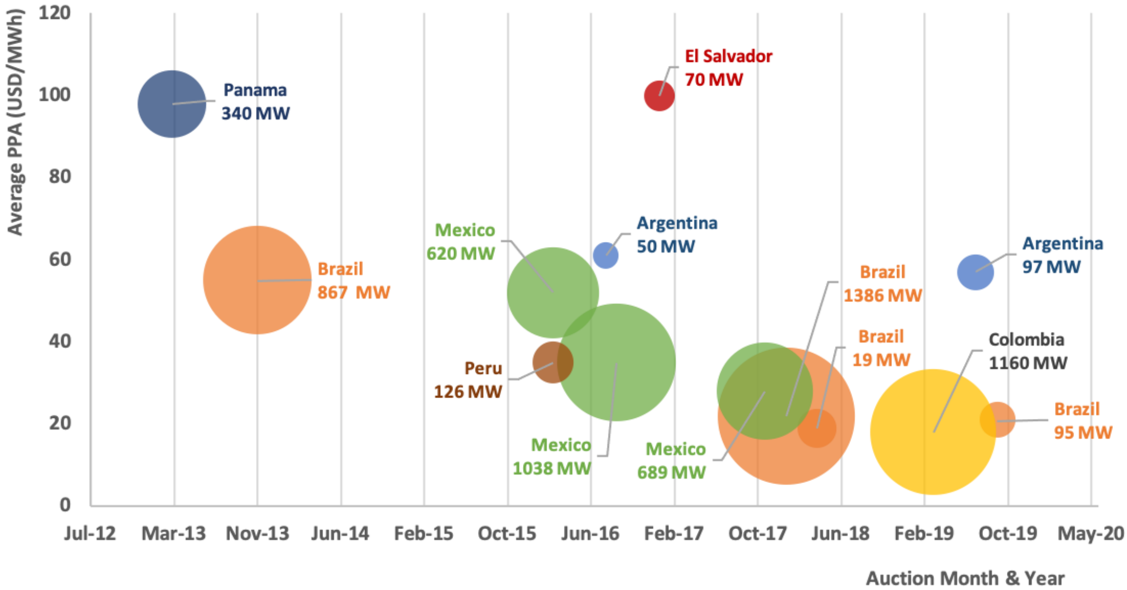
Figure 6. Evolution of bid prices for utility-size PV projects in the region



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

While the reduction in prices is smaller for wind installations, it follows the same tendency and has resulted in lower costs than PV units. The actual market prices are considerably lower than projections made just a few years ago (i.e., IRENA, 2016). A recent report[64] indicates that recently, wind farms have gotten so cheap that you can build and operate them for less than the expected cost of buying fuel for an equivalent natural gas plant. The current PPAs are at a level of least-cost fossil fuel alternatives, without the need for fiscal incentives. Prices are such that companies are deciding to build the projects without any subsidy or PPA associated.[65]

Figure 7. Evolution of bid prices for wind projects in the region



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

Solar-plus-storage facilities and concentrated solar power (CSP) prices are not included in the data in figure 5, 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.

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.

3.3 PROJECTED COSTS OF GENERATION IN THE REGION

Based on the results of recent auctions and trends, an update of the estimated current levelized cost of generation has been made, including fossil fuel options using current (2018) prices in the international market for fossil fuels, FOB prices for natural gas in Brazil and Mexico, and FOB prices for low-sulfur coal in Colombia. Solar and wind options have been updated with information on projected costs for turbines and PV modules

64 https://emp.lbl.gov/sites/default/files/wtmr_final_for_posting_8-9-19.pdf

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

(BNEF, 2019, NREL, 2019).[66] Options for PV-plus-storage and wind-plus-storage have been added reflecting recent developments, including the AURA III project commissioned in Mexico (Sanchez-Molina, 2019) and the proposed PV-plus-storage project Espejo de Tarapaca in Chile (PVtech, 2019).[67]

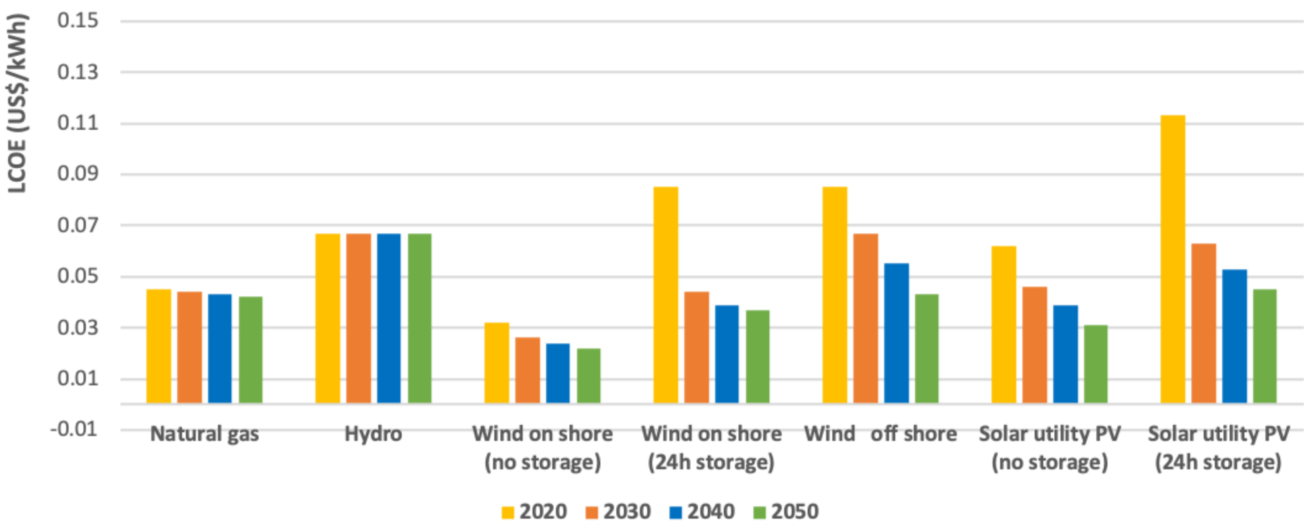
Estimates for marine options (wave and tidal) have been updated based on information compiled by the UK Marine Resources Board and adjusted to reflect the state of development in Chile. The projected cost of fossil fuel options has been adjusted to reflect the expectation of future fuel prices, including a downward pressure exerted by increased competition of renewables in power generation.

The results are presented in Figure 8. Onshore wind is already well below the costs of generation with coal and petroleum derivatives, and even with natural gas and 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 reductions in investment costs. Both wind and solar represent logical investments for capacity expansion just on purely financial grounds.

The results also indicate that 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 to justify new coal plants 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. Investments in natural gas capacity appear to be far from competitive in the future (see Figure 8). Locking in natural gas infrastructure at this time may result in capital losses once these units cease to be competitive in the future.[68]

Increased competitiveness of options including storage offer an additional challenge to the arguments for continuing operation of fossil-based generation based 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.

Figure 8. Projected LCOEs for power generation in the region



Source: Author's estimates using GACMO

66 https://atb.nrel.gov/electricity/2019/index.html?t=ow
67 The costs of storing power in Latin America are reviewed later in the report.
68 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.

CHAPTER 4

Transmission and Distribution

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 to all domestic needs and allowing for optimal use of generation assets, resources, and storage but will require an efficient, modern grid.[69] 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 hydropower as a large storage regional facility as well as other storage options; and
- **d.** reviews the complementarity of different renewable resources and the current status and prospects for regional integration.

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

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 grid[70]should be able to enhance stability and reliability, with ready access to and exchange with distributed generation systems while reducing overall costs,[71] enabling net metering[72] and the participation of power storage facilities and even 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 and 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. 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. 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.[73]

70 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 consumers and help provide adequate demand to the production. It also allows the demand to provide ancillary services to the system.

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

72 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.

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

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

	Market regime	Generators	Operators Distributors	Access (%)	Grid
Argentina	Open, unbundled, in a competitive, mostly liberalized market.	75% of generation capacity in private hands.	*Compañía Nacional de Transporte Energético en Alta Tensión* (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 governmen-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.

Distributed generation.[74] 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

74 Distributed generation (DG) is generally defined as that connected to a distribution network, rather than to a 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.

changed and is now seen as a mechanism to strengthen resilience and reliance at a local level, while enabling small and medium scale generators access to the grid. 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 isolated mountain regions or island countries in the Caribbean.

In well-integrated areas, DG can still play a significant role in supporting the national generation and distribution system, through use of dispersed yet strong endowments of renewable energy, provided the regulatory and market mechanisms are in place.[75] These would include the set-up of a supportive policy framework; provisions and regulations for access to the grid, including net metering and associated accounting systems; and allowances for installed capacity for self-generation (see Table 2). Overall, there is growing interest and an expanding (but still small) market share for distributed generation in the region, particularly in Mexico, Brazil, and other countries, where management tools are well-developed. DG is allowing the end user to also be a participant in the demand and supply market.

Table 2. Supporting tools for distributed power in the region

	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	M	500
Panama	M	500
Peru	Not defined	Not defined
Uruguay	E	100

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

Distributed generation is not necessarily restricted to small installations. On the contrary, 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). Also, distributed power is still largely based on solar PV installations and wind; however, it could eventually be based on geothermal or other sources. By the end of 2018, there was close to 1 GW of installed distributed generation PV capacity in Latin America, about half of which is in Brazil. No data on wind-assisted DG in the region was available. In integrated systems or where access is widely spread, distributed generation would be economically justified if it reduces the cost of supply to the system at large.

At some point, distributed generation could be supported by local storage capability, enabling demand

75 An extensive treatment of net metering policies in the region is provided in Mejdalani, A., et. al, 2018.

nodes to be grid-independent in practice.[76] Regardless, distributed generation has an important role to play in addressing niche circumstances or in markets where it can provide a unique or less expensive solution. 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
Household installations (rooftop)	Individual households	Could be financially attractive in areas with high solar radiation and high electricity costs.

Source: Author's elaboration

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 niche for their use. For example, isolated areas (islands without a national grid, isolated mountains, or forested and indigenous communities), necessitate 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 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 the coupling of power demand with the transport sector. There are now advance 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 control technology and the deployment of adequate business models[77] for utilities and other power suppliers.

The participation of large shares of variable renewable energy sources requires active demand management to ensure integration of these resources and flexibility of response. Fortunately, there are now systems and

76 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.

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

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.

Otherwise, there would be a risk that the technologies employed to interlink different elements of a more complex supply system and new demand from the transport sector could strain the energy system or lead to substandard operation conditions. Some of the elements to consider in effective demand management and management strategies are summarized in Table 4.

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

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 $0.05/kWh by 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).

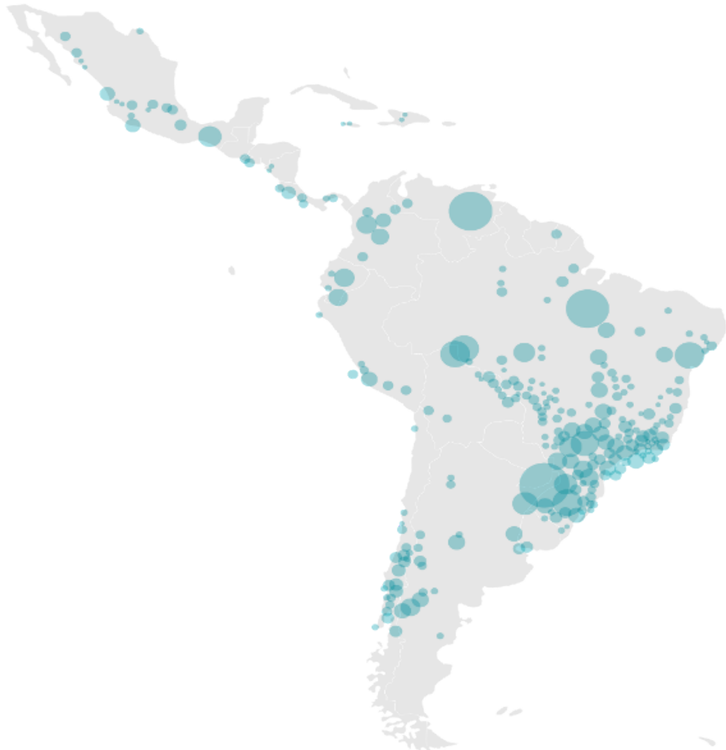
The deployment of modern transmission infrastructure, like HVDC, will reduce losses over longer transmission distances and contribute to a reduction in transmission costs in integrated systems. Behind-the-meter systems and distributed generation may reduce transmission costs at a local level. Adoption of new management systems and digitalization 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 op-

erate 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 bi-national power plants. Figure 1 presents the location of all hydropower units in the region that are 1 GW or larger.

Figure 1. 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, (Oct, 2019). www.resourcewatch.org.

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 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.

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 as noted. 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

While heavy reliance on hydropower by the electricity sector 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 (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 could 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.

Hydropower-based systems would see 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. Also, the potential role for existing hydropower facilities in facilitating market entry of wind and solar plants could go beyond national markets. This is a key argument for

interconnection of national systems. Hydropower is an asset that facilitates the transition. However, as demand grows, it is doubtful that hydropower can retain its current relative share. There are increasing environmental and social requirements on new units and 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, as well as, 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.** Large battery storage systems for renewable energy facilities are expanding quickly. These systems enable intermittent generation to provide continuous service. As costs for power storage systems fall, renewables plus storage will become more competitive.[78]
- **d.** There are other power storage alternatives (see EESI 2019 or 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.

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.[79]

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 cost-competitive systems that would minimize transmission losses. High Voltage Direct Current (HDVC) systems can meet these requirements. Specifically 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; and,
- **c.** reducing the capital, operational, and maintenance costs of transmission over longer distances.

78 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. In the Dominican Republic, two 10 MW 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/. A 112 MW is under construction in Chile. It will be paired with the 180 MW Andes Solar project also under development.

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

HVDC systems would be required for large-scale integration in 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 a distance of 2400 kilometers, 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 kilometer extension and 600 kV capacity.[80]

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.[81] 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.

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 to local demand, even where regional links are established. There are, however, a number of 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 kilometer, 230 kV transmission

80 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.

81 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, Central America, and 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).

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 kilometer, 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 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 areas between Brazil, Argentina, and Uruguay;

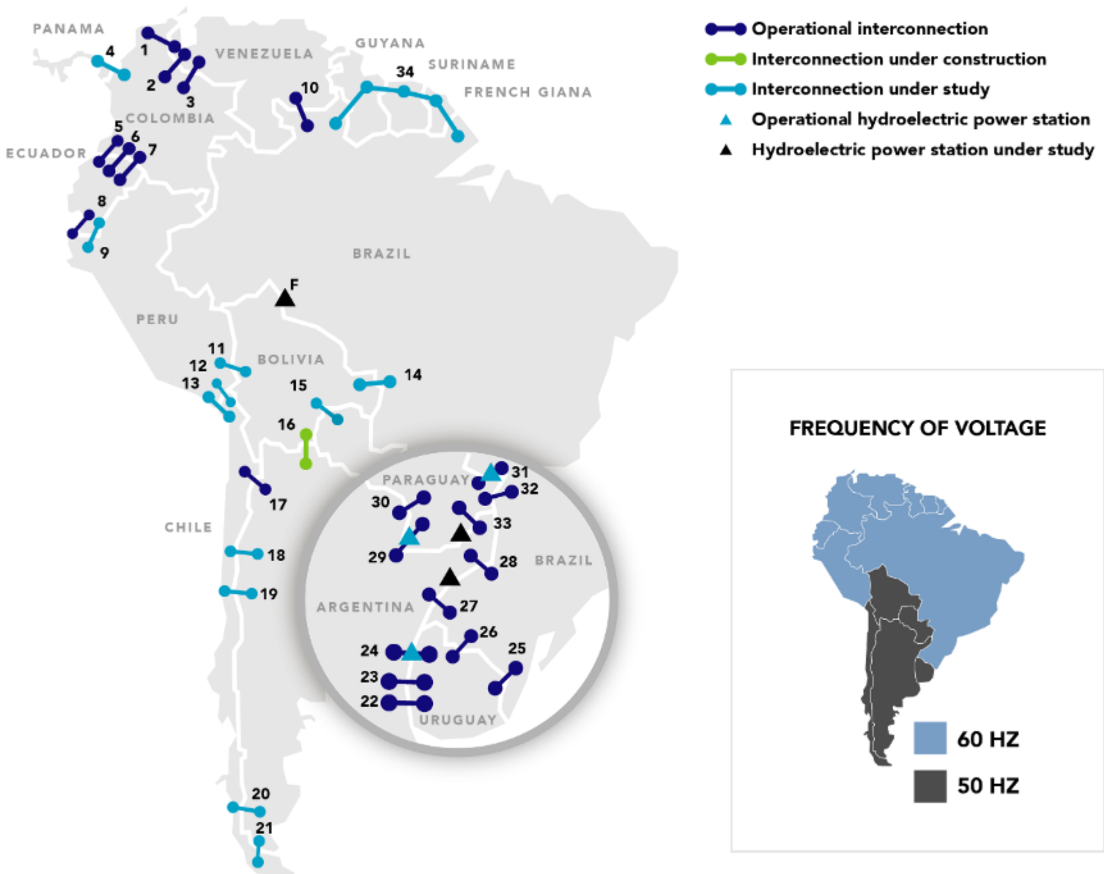
e. The main interconnections in the region with the location of large reservoirs, and existing HVDC systems in operation or planning, for the countries of interest (as shown in Figures 2 and 3).

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

Figure 2. Regional electricity links in Central America

Source: CIER, 2019

Figure 3. Regional electricity links in South America



Source: CIER, 2019

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 distributive 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 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 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. CAF has estimated a tag of U.S. $ 4.6 billion investment required to establish the most critical links (CAF, 2012).

CHAPTER 5

Technology and Economic Trends of Electric Transport in the Region

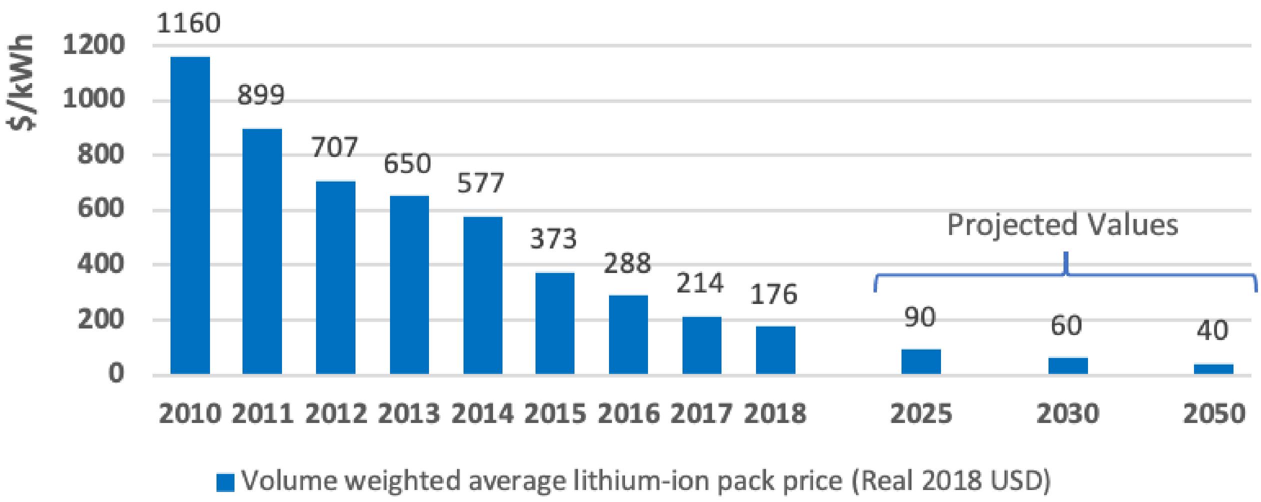
This section reviews current technology trends in electric drives, storage facilities for vehicles, and charging stations of relevance to the region. An assessment on impacts on energy use by electrification of transport and updates of projections for financial costs of passenger and cargo movement,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

Reductions in energy storage costs, especially in lithium-ion batteries, make it possible to consider faster market entry of electric vehicles[82]. 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. 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.[83] The net impact of COVID-19 on electric vehicles has been subdued by the large pent up demand and the continuing reduction in costs.

82 The cost reduction in batteries also impacts the electric utility industry, as cheap energy storage could change the relative competitiveness for domestic solar power applications tied to batteries. It could also make natural gas plants more expensive to operate as these are forced to cycle on and off more frequently because of solar and wind penetration.

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

Figure 1. Recent and projected costs for battery packs for electric vehicles (US$/kWh)



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

Besides energy storage, there are other aspects of technology that are changing fast with applications for 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 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 voltage suitable for heavy vehicles (1000 volts or higher). Heavy-duty vehicles require 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; 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 Sweden[84] and in Germany.[85] 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.

e. On the software side, there is 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. Electric vehicles have the potential to become one more active player in the demand and supply balance of power systems and an essential element of a shared, automatic, and electric economy.[86]

84 https://www.forbes.com/sites/sebastianblanco/2018/04/30/sweden-opens-up-electric-highway-called-eroadarlanda/#3cd75f3346ce
85 https://www.bloomberg.com/news/articles/2019-05-13/germany-s-first-electric-highway-charges-trucks-as-they-drive
86 https://3rev.ucdavis.edu

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 worldwide[87] 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.[88]

Buses. The large number of buses in the region, concentrated in urban areas, offers an important market for the development of an electric bus and ancillary industry tailored to the regional needs. The bus characteristics and requirements in the region are different of those under development elsewhere (capacity, climate control, and route lengths). Analysts (BNEF, 2019) predict that this segment of the fleet will continue to gain in competitiveness and market share ahead of other types of vehicles.

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.[89] Electric trucks in the region will become a viable freight and logistics tool, provided a supporting infrastructure and supporting regulations are available. As discussed earlier, other alternative for long-haul or heavy-duty transport is the set-up of electric highways.[90]

5.3 MARINE VEHICLES

Currently, electric ships are usually using a diesel-electric hybrid system, which is mostly used by offshore and cruise vessels. But all-electric barges and container ships are being commissioned in Europe and Asia. All-elec-

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

88 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.

89 A growing number of experiences and commercial announcements of electric cargo vehicles (Amburg, 2019) have 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.

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

tric 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.

Hydrogen has been suggested by some[91] as an energy carrier suitable for use in heavy duty vehicles (or transport vehicles in general). Its generation, however, would require either the hydrolysis of water using fossil energy, spare hydropower, or energy from other renewables. The report assumes that idle hydropower capacity could be more efficiently used to directly power electric vehicles. The use of hydrogen is beyond the scope of this report.

Some of the specific requirements and opportunities associated with heavy duty vehicles are presented in Table 1.[92]

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.
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.

5.4 CHARGING FACILITIES

The systems and technology of electric charging is evolving as fast as 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.

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 may be appropriate in urban areas of Latin America, where apartment buildings predominate. However, many apartment dwellers

91 https://webstore.iea.org/the-future-of-hydrogen

92 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. By the end of 2019, Chile will 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.

may use a fast-charging network with stations everywhere, for example, at parking stations and garages rather than relying on slow-charging systems. This will depend on the local power and transmission systems but even more 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 development of fast and high-capacity stations with a summary of next steps needed are summarized in Table 2.

Table 2. Summary of technology needs and foreseeable next steps for charging station infrastructure in the region

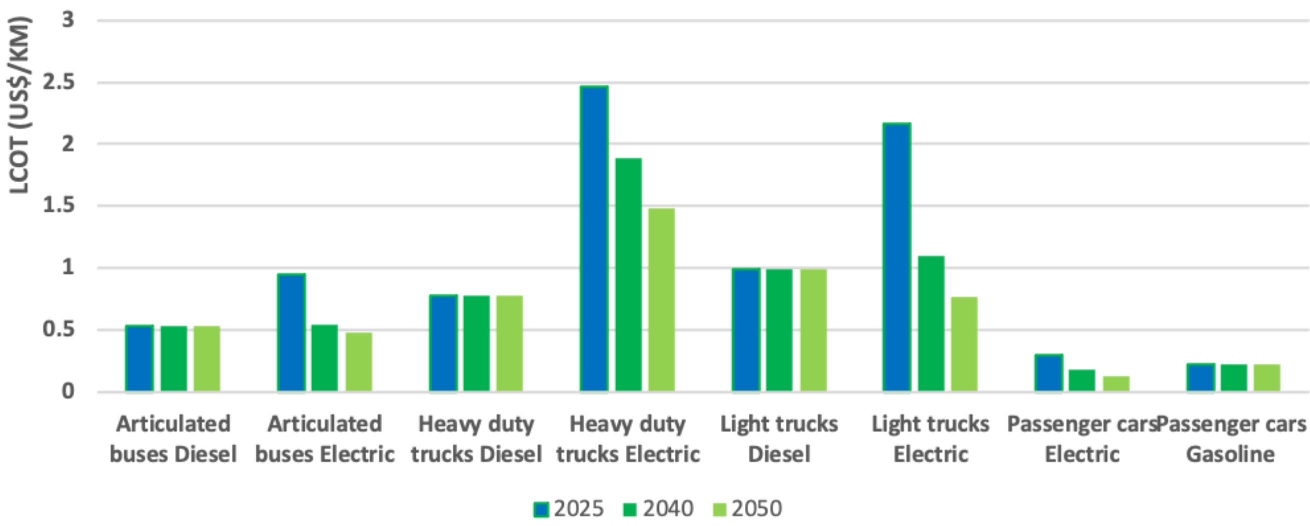
System needs	Current status	Next steps
Inter-operability of charging systems.	Several charging architectures, speeds, and voltages have entered the market.	Market entry would benefit from the adoption of standards for light and heavy-duty vehicles at a regional level, facilitating integration and economies 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.

5.5 PROJECTED COSTS OF ELECTRIC TRANSPORT

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),[93] are presented in Figure 2.

93 LCOTs measure the levelized capital, operational, and maintenance charges during the lifetime of the vehicle. It is used instead of TCO (total operation cost inclusive of taxes and levies) to reflect costs on a pure economic rather than financial basis.

Figure 2. Projected LCOTs for electric transport modes in the region



Source: Author's estimates using GACMO

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. Savings from lower levelized cost of transport can transfer to the wider economy.

Impact on energy use and energy efficiency

The coming onstream of large loads from the transport sector will represent a new sizable demand, requiring additional generation capacity and distribution infrastructure. The new demand may have well defined peaks corresponding to recharging periods at least for fleets and thus will need to be carefully planned to minimize additional capacity needs on the electric grid. As a good fraction of light vehicles will 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

This chapter deals with the strategic opportunities, costs, and benefits of a coupled decarbonization of the energy and transport sectors. The aspects considered include: a) the benefits on energy security; b) the impact on power generators (load balancing); c) the health benefits from improvements in air quality; d) the impact on refining costs and infrastructure; e) dimensioning of the implications of stranded assets in oil and gas reserves and power generation; and e) improvements in overall energy efficiency.

6.1 ENERGY SECURITY

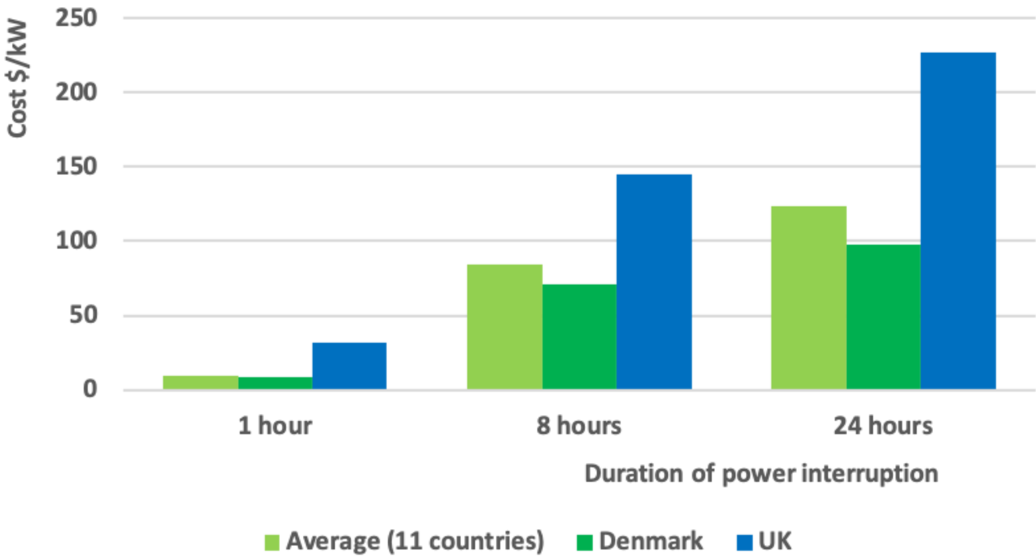
A secure energy system has been characterized (USDOE, 2017) as having: a diverse blend of energy sources, a reduced carbon footprint, access to local or domestic supply, resiliency to external impacts, and capacity to respond to emergencies. It would also help if the energy supply system is not vulnerable to political disruptions and price volatilities. 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 Nino Southern Os-

cillation (ENSO) during 1992-1993, resulting in the depletion of hydropower reservoirs and triggering major losses for the economy for an extended period of time. 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 number of studies assessing costs resulting from interruptions of power supply.[94] In particular, an assessment of the cost of power interruption in several countries (Raessar P. et. al., 2006) found an average cost of nearly $9/kW for a one-hour interruption, that escalated depending on the duration of the event, reaching nearly $120/kW for a disruption lasting one day.

Figure 1. Estimate of cost of interruption of power supply



Source: Raessar P. et al.,2006

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:[95] the diversity of the energy supply system, the dependence on imports, and greenhouse gas emissions (dependence on fossil sources). A suite of three corresponding indexes have been used in the technical literature (Gupta, 2016, U of Padua, 2016).

94 (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 U.S. (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 U.S., resulted in an estimated 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 U.S. consumers related to power quality problems (interruptions and other quality events), finding out that the annual costs amounted U.S. $79.000 million, 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).

95 A thorough assessment of types of risk in the energy sector can be consulted in University 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 Table 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 the intervention scenario, 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. Imports of fuels for transport have a sizable impact on energy dependence in Costa Rica and Uruguay. Under the intervention scenario, 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.
- Finally, the reliance on fossil sources for power generation is also reported in Table 1. 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 CO_2.

Table 1. Factors affecting resilience to disruptions in the power sector in the region

	Current diversity of supply of power generation capacity		Current energy import dependence of the economy	Current fossil fuel dependency in power generation
	Share of largest capacity as %	Share of largest generation as %	Imports of energy feedstocks as a % of TPES	Share of fossil fuels in electricity generation as %
Argentina	58 (gas)	51 (gas)	20	67
Brazil	64 (hydro)	66 (hydro)	20	17
Chile	34 (hydro)	38 (coal)	72	57
Colombia	74 (hydro)	64 (hydro)	12	34
Costa Rica	64 (hydro)	74 (hydro)	54	2
Jamaica	-	87 (oil)	-	87
Mexico	40 (gas)	60 (gas)	45	81
Panama	56 (hydro)	60 (hydro)	-	33
Peru	37 (multifuel)	46 (hydro)	42	50
Uruguay	55 (hydro)	59 (hydro)	45	3

Source: Based on data from ENERDATA, consulted September 2019

In summary, under the intervention scenario, the diversity of supply will shift toward renewables, energy import dependence will be reduced as transport fuels, imports of power plant fuels would be eliminated, and fossil fuel dependency of the power sector would be eliminated by mid-century.

Under the intervention scenario, 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.

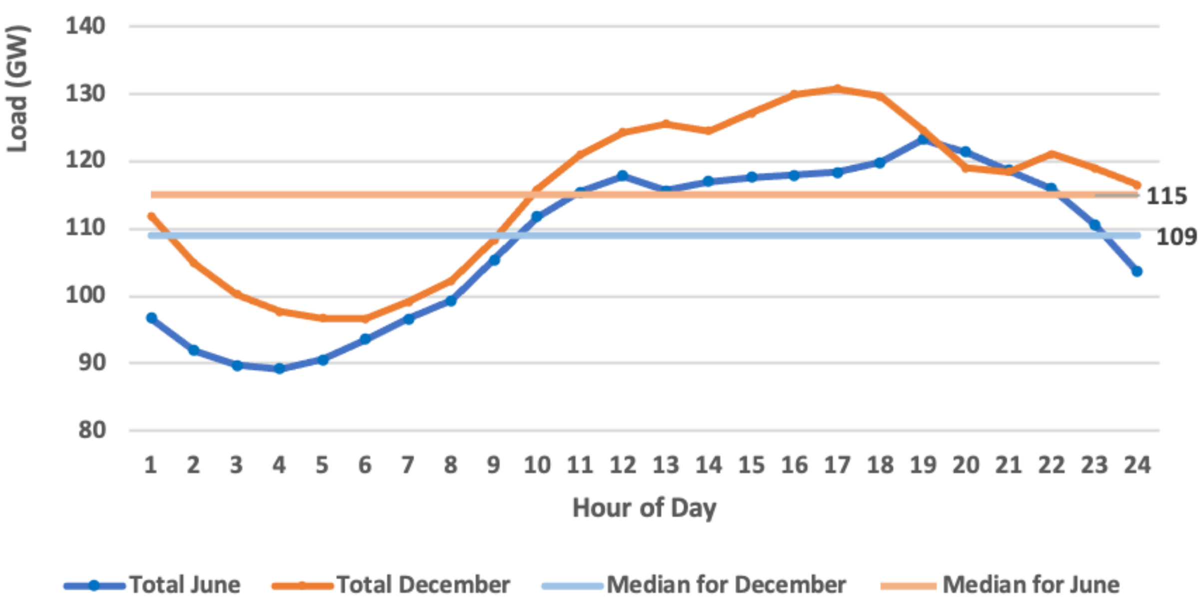
6.2 IMPACT ON POWER GENERATORS (LOAD BALANCING)

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, and 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 kilometers 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 sectors 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). Similar dynamic is experienced at a national level.

Figure 2. Aggregated load curve for Latin America



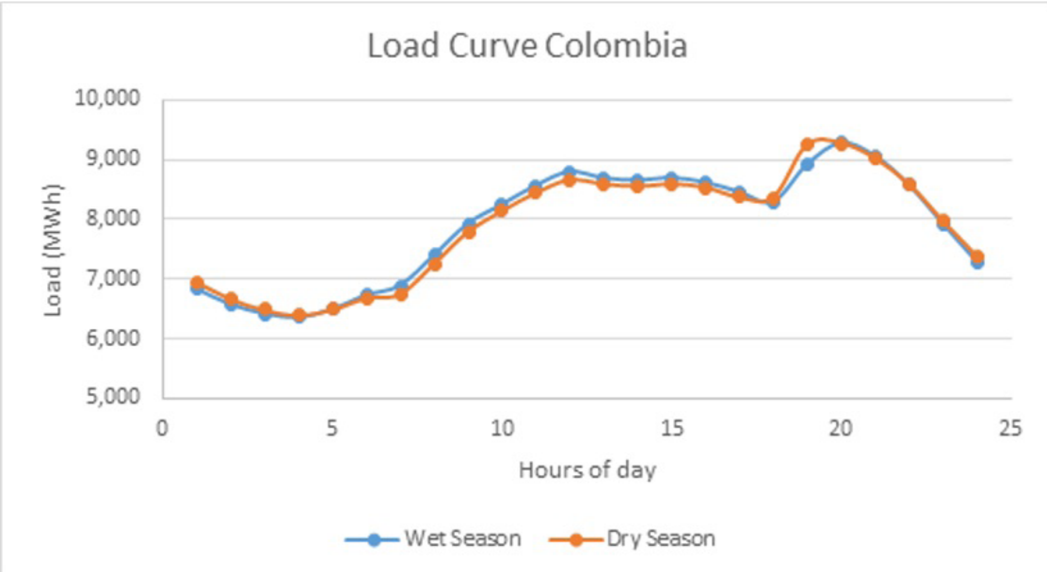
Source: Compounded graph from individual load curves, provided through personal communication from OLADE

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 3).[96]

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 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 hydro-dependent in power systems today.

Figure 3. Load curve in Colombia and "valley filling" with electric equivalent of diesel demand



In addition, a large transport fleet (trucks 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 is viable. This has been termed "vehicle-to-grid operation" (V2G) (J. Druitt 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.[97]

6.3 HEALTH BENEFITS

Urban air pollution in Latin America, has long been identified as a major health concern.[98] It has also been linked to impacts on vegetation and in agriculture. The World Health Organization (WHO) has recommended

96 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.

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

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

human exposure indicators (including for particulate matter) that should not be exceeded,[99] and national agencies like the U.S. Environmental Protection Agency have issued thresholds[100] 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, for example) 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.[101]

Many cities in Latin America exceed safe thresholds and, despite efforts to address the problem of unhealthy levels of particulate matter and other airborne pollutants, they continue to prevail (Table 2). The region is highly urbanized and therefore a high percentage of the total population in Latin American nations is exposed to these effects.

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.[102] Congestion in urban areas increases 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).[103]

The assessment of health and environmental costs of air pollution in Latin America has been the subject of other studies. 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).[104]

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 U.S. $44-103 per person year. This translates to costs of between U.S. $23-53 billion (2005) for the urban population in the region.[105]

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

100 https://www.epa.gov/criteria-air-pollutants/naaqs-table

101 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 in the region died prematurely 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.

102 Besides being GHG emitters, power plants burning fossil fuels are potential sources of criteria pollutants (NOx, SOx, CO2, 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 NOx. Exposure to these pollutants has been linked to health impacts in some urban populations (World Bank, 2002).

103 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.

104 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).

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

Table 2. Some cities in Latin America exceeding recommended levels of exposure to particulate matter

City	Annual mean PM_{10} (micrograms/m^3)
Bogota	52
Buenos Aires	26
Kingston	48
Lima	94
Mexico City	56
Montevideo	26
Panama City	31
Rio de Janeiro	49
Sao Paulo	35
Santiago	64
Montevideo	26
Total urban population	513

Source: WHO,[106] Rioja-Rodriguez et al, 2016. WHO Standard for PM10: not to exceed 20 µg/m3 annual mean

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 avoided costs from the elimination of PM emitted by transport have been estimated based on: a) the analysis by OECD, 2014, in the case of Mexico City; b) the quantification by Cifuentes, L.A. et al., 2005 for the entire region; c) the analysis by Karagulian and colleagues for urban areas in the region (see details in Annex 7). The results are included in Table 3.

106 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=

Table 3. 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 estimates. See Annex 7 for details

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 transportation 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.[107]

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 additional refinery infrastructure, including 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.

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, 10% of car fleet by 2025), would eliminate the need for additional refining capacity, and possibly reduce the need for imports of gasoline and diesel (estimated at 0.5 bbpd and 1.0 bbpd respectively by 2030); but 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.

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

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 a 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, a reduction in the domestic production cost per unit of gasoline and diesel of about 3% in the total refining cost is estimated for eventual exports at that point in time.

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 path for the sector would then initially imply cancelling or postponing plans to expand refinery capacity, and later, 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 at between U.S. $2070 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-degree Celsius 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, transportation, 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 a loss in the value of reserves. But 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 the value of fossil fuel reserves (if prices fall 1% on a yearly basis) has been estimated (Manley D. et. al. 2017) at U.S. $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 takes into account the age of the individual thermal units, assuming typical depreciations timetables for each type of unit.[108] The region has an installed capacity of 172 GW in 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 4.

The estimate also takes into account 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

108 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.

natural gas plants. The schedule of retirements for power plants is presented in Table 4 with the estimate value at retirement. The value of the stranded assets is estimated at U.S. $40.5 billion.

Table 4. Value of retired generation capacity and schedule of retirement [109]

	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.

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

Figure 4. Location and relative size of thermal power plants with nominal capacity above 0.5 GW, as of October 2019

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.

Value of displaced refining capacity. As the market for gasoline and diesel shrinks, two effects on refining capacity are expected: a) refiners will first likely see a cost reduction, as most expensive refining units are in use to maximize the middle distillate (gasoline and diesel)[110] range of production; and b) 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 a simultaneous electrification transition, the rate of retirement would also accelerate. Some refiners in the region (for example, in Trinidad, Tobago, and Venezuela) cater to markets in the U.S., so these were not included in the retirement list. Otherwise, for the purposes of this analysis, it is assumed that refiners will not substitute domestic market loss with exports. The corresponding estimates for refineries are presented in Table 5.

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

Table 5. Value of retired refinery capacity

	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.

Other assets displaced. Full decarbonization would also make substantial storage, distribution, and retail facilities obsolete. Unless other uses are found,[111] 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 Section 8.

Impact on fossil fuel subsidies. Besides the economic impacts on costs of production and capital assets, the use of subsidies for fossil fuels would be eliminated. Diesel, gasoline and coal receive some subsidies in the region, sized at about U.S. $64 billion/year (IDB, 2017). Early phasing out of the subsidies would accelerate the transition in countries where these are prevalent.

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).

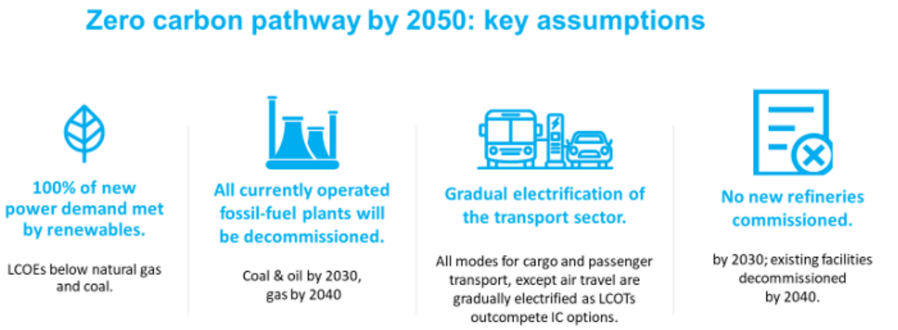
111 It has been suggested that gas pipelines could be used in hydrogen transport. The use of hydrogen has not been considered under the intervention scenario.

CHAPTER 7

Pathway to a Coupled Decarbonization of Power and Transport

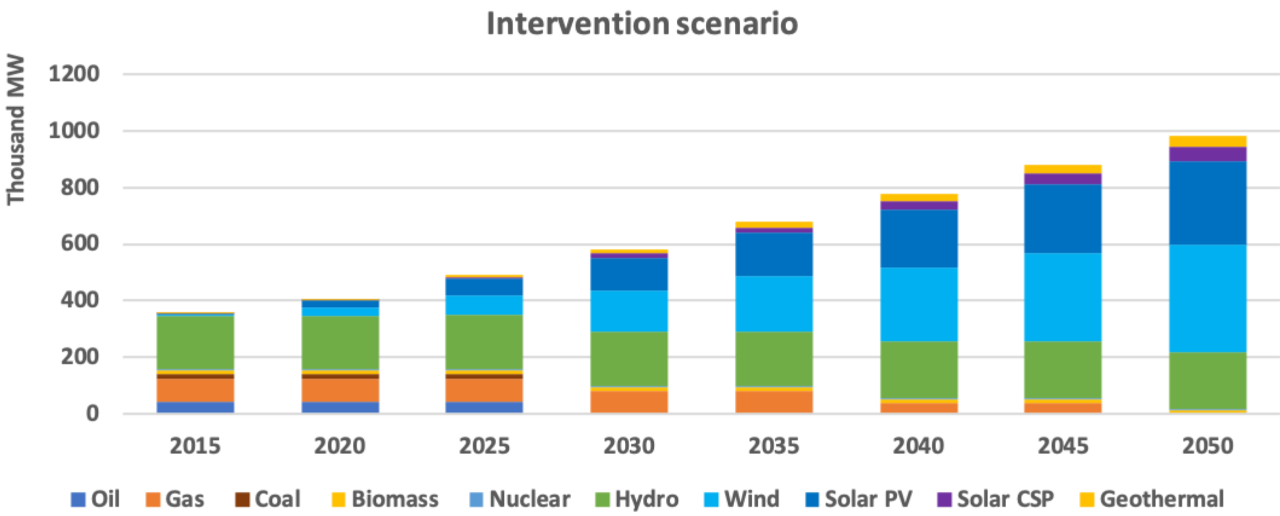
The decarbonization scenario, was built around the assumptions that the growing experience, and competitiveness will take advantage of the substantial endowments of renewable energy to displace fossil fuel generation facilities as new entrants in the regional power system. In addition, under the scenario, existing coal-based units would be mothballed by 2030 and gas-powered plants by 2040. As for transport, the scenario projects a gradual electrification as electric drives outcompete internal combustion engines. As a result of the reduction in demand for middle distillates as transport fuels, no new refineries would be commissioned by 2030 and existing refineries catering to production of gasoline and diesel would be decommissioned by 2040.

Figure 1. Zero carbon pathway by 2050: key assumptions



Decarbonization of power. As indicated, in the intervention scenario, all future demand is met through expansion of renewable energy capacity; no new fossil fuel power capacity is built after 2020. The new capacity is allocated proportionally between wind, solar PV, solar CSP, hydro, and geothermal power,[112] making allowances for those countries where geothermal potential is not available. The existing capacity for coal is decommissioned by 2030 reflecting lack of competitiveness, and gas units would be decommissioned by 2050. Nuclear and biomass are kept constant at current values. A list of assumptions is included in Annex 7. No gains in additional efficiency are considered beyond those considered under the reference scenario. The makeup of future capacity, under the intervention scenario, is depicted in Figure 2.

Figure 2. Growth in capacity of renewable energy under a zero emissions pathway (net additions)



Source: Author's estimates

Converting to a fully renewable system, under the assumptions indicated above, is estimated to require cumulative investments to the order of U.S. $800 billion, 2018, (U.S. 698 billion, 2010)[113] and would deliver zero

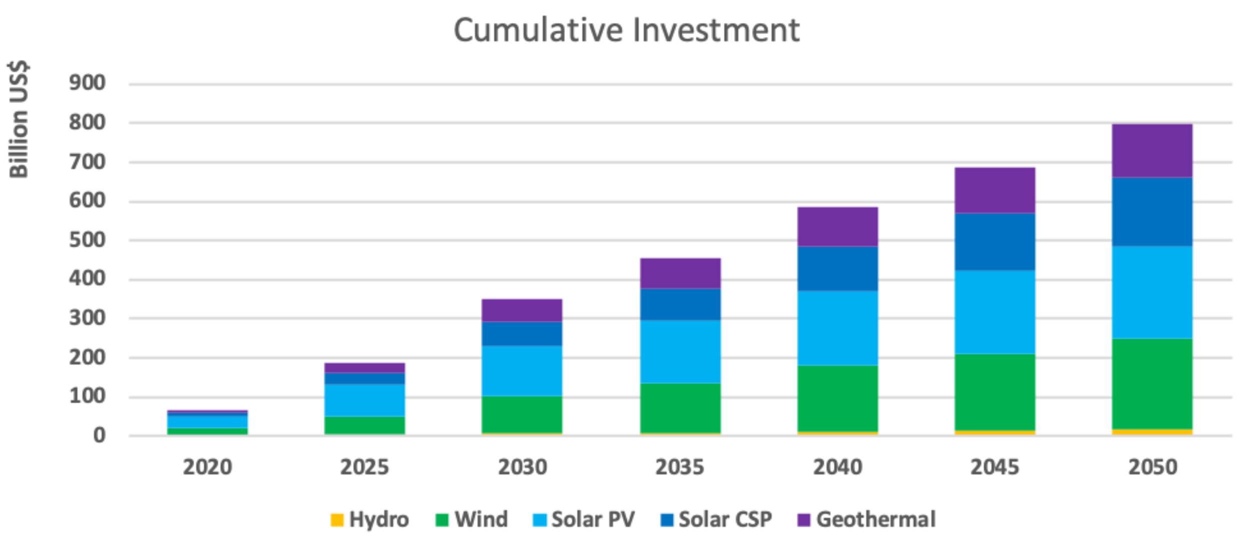
112 The ratio of new capacity considered in the zero emissions scenario is 50% wind, 35% solar PV, 5% solar CSP, 2% hydro, 5% geothermal, and 3% other (including biomass, marine, and utility-size storage). The PV fraction includes utility size and distributed capacity. In some nations, distributed PV is already an important market. See Annex 7 for additional details.

113 The estimated investment in some countries in the region are also included in Annex 7

CO_2 emissions. This level of investment reflects the anticipated requirements necessary to meet the projected energy demand under the reference scenario by mid-century.

The investment associated with the reference scenario is estimated at U.S. $962 billion, 2018 (U.S. $840 billion, 2010) (see Figure 6, Chapter 2); while the capital investments linked to the scenario in compliance with the Paris Agreement, which includes heavy reliance on carbon capture and storage would be about U.S. $2.1 trillion (2018) (U.S. $1.8 trillion (2010)) mainly due to the use of expensive carbon capture and storage technology to achieve zero emissions by mid-century. Clearly, a pathway that takes advantage of the competitiveness of renewables in the region is less capital-intensive.

Figure 3. Investments required under a zero emissions pathway



Source: Author's estimates

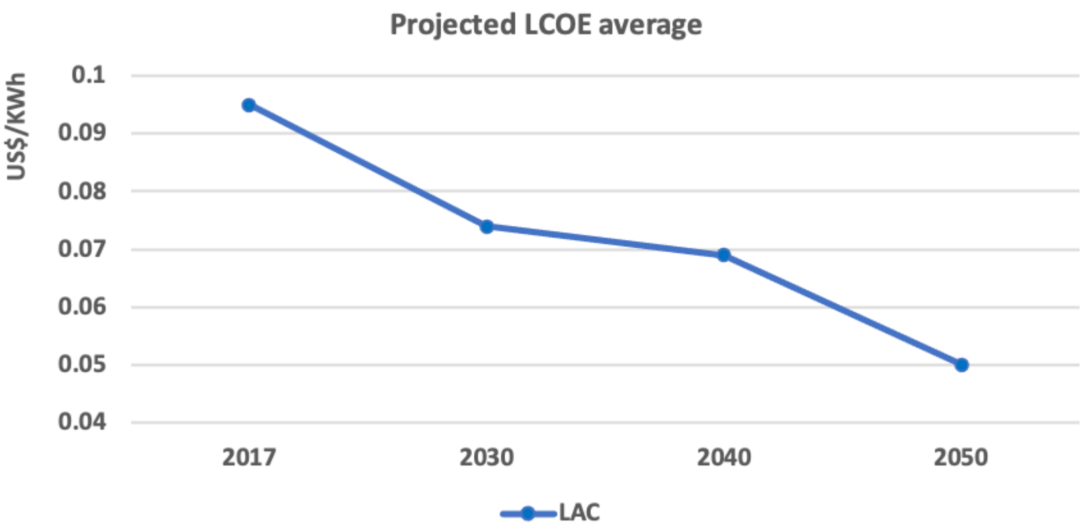
The lower capital and operational costs associated with the capacity matrix under the intervention scenario should result in projected lower electricity generation costs. The projected composite LCOE, under the intervention scenario, is estimated to be $0.048/kWh by 2050.[114] While the estimated cost of generation under the baseline scenario is $0.097/kWh, for about 50% relative savings. Thus, the overall savings in electricity costs are estimated at U.S. $222 billion in 2050[115] but, it does not include the future demand caused by an electrified transport sector. The reductions in generation costs could be directly accrued by all consumers of electricity, making manufacture more competitive and delivering savings to households. An estimate of reduction in compounded costs of power generation for some countries is shown in Figure 4.

The zero emissions pathway implies that future investment in fossil-fuel power generation facilities 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 U.S. $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.

114 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.

115 Based on a demand of 16.7 EJ

Figure 4. Projected compounded LCOEs from technology makeup of the power matrix for some countries under the zero emissions pathway (US$/kWh)



Source: Author's estimates, based on GACMO outputs

Decarbonization of the transport sector. In the intervention scenario all modes for cargo and passenger transport except air travel,[116] switch to electric drives by mid-century; and no internal combustion (IC) fleet is in operation by then.[117] As the energy efficiency of electric drives is three times higher than for IC engines, the energy demand of the transport sector under the intervention scenario is much lower compared to the BAU scenario. Transitioning the transport sector to electric drives is calculated to represent savings to the order of 12 EJ by mid-century.[118] 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 4.

On the other hand, electrification would add to the 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. The additional capacity required is estimated at about 327 GW[119], mostly required by 2040 and afterwards. A fraction of this demand (about 40,000 GWh/year or an estimated equivalent to 10 GW of nominal capacity) can be expected to be met through demand side flexibility (valley filling). The calculation is included in Annex 8. Under BAU conditions it would cost about U.S. $327 billion to meet the additional power demand by 2050. The calculations are also included in Annex 8.

But, if the electrification of transport is coupled to the full decarbonization of the power sector, the cost of the additional capacity to meet this demand is expected to be lower; this is because the capital costs associated to power generation under the intervention scenario are lower than under the BAU, in the future (see Chapter 3). The difference in costs is estimated to be about U.S. $ 103 billion. This is an additional benefit of coupling the transition process. Details of the estimate are also included in Annex 8[120].

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

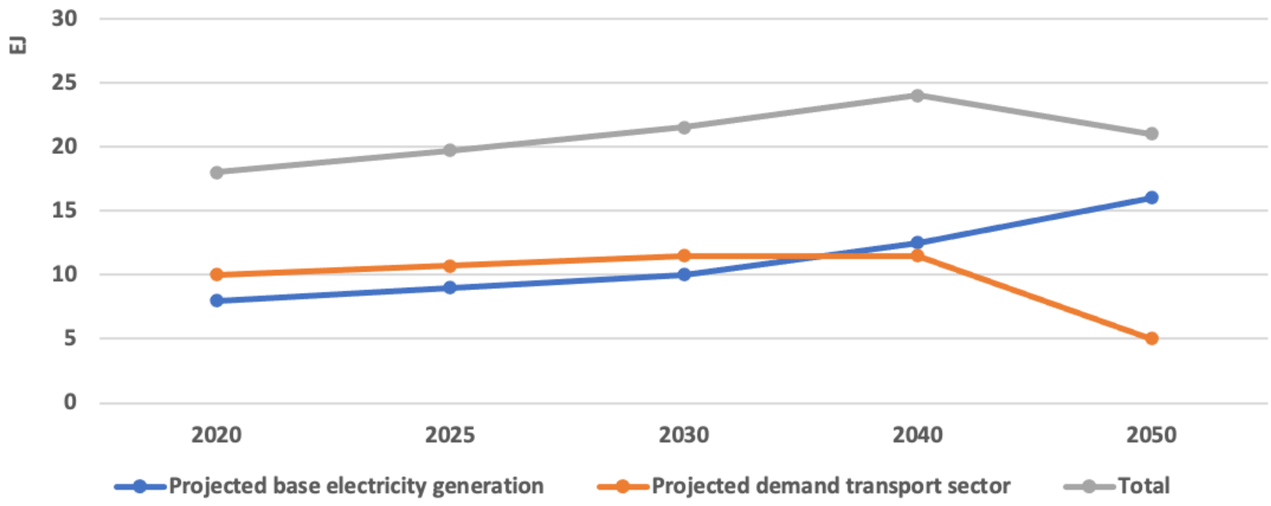
117 The intervention scenario assumes that there is a faster transition to electric drives for cars and buses, a slower transition for trucks and rails, and an even slower transition for vessels. Details on the schedule of transition are included in Annex 7.

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

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

120 The analysis only shows the advantage in capital costs of coupling the electrification of the transport sector to the decarbonization

Figure 5. Projected demand under by a coupled power and transport sectors for a zero emissions pathway (EJ)



Source: Author's estimates

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.[121] If properly managed, electric transport demand could also improve the operation of baseload generation capacity through its flattening of demand.

A fully electric transport sector 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, by mid-century. The assets retired have been calculated to have a residual value of U.S. $10.2 billion.

As a result of lower future electricity costs and lower equipment costs, the LCOTs for electric transport are projected to become lower than vehicles with IC engines. 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 best 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[122]. Under these assumptions, It is estimated that the overall savings in passenger transport costs to the economy would of the order of U.S. $ 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

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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.

121 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).

122 This assumes that there is no residual effect of the pandemic on level of service by 2050.

savings in capital costs to the economy would of the order of U.S. $ 41 billion in cargo road transport. No estimates were made for cargo transport in other modes (rail, vessels).

The combined transition includes an estimated U.S. $30 billion in avoided health costs, which is the most conservative of the valuations summarized in Annex 9. Improved security of supply and efficiency were not monetized. A summary of the costs and benefits is presented in Figure 5.

Figure 5. Combined costs, benefits, and avoided costs by mid-century under a coupled power and transport zero emissions pathway (in U.S. billion dollars, rounded to the nearest billion)[123]

CUMULATIVE IMPACT ON CAPITAL ASSETS	
Reduction in capital investments in the power sector:	162
Reduction in capital investment to meet power demand by electric transport[124]:	103
Value of stranded assets in the power sector:	80
Value of stranded assets in the refinery sector:	10
Net cumulative savings in capital assets:	**175 billion**
ANNUAL SAVINGS IN 2050	
Savings in electricity cost[125]:	222
Reduction in annual costs of passenger road transport:	328
Reduction in annual costs of cargo road transport:	41
Avoided cost of illness:	30
Net annual savings:	**621 billion**

Source: Author's estimates.

Annual savings linked to the coupled transition by 2050 are valued at U.S. $621 billion. These savings also represent a reduction in the value of products and services that make up the Gross National Products (a reduction in GNPs that result in increased welfare). Cumulative savings in capital costs by 2050 are valued at U.S. $265 billion against the BAU scenario. Cumulative losses in capital of retired fossil generation and refinery capacity were estimated at about U.S. $90 billion by 2050.

123 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.

124 The Reduction in capital investment to meet power demand by electric transport is calculated as the difference in capital costs to provide the required energy under the GCA-BAU power system and the Intervention Scenario.

125 Does not include reduction is electricity costs for the transport sector which are captured in the reduction in costs for road transport.

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: a) solar; b) wind; c) electric batteries for vehicles and fixed installations; d) electric bus manufacture; e) smart grid operations; and f) associated R&D, as representative of the type of opportunities as the energy and transport transition takes place.

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.

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 analysis by the Secretariat to the UNFCC[126] found that job creation and

126 https://unfccc.int/sites/default/files/resource/Just%20transition.pdf

enterprise formation will be a function of the speed and depth of transformation of the economy. It found that the 1.5°C scenario would increase the renewable energy capacity faster, so employment would 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 decarbonization[127] 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), 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).[128] 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 located in China (IRENA Renewable Energy and Jobs, 2019). Information available today places the job creation in solar energy[129] in Germany and the United States between 3,600 and 22,000 jobs created per GW installed in 2018;[130] 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,[131] in an industry now with an accumulated PV capacity of 3 GW.[132]

Under the intervention generation, 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 to this demand will require 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.[133]

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 U.S., turbine technician is one of the fastest-growing green occupations in the labor market (US Bureau of Labor Statistics, 2019). In the U.S., there are 1370 jobs per GW of wind energy installed;[134] in

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

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

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

130 https://www.cleanenergywire.org/factsheets/solar-power-germany-output-business-perspectives; https://www.seia.org/solar-industry-research-data

131 https://www.statista.com/statistics/987629/renewable-energy-jobs-industry-mexico/; https://cceea.mx/blog/energia-solar-fotovoltaica/la-energia-solar-en-mexico-triplico-su-capacidad-en-2018

132 https://www.pv-magazine.com/2019/01/16/mexicos-installed-pv-capacity-tops-3-gw/

133 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

134 https://www.awea.org/wind-101/benefits-of-wind/powering-job-growth

Denmark, there are an estimated 6,000 jobs per GW of wind installed. Furthermore, the offshore wind option has large potential in the region and its deployment will require substantial investment in the local supplies industry and 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.[135]

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.[136] 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.[137] 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 79% of the world's lithium resources. 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 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.[138] Other heavy vehicles share a similar platform. One recent study[139] on the automotive market in Europe estimated the net creation of about 0.01 permanent jobs created per electric vehicle in service. This estimate takes into account 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 take into account that 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 systems, and international links with HDVC systems will all create new jobs and promote the formation of enterprises in the region. A study by KEMA for the GridWise Alliance found that in the United States, a $16 billion investment in a smart grid could create up to 280,000 new jobs. A similar assessment found that $50 billion of additional investment in a smart grid over five years ($10 billion per year), could create approximately

135 https://spectra.mhi.com/why-offshore-wind-creates-so-many-jobs
136 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Jun/IRENA_Leveraging_for_Onshore_Wind_2017.pdf
137 https://www.evwind.es/2019/07/07/wind-power-in-brazil-reaches-15-1-gw/67910
138 http://laborcenter.berkeley.edu/bringing-back-good-manufacturing-jobs-america-one-electric-bus-time/
139 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

239,000 new or retained jobs for each of the five years on average, in the United States.[140] Investments in smart grids in South America have been estimated at U.S. $20.1 billion until 2017.[141] Industry sources also estimate an investment of U.S. $6.4 billion in smart grids in Mexico over the next decade.[142]

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.

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 Dominich (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.)) have 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 Table 1.

Table 1. Estimate of additional jobs (millions) generated regionally under the intervention scenario per energy technology by mid-century[143]

Industry	Construction (Job years[144])	Manufacturing (job years)	Operation and maintenance (jobs)
Hydro run of river	0.30	0.15	0.01
Wind Energy	3.36	3.81	0.33
Solar PV	11.43	5.88	0.60
Geothermal	0.69	0.39	0.03
Solar CSP	1.35	0.60	0.09
Total renewable energy	17.13	10.83	1.06
Job losses in fossil-fuel based power generation	1.68	1.28	0.04
Job gains in heavy duty vehicle operation and maintenance			3.8[145]
Jon gains in light vehicle operation and maintenance			1.5
Job gains in grid modernization			1.4[146]
Total			**7.7**

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

141 https://www.smart-energy.com/industry-sectors/smart-grid/smart-metering-to-cover-50-of-south-americas-smart-grid-investments/

142 https://www.tdworld.com/metering/mexico-smart-grid-and-smart-cities-market-84-billion-over-next-decade

143 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.

144 Job years is a metric used to assess the size of temporary jobs created by activities with a limited time frame.

145 Job estimates are 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 & 11.

146 Job estimates based on an investment of U.S. $26 billion between now and 2030 and using the factors for job creation in: https://www.smart-energy.com/regional-news/north-america/new-study-confirms-job-creation-potential-of-smart-grids-in-u-s/.

Opportunities for new economic activity. 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 vehicle design, manufacture and assembly. All these activities would generate 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. The bus segment of the fleet seems attractive enough, given size of market to bus manufactures to house facilities in the region.

Marine energy is of growing interest and is unique in the region. This is an area suited for investment in R&D. There is already growing interest in the 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,[147] 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 2.

Table 2. Opportunities for new/expanded economic activity

Opportunity	Location	Considerations
Vertical integration of wind energy power plants	Brazil, Argentina, Mexico, Chile	Significant domestic international capacity; large generation potential
Marine energy development	Chile	Unique access to resourcecs. 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, Chile	Significant domenstic industrial capacity; large domestic markets
BRT software and management tools	Brazil, Mexico, Colombia, Chile, Peru, Ecuador	Management experience with BRTs
Manufacture of local components for wind and solar and equipment installation	All countries in the region	Local demand
Electric vehicle service and maintenance	All countries in the region	Local demand
Smart grid installation and maintenance	All countries in the region	Local demand

Source: Author's estimation

147 https://publications.iadb.org/publications/english/document/Marine-Energy-in-Chile.pdf

Investment requirements. Embarking on the intervention scenario will create a demand for capital investment in renewable energy technologies, electric transport systems, charging infrastructure, and other ancillary capital investments. The actual investment requirement under the intervention scenario will actually be lower than that estimated under a BAU scenario or a scenario where climate goals are met by mid-century with reliance on carbon capture and storage. In that respect, the investment requirements are less onerous. Also, as the operation costs are much lower for renewable energy plants, the working capital requirements for electric vehicles will be lower but investments will be required for mostly new charging infrastructure.

For the transport sector, this analysis also projects a reduction in the costs of rolling stock, except for heavy duty segments during the period of analysis. The maintenance structure for electric will be less onerous. Investments will be required in assembly and manufacture.

In the context of the anticipated cost efficiency of these investments (and the competitiveness and lower environmental impacts), vis-a-vis funding fossil fuel infrastructure, one would expect higher investment eagerness in the private capital market. Still, the amoun involved is large, and given the nature of the sectors, the investment will come mostly from private sources of capital. There is already a substantial influx of private capital in renewable energy, eased by transparent auction processes and the use of power purchase agreements. But to ensure that barriers to capital investment are minimized, strong market mechanisms and transparent tendering and auction design are required to attract near-term private sector investment in the renewables sector and stable policy and regulatory environments are required.

Public investment would be associated with the set-up of public sector policies, removal of barriers, and a financing role for the less capital-intensive off-grid sector. The public sector will, on the other hand, benefit from the elimination of fossil fuel subsidies, which have been estimated at U.S. $200 billion annually (IMF, 2014).

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. A skilled, educated labor force will contribute to attracting component 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.

CHAPTER 9

Policy Options for an Accelerated Transition

The policy environment in support of delinking carbon emissions from economic activity has made recent progress, in particular in support of a cleaner power matrix, and a cleaner transport system. There is also, in general, a positive posture in support of climate mitigation and adaptation actions in most countries; and widespread public support for measures to address climate change. In some nations, this has resulted in the enactment of policy frameworks in support in support of a diversified and renewable energy matrix.[148] The Nationally Determined Contributions (NDCs) to the Paris Agreement continue to evolve reflecting some of these developments.

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.[149] The trends in technology and economics have contributed to the growth of the use of renewables 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 necessary a strong, bold policy agenda. The elements of such agenda are explored in this section.

The scope of this chapter is not to analyze the policy framework in each country in the region.[150] Instead, emphasis is made on directions 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.

Policy agenda for power sector transition. Adoption of renewable energy for power generation has been facilitated by at least four policy elements:

148 Additional information can be consulted at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_IEA_REN21_Policies_2018.pdf

149 For example, measures that would discourage market entry or renewables.

150 A detailed policy review for renewables can be consulted at: https://www.irena.org/publications/2018/Apr/Renewable-energy-policies-in-a-time-of-transition;

a. policy commitments and targets under the Paris Agreement and a favorable policy posture to mitigate greenhouse gas emissions and improve the resilience of associated infrastructure to the impacts of climate change;
b. the set-up of national targets for participation of renewables in the power matrix;
c. adoption of enabling regulations to facilitate private investment and access to transmission and distribution infrastructure; and
d. encouragement of private players to compete in the electricity market and invest in electricity generation and trade. These and other aspects have been discussed in the previous report and other sources. New or additional policy goals and instruments, part of a bolder agenda, are summarized in Table 1, and described in more detail below.

Table 1. Key macro goals and instruments that are part of a bold policy agenda in support of the coupled decarbonization of the power and transport sectors

Goal	Policy	Instruments
Reduce the cost of stranded assets in the power generation and refinery sector.	Discourage capital investments in the fossil industry.	Clear energy and transport policy adopting zero emission goals by mid-century. Allow early depreciation of assets.
Promote more flexibility, storage capacity and integration of distributed options to ensure that variable resources can operate in a cost-effective manner.	Promote investments in a modern, smart transmission and distribution infrastructure.	Clear regulations on demand management and the use of storage, net metering and distributed options.
Optimize allocation of generation and transmission infrastructure to meet demand.	Promote regional grid integration.	Market-based power exchange with neighboring countries.
Internalize health and climate costs in transport emissions.	Develop fiscal measures that enable allocation of the costs of health and climate impacts.	Fiscal measures to pass costs to emitters of airborne pollutants and GHGs. Use revenues to promote public investments in enabling infrastructure.
Encourage level playing field for use of renewables and electric transport	Promote economic competition of new technologies with fossil fuels.	Eliminate subsidies for use of fossil fuels
Facilitate market entry of electric transport.	Direct the removal of regulatory and policy barriers.	Adopt standards for charging. Review/modify road standards. Enact transit and parking preferences. Regulate composite fleet emissions.
Promote technology and business development in support of the transition.	Promote investments in R&D and technology development in zero carbon technologies.	Clear technology and science policy in favor of zero emission goals by mid-century. Fiscal measures to support investments in R&D.

Discourage investments in new capital assets in the fossil industry. The pathway to decarbonization requires an immediate change of direction. While there is 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 pe-

riods,[151] thus it is important that a strong signal be issued now to prevent additional locking-in of emissions, which may, in the end, become stranded assets. An important first step is to ensure that any new capacity is based on renewable sources of energy.

The transition is being aided by the competitive character of renewables in the region, when allowed to play in an open market, but may require policy directions to steer investments away from fossil fuels for power generation and establish sunset provisions for fossil fuel power generation and internal combustion engines. Examples of fiscal instruments to consider include the elimination of fossil fuel subsidies and taxation of fossil fuel generation capacity. The same applies to new investments in refining and fuel distribution systems.

Public support for investments in modern transmission and distribution infrastructure to enable integration of variable resources. As discussed earlier in the report, 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. 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. There are already good accounts of how to do this, in Denmark,[152] Germany, Costa Rica, and Uruguay, for example.

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 dispersed generation and ability to store energy has also been part of the transition of the power system in Germany.[153] Variable resources are integrated fully and very little of the net demand is now non-fluctuating. On the other hand, the experience in Costa Rica illustrates how investments in geothermal contribute to increase firm baseload 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.

Promote regional integration of the transmission system. The region already has 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 among 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 hydropower 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 interconnection needs to be completed while avoiding any impacts on natural ecosystems.

Encourage market instruments to make use of plentiful renewable energy endowments.

- **Auctions.** Competitiveness of energy resources can be maximized through the use of market auctions to set real market pricing and ensure transparency.[154] Experience with auctions has been encouraging and should continue to be promoted. Auctions should convey certainty to the market and provide clear

151 https://qz.com/61423/coal-fired-power-plants-near-retirement/

152 https://www.agora-energiewende.de/fileadmin2/Projekte/2015/integration-variabler-erneuerbarer-energien-daenemark/Agora_082_Deutsch-Daen_Dialog_final_WEB.pdf;

153 https://energypost.eu/how-german-energiewendes-renewables-integration-points-the-way/;

154 A good review of the criteria and advantages of power auctions can be consulted at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/Jun/IRENA_Renewable_Energy_Auctions_A_Guide_to_Design_2015.pdf;

policy directions while preserving flexibility to changing market conditions. A guide on the design and results of auctions is available from IRENA.[155]

- **Enable distributed energy.** Most countries in the region are already in the process of setting an enabling environment for distributed energy. Given its potential and advantages to promote to improved system operation, a stable, flexible regulatory framework is required. Countries are already establishing policy and regulatory frameworks for distributed generation, including technical standards, permitting processes, grid access protocols, and other instruments.
- **Storage.** Policies promoting and 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.
- **Renewable energy voluntary programs.** Such programs 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 energy efficiency measures, buy green energy, or improve the transport system of the company.

Policy agenda and measures for electric transport. The transition to electric transport is at an earlier stage and will require a much more forceful support agenda. Elements of the policy suite include:

- **Promote adoption of electric vehicles in future public transport systems 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 warrants 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.
- **Promote early adoption of standards for heavy vehicle and marine fleets.** The technology for heavy vehicles is moving fast. A proactive policy to attract vehicle and battery manufacturers to the region would speed adoption of solutions for these segments of the market. The region should facilitate fleet tests and pilot tests and promote assemblage of vehicles. The region should also encourage power storage facilities at fleet, transport depots and ports to help manage demands. A proactive industrial policy to attract vehicle and battery manufacturers to the region would speed adoption of solutions for these segments of the market. It could also send a strong signal to disincentivize investment in new ICE manufacturing/assembling plants, which risk becoming stranded assets over the medium term.
- **Review and modify road regulations** that conform to the weight requirements of heavy electric vehicles and facilitate investment in modernization of road infrastructure.
- **Promote the deployment of charging infrastructure.** Incentives, in the form of tax credits and rebates, could be directed to gasoline stations to promote the set-up of charging infrastructure aiding in the transition of the distribution system to electricity. Parking lots should also be encouraged to buy in into electric charging infrastructure. EV charging units can go beyond gas stations. Thus, incentives could also be made available to real estate developers, local governments, commercial areas, and the hospitality industry in order to provide alternatives for EV charging.

155 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/Jun/IRENA_Renewable_Energy_Auctions_A_Guide_to_Design_2015.pdf)

Strengthen measures to promote electric transport mode in light vehicles.

- **A transport fuel tax for gasoline** is a measure with direct impact on private automotive, taxi, and other light vehicle fleets.
- **CO 2 emission standards** imposed on vehicle distributors and manufacturers could mirror progress being made in Europe and California preventing the dumping of obsolete technology in the region.
- **Adopt all-electric mode in government fleets.** Electric government fleets are visible and provide a clear intention to move the market in direction of electrification.
- **Adopt incentives to promote transport companies to move to all electric vehicles.** Fleets of taxis and shuttle buses can be an early target to publicize electric options.
- **Transit and parking preferences** for electric vehicles can stimulate purchase of commuting vehicles.
- **Short-term fiscal measures** to bridge existing price differentials with internal combustion vehicles (such as tax credits, reduced sales tax, and reduced tariffs).

Encourage the development of a carbon market/carbon taxes. This is one of the measures with potentially larger impact. There are already functioning carbon markets in the region, including in Colombia, Chile, Mexico, and a proposed regional market for the Pacific nations. The experiences in the design and operation can inform expansion and adoption in other countries. A regional market 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. The carbon taxes should reflect the level of emissions.

Internalization of health 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 early stage of the transition. The costs could be made to be paid by the emitters through the enactment of fiscal measures.

Cross-support charging of electric vehicles. Differentiate charging tariffs and/or fees 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.

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.

Address refineries.

- **Plan for no additions of refinery capacity.** This would be signal to the refinery sector that future demand of energy by internal combustion engines is being phased out.
- **Allow early exit of refineries to minimize the value of stranded assets.** This would entail policies to encourage sunset provisions for refineries, distribution centers and infrastructure.

CONCLUSION

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. This transition represents an important opportunity to raise the level of ambition of Nationally Determined Contributions (NDCs) and long-term strategies with many no-regret[156] options to meet international climate commitments, established under the Paris Agreement and to support the achievement of Sustainable Development Goals.

Decarbonization of the power sector

The first steps of this transition are already in place in the region. In the power sector, renewables already account for over 51% of generation and non-conventional renewables have expanded their capacity by 50% since 2012, now accounting for 12% of the total. Plants under construction or contracted will greatly add to the total. Electricity in the region is already one of the least carbon-intensive worldwide (242 t CO_2 per MWh). The changes in electric transport have been slower and there is not comparable supporting infrastructure; however, there is already an increase in demand for electricity by the sector (0.06 EJ, 10 times the figure for 2012) with ambitious plans and announcements for passenger and cargo vehicles.

A full decarbonization of the power sector, based on a substantial resource endowment, rapid technological change leading to lower costs, and strong institutional capacities and experience is found to be technically and economically feasible as well as financially attractive for private investment.

156 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.

- Energy demand is anticipated to more than double to about 17 EJ by mid-century, requiring substantial additional investment. Meeting the projected demand with a mix of fossil fuels and renewables, as projected by GCAM under a BAU scenario, would still result in over a gigaton of annual emissions of CO2 by mid-century, placing the region further away from the pathway committed at in the Paris Agreement and resulting in a higher level of required investments.
- The analysis forecasts that the displacement of fossil fuel-based capacity in power generation by renewable energy sources would result in reduced costs of electricity, as wind, solar, and hydro already outperform or match the generation costs of coal and gas and are projected to continue to improve their relative competitiveness with fossil fuels in the future. The reduction in electricity costs by mid-century, through renewable-based generation, would reflect in savings to the economy of the order of U.S. $222 billion per year by mid-century.
- It also concludes that a fully-renewable energy matrix will require substantially less capital investment than a fossil fuel-based infrastructure (about U.S. $162 billion less) and result in over one million new permanent jobs generated by 2050 and about 25 million job years during construction and manufacturing. It would also be significantly cheaper than projected investments in carbon capture and storage to achieve the same goals (about U.S. $400 billion less).
- In addition, a diversified renewable power matrix in the region would deliver improved 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.
- The analysis also finds compelling arguments for the use of distributed energy resources taking advantage of efficient use of local renewable resources and low capital costs to strengthen resilience of supply and complement central grid operations.
- The deployment of renewables to meet all electricity demand in the region, will result in the retirement of the fossil fuel power units, causing a loss in not-depreciated value estimated at U.S. $80 billion by mid-century. The projected loss of competitiveness represents a clear cautionary signal for the sector against additional investment of capital in fossil fuel capacity.

Coupled electrification of the transport sector

The report also concludes that the coupled transition of the transport sector toward electrical modes would benefit from the trends in the power sector and contribute to improve its operation with significant economic, financial, and health benefits.

- Demand for transport services is projected to double its current energy use to about 18 EJ by mid-century, resulting under a BAU scenario, with an annual emission of 1.2 GT CO_2 by mid-century, a doubling of current levels.
- Eliminating emissions from the heterogeneous transport fleet in the region 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 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 transportation and must be included in the process to facilitate the changes required.
- 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 U.S. $30 billion by mid-century.

- Electrification will also cause significant reductions in levelized cost of transport, induced by the comparatively higher efficiency of electric engines and the anticipated lower capital costs of rolling stock. The combined demand by power generation and electric transport has been calculated to be of the order of 21.5 EJ by mid-century.
- Moreover, with demand-side management measures in place, steering electric charging toward periods of lower load in the daily demand curves (valley filling), electricity use by the transport sector might improve operational parameters of the electric sector, flattening the demand curve 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.
- 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 U.S. $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.
- Most importantly, the reduced cost of rolling stock and electricity will reduce the cost of transport of passengers and cargo. The reductions in road transport are estimated at U.S. $369 billion by 2050.

Benefits from a coupled transition

The coupled transition of both sectors toward full decarbonization, the report concludes, would generate the following benefits.

a. Substantial economic savings in the region, derived from reduced power and transport costs, are valued at about U.S. $591 billion per year.
b. It is also estimated that elimination of exposure to particulate matter in urban areas would conservatively result in annual avoided cost of illness of about U.S. $30 billion.
c. The transition would result in savings in capital outlays estimated at about U.S. $265 billion by 2050, derived from anticipated lower capital requirements from renewable energy sources.
d. The use of renewables for all power generation, grid modernization and electrification of the fleets are calculated to generate 7.7 million permanent jobs and 28 million job years of temporary jobs.

The savings represent a reduction in the costs of products and services (a reduction in GNP) that results in a net increase in economic efficiency and welfare.

Priority policy agenda

While technology, economics, management practices, and market trends are found in support of the coupled transition, the report recommends a suite of policy actions in the power sector to:

a. Discourage investments in new assets for fossil fuel-based power generation through clear energy and transport policies, adopting zero emission goals by mid-century and enacting sunset provisions to encourage the early retirement of fossil fuel capital assets;

b. Encourage investments in transmission and distribution infrastructure compatible with variable, intermittent power sources and use of distributed generation and storage, through the adoption of clear regulations encouraging open access and competitiveness, as well as in support of demand management, the use of storage, net metering, and distributed options;
c. Accelerate regional grid integration through market-based power exchange mechanisms with neighboring nations.

It also recommends the adoption of policy measures in the transport sector to:

a. Accelerate development of charging and maintenance infrastructure for passenger electric vehicles through adoption of standards, regulations, transit, and parking preferences;
b. Encourage early adoption of standards for heavy vehicles and marine vessels; and
c. Modernize road regulations to conform with the requirements of heavy electric vehicles.

The report also finds a priority to complement existing policy frameworks and regulations that pass costs to emitters of airborne pollutants and GHGs through the adoption of fiscal measures, carbon markets, and levies reflecting the cost of these emissions to the regional economy.

This is an opportunity for sizable economic and climate benefits in the coupled decarbonization of the power and transport sectors. It can lend support to increased NDC ambitions. It represents a pathway that would deliver climate goals at net economic benefits without negatively affecting access to, or quality of, services.

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ANNEX 1

Global Change Assessment Model (GCAM)

For the 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 a 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.

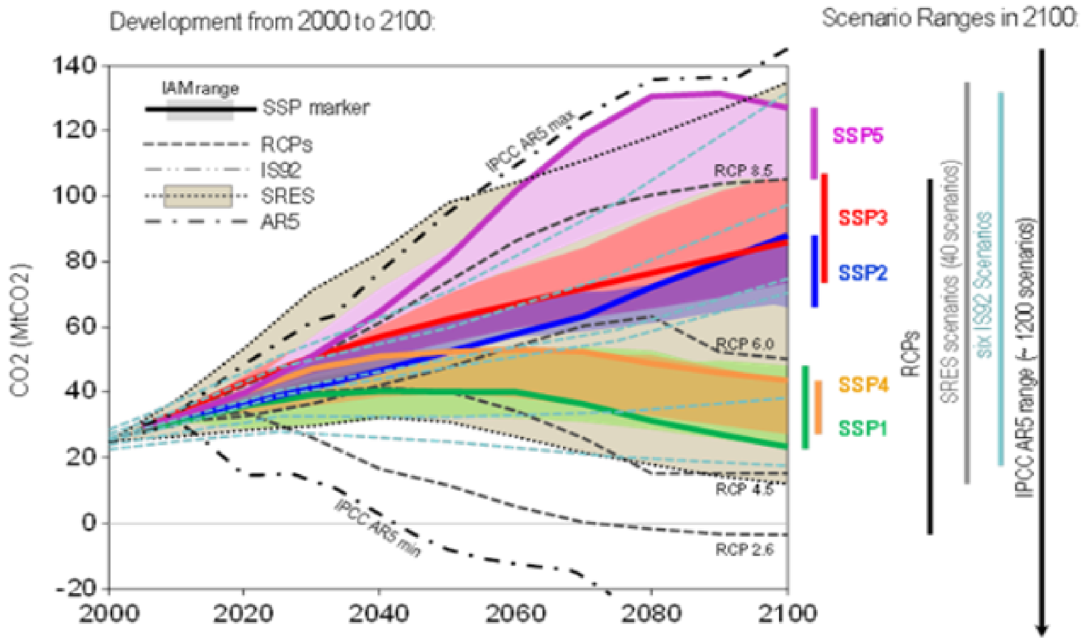
In GCAM's reference scenario, socioeconomics are consistent with the Shared Socioeconomic Pathway 2 (SSP2), "middle of the road" scenario (Fricko et al. 2017).[157] The SSP2 scenario as described by Fricko et al. results in a global final energy demand of 640 EJ/yr by 2050 and leads to 6.7 W/m^2 of radiative 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^{o}C.[158] To reach this level of emissions, the power sector relies heavily on carbon capture and storage.

157 https://www.sciencedirect.com/science/article/pii/S0959378016300784

158 In fact, the 2100 temperature anomaly in GCAM RCP2.6 reaches about 1.7C.

Figure 1. SSP Land Use-Energy-Economy-Emissions Scenarios



Riahi K., et al, 2018

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 that:

a. Starting around 2021, 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.

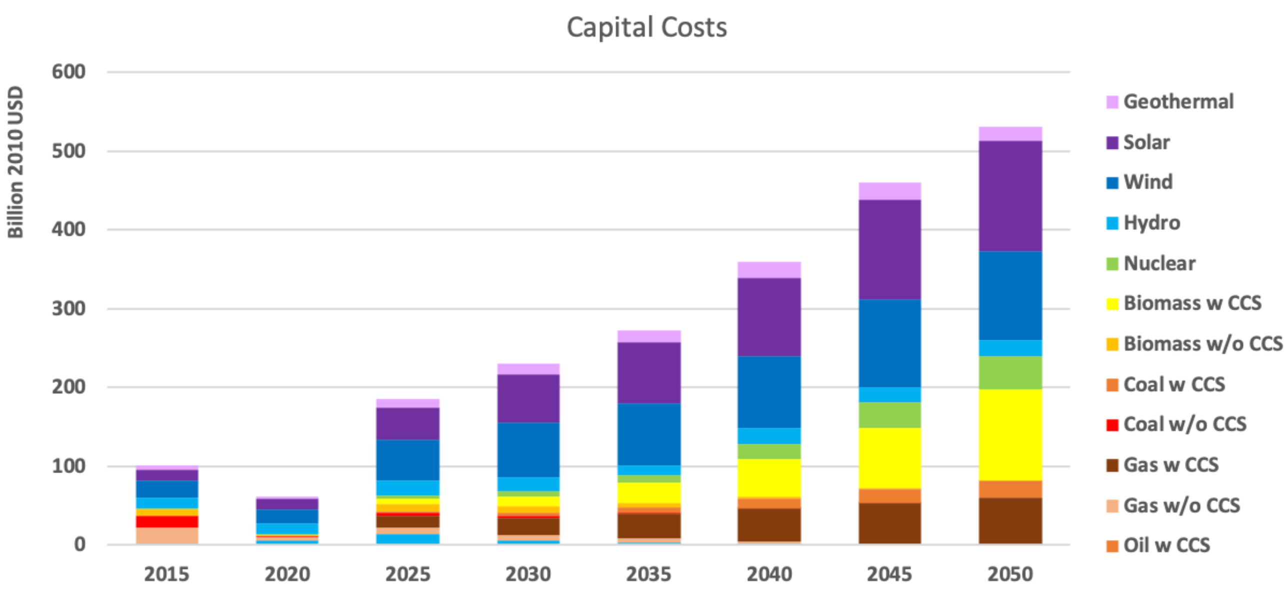
For the transport sector, the pathway includes:

a. 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 of time. 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.

The GCAM RCP scenario relies heavily on carbon capture and storage to meet total decarbonization of the power sector by 2050. The total capital outlay for this scenario is calculated at U.S. $1.9 trillion (2010) (U.S. $2.2 trillion (2018)).[159]

Figure 2. Capital outlays, per period of five years, to meet power demand under the GCAM RCP Scenario until 2050.



Source: GCAM outputs, obtained October 2019. The cummulative capital costs until 2050 are estimated at U.S. $ 2.2 Trillion (2018 values).

159 For conversion to USD (2018), an inflation factor of 1.15 was used.

ANNEX 2

Carbon Footprint of Natural Gas

Natural gas is essentially methane (CH_4). Typically, in natural gas, there will be minor amounts of heavier weight hydrocarbons like ethane (C_2H_6), but for purposes of this calculation and because these other compounds are present in minor amounts (if not, they are typically separated) and would emit more CO_2 per unit of carbon, their contribution will be ignored. Coal is just C.

Upon total combustion, natural gas emits less CO_2 than coal per unit of weight. This is the result of its molecular composition. This is known as the stoichiometry equation.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

For each 16 tons (considering the respective molecular weights) of CH_4, 44 tons of CO_2 are released.

For coal, the stoichiometry equation is:

$$C + O_2 \rightarrow CO_2$$

For each 12 tons of coal, 44 tons of CO_2 are released. That is, one ton of carbon emits 33% more CO_2 than one ton of natural gas.

But methane has a much greater warming potential than CO_2. That is, if methane is released to the atmosphere, it would have a greater warming effect per unit of molecular weight than CO_2. Taking into account the residence time in the atmosphere, the IPCC[160] 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 CO_2.

160 www.ipcc.ch

Table 1. Global warming potential of some greenhouse gases

Industrial designation or common name	Chemical formula	GWP values for 100 year time horizon		
		Second Assesment Report (SAR)	Fourth Assesment Report (AR4)	Fifth Assesment Report (AR5)
Carbon Dioxide	CO_2	1	1	1
Methane	CH_4	21	25	28
Nitrous oxide	N_2O	310	298	265

Source: http://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf

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 a net reduction of 33% in CO_2 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,[161] it was found that 2.3% of methane is leaked into the atmosphere.

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 emissions from natural gas at 8% of total GHG emissions from the oil and gas industry.[162] In Argentina, Codeseira[163] estimated that between 2002 and 2014, the distribution system for natural gas to the end users lost between 2 and 10% in weight.

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 CO_2
CH_4 (.033%x28 CO_2) =	0.92 tons of CO_2 equivalent.
Total=	3.67 tons of CO_2 equivalent.
Per ton of C:	
Combustion of C, 1 ton yielding	3.67 tons of CO_2

161 https://science.sciencemag.org/content/361/6398/186
162 https://imco.org.mx/wp-content/uploads/2018/02/AFB-Emisiones-de-metano-en-el-sector-petr%C3%B3leo-y-gas.pdf
163 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.

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

Intensity of energy fields. For the Atacama desert, a solar irradiance of 265 W/m^2 was considered. For Sonora/Chihuahua, it was 190 W/m^2. 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.

Table 2. Estimate of the equivalent electricity potential of large oil producers

Oil Producing Nation	Annual Oil Production (MMBBL) (AOP)	Estimated annual electricity production at site (PWh)	Renewable Energy Area	Energy intensity	Total area (km^2)	Efficiency of conversion to power	Years of generation of 10% of area to equal electricity generated through oil production
Saudi Arabia	4.53	3.85	Atacama	265 W/m^2	102,000	20% in PV	0.7
Iran	1.63	1.1	Sonora Chihuaha	190 W/m^2	260,000	20% in PV	0.1
Brazil	1.27	1.0	Coast line of Brazil	500 GW	7500 km	20% on line factor for wind plants	1.2

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

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 GW x 0.25 x 8760 hours of operation/year = 0.22 TWh

ANNEX 5

Road Transport Fleet in Some Countries in the Region

The road transport fleet in some countries is described in Table 1.

Table 1. Size of the road transport fleet in some countries (in thousands of units)

	Autos	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

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. However, the COVID-19 emergency has reduced the demand on motorized road transport for passengers, while increasing the use of non-motorized transport. It has likewise increased the demand for urban cargo (delivery services).

The long-lasting impacts of the emergency can not be predicted at this moment. It is expected however that after the emergency abates and the economies recover, the motorization rate will continue to grow at a 3% rate per year until 2030. 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 assummed to double in size by 2050. The truck fleet would double as well.

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 Comissioning 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	Country	Capacity (Thousands of Barrels per Day)	Most Recent Commissioning Year	Installation Cost (U.S. $ billion)
ARG	Argentina	580	2010	2.32
BRA	Brazil	2285	2010	9.14
CHL	Chile	258	2010	1.03
COL	Colombia	421	2010	1.68
	Curacao	320	2010	1.28
	Ecuador	175	2010	0.70
MEX	Mexico	1546	2010	6.18
PER	Peru	253	2010	1.01
	Trinidad & Tobago	165	2010	0.66
VEN	Venezuela	1303	2010	5.21
	Other South & Central America	384	2010	1.54
	Total Latin America	7690	2010	30.76
	Total South & Central America	5979	2010	23.91

ANNEX 7

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.

Table 1. Assumed Make up of Future Power Generation Capacity

Country	Current capacity of renewables (GW)			
	Hydro	Wind	Solar	Geothermal
Argentina	11.28	0.75	9.22	
Brasil	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

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.

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 whichrepresents 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.

ANNEX 8

Estimate of Costs of Transport under the Intervention Scenario

The size of the transport service for passenger and cargo transport by mid-century 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	2771	4595	4135	460
2030	56	1571	3772	5643	5079	564
2050	84	1456	5814	7584	6826	758

Source: GCAM outputs.[164]

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 similar to LCOE, where the capital, operation and maintenance costs are levelized on an annual basis during the lifespan of the asset.

164 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	Tons cargo/vehicle	5	15
Total Cost of Service in U.S. $ billion					
Conventional	8.2	668.6		1242	39
Electric	26.6	324.2		1160	80
Difference	+16.4	-344.4		-82	+41

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 mid-century (see LCOT table in Chapter 5), with a net saving for passenger transport of U.S. $ 328 billion. Similarly, the electrified cargo fleet (just trucks) has a combined savings of U.S. $ 41 billion. The total annual savings are estimated at U.S. $369 billion.

ESTIMATED CAPITAL REQUIREMENTS TO MEET ADDITIONAL POWER DEMAND FROM ELECTRIFICATION

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 = U.S. $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 U.S. $214 billion for savings of U.S. $ 103 billion.

Table 3. Estimated capacity required to meet electricity demand by the power sector by mid-century (GW)

Year	Share of new capacity on line (%)	Wind	Solar	Geothermal	Hydro
Capacity installed by 2040	40	71.9	52.3	3.9	2.1
Investment per MW by 2040 (U.S. $ million)		600	600	3764	1138
Total Investment by 2040 (U.S. $ 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 (U.S. $ million)		550	400	3262	1138
Investment by 2050 (U.S. $ billion)		59.3	39.2	19.2	6.1

ANNEX 9

Valuation of Avoided Health Impacts

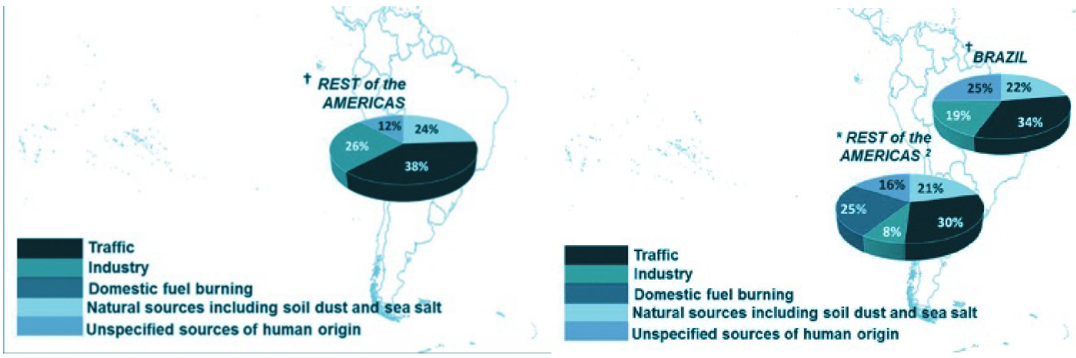
To estimate the value of avoided health impacts, the following studies were considered:

a. OECD (OECD, 2014), which found that in OECD countries, the cost of air pollution including death and illnesses was about U.S. $1.7 trillion, with Mexico accounting for U.S. $39 billion. The study also found that 50% of particulate matter is caused by the transport sector.

b. The review of contributions to cities' ambient particulate matter (PM) by Karagulian and colleagues,[165] which attributed 38% of PM_{10} emissions and between 30-34% of $PM_{2.5}$ to traffic in LAC cities (see Figure 1). For purposes of the analysis, it is assumed by the authors that a majority of the attribution is derived from diesel combustion.

c. The analysis of urban air quality and human health by Cifuentes and colleagues (2003) estimated regional economic benefits in terms of avoided costs of illnesses to the order of $3-8 per person a year.

Figure 1. Attribution of emissions of PM_{10} and $PM_{2.5}$ by source in cities in the region



Source: Adapted from Karagulian F et al 2015

The estimates using each of the methods above is summarized in Table 1.

165 https://www.sciencedirect.com/science/article/pii/S1352231015303320

Table 1. Valuation of health benefits from elimination of exposure to PM by alternative methods

Method	Value of health benefits (U.S. $ billion (2018) per year)
Avoided exposure resulting from a 10% reduction of PM to urban populations (Cifuentes et al, 2005)	30-68
Impact of elimination of PM from diesel combustion in transport (based on estimates for Mexico; OECD, 2014)	113
Impact of elimination of PM from diesel combustion in transport in urban areas (based on regionwide estimates; Karagulian et. al., 2015)	32

The avoided exposure uses the per capita WTP factors by Cifuentes and colleagues, 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 colleagues in the region. The most conservative valuation of the different studies is $30 billion/year, which is used for purposes of the report.

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	12000
Electric cars	12000
Diesel buses (18m)	100000
Electric buses (18m)	100000
Diesel buses (12m)	40000
Electric buses (12m)	40000
Diesel light trucks	12000
Electric light trucks	12000
Diesel heavy trucks	37500
Electric heavy trucks	37500

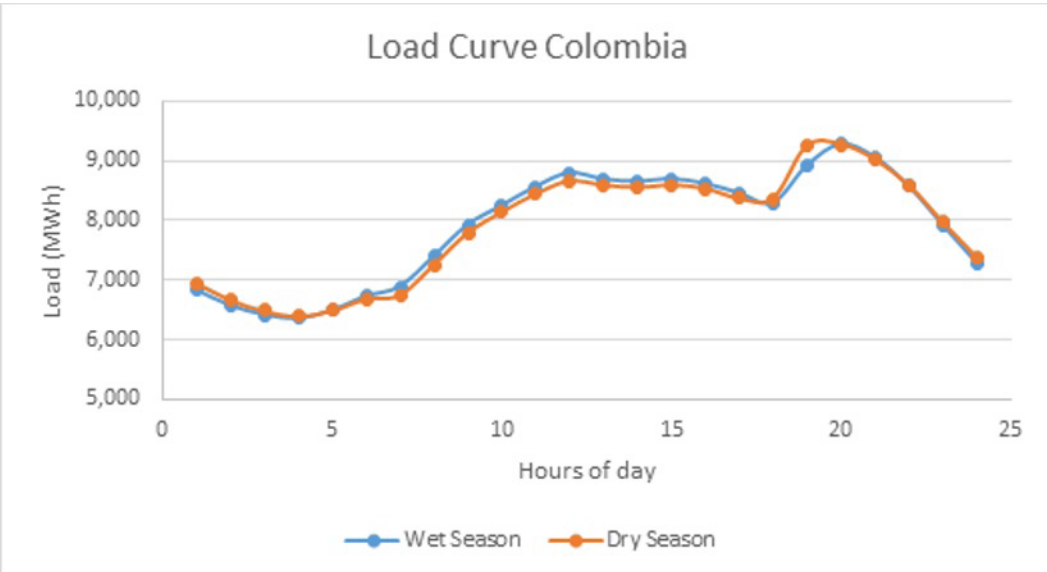
Table 2. Future capital cost of road transport fleet (U.S. $ in 2018)

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

Figure 3. Load curve in Colombia



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 on line 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	6800	3900	400	34
CSP	8900	4000	700	51
PV	13000	6700	700	296
Wind	3000	3400	300	373
Hydro	7500	3900	200	14

Source: Adapted from Dominich et al 2018

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 per heavy vehicle and .01 jobs per light vehicle were used.

For jobs related to smart grid construction, operation, and maintenance, it was estimated that 52,500 jobs would be generated for each U.S. $1 billion of investment.

Praise for "The Opportunity, Cost, and Benefits of the Coupled Decarbonization of the Power and Transport Sectors in Latin America and the Caribbean"

"The authors surface the exciting pathway that lies ahead for Latin America if it seizes the opportunity offered by energy transitions and aggressive moves to decarbonize transportation. With incredible natural endowments, plummeting prices for modern renewable energy, and with a need for more equitable economies, a clean future is within reach, and with it jobs, clean air, more competitive cities and a region at peace with nature."

—Rachel Kyle (Dean Fletcher School of Law and Diplomacy, Tuffs University)

"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… 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 Topping (President Climate Institute)

"The authors have focused on the opportunity of a interlinked transition of the electricity and transport sectors in Latin America and the Caribbean. 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 Alberto Moreno (ex-President Inter-American Development Bank)