DDP DEEP DECARBONIZATION PATHWAYS

POLICY LESSONS FROM THE

Deep Decarbonization Pathways in Latin America and the Caribbean Project

OVERALL SYNTHESIS AND COUNTRY TEAM PERSPECTIVES

DDPLAC

DDPLAC Consortium. Edited by C.Bataille

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Contacts: *Chris Bataille,* chris.bataille@iddri.org *and Henri Waisman,* henri.waisman@iddri.org

DEEP DECARBONIZATION PATHWAYS (DDP) INITIATIVE

The DDP initiative is an initiative of the Institute for Sustainable Development and International Relations (IDDRI). It aims to demonstrate how countries can transform their economies by 2050 to reduce their greenhouse gas emissions in a deep and coherent way, with the aim of reaching carbon neutrality as soon as possible in the second half of the 20th century. The DDP initiative is based on the Deep Decarbonization Pathways Project (DDPP), which analysed the deep decarbonisation of energy systems in 16 countries prior to COP 21 (deepdecarbonization.org). Both projects share key principles. Analyses are carried out at the national scale, by national research teams, working independently from their governments. These analyses adopt a long-term time horizon to 2050 to reveal the necessary short-term conditions and actions consistent with the achievement of long-term climate and development objectives. Finally, national research teams openly share their methods, modelling tools, data and the results of their analyses to share knowledge between partners in a very collaborative manner and to facilitate engagement with sectoral experts and decision-makers. The development of long-term deep decarbonisation sectoral trajectories in different countries, in this case with freight transport in France, is part of this broader initiative.

DDPLAC Consortium

The Deep Decarbonization Pathways in Latin America (DDPLAC) consortium is managed by the Institut du Développement Durable et des Relations Internationales (IDDRI). It consists of a group of independent experts in the following institutions

- Fundacion Bariloche, Argentina
- Centre International de recherche sur l'Environnement et le Développement (CIRED)
- Universidad de los Andes, Colombia
- Universidad Del Rosario, Colombia
- Pacific Northwest National Laboratory (PNNL)
- Universidad de Costa Rica, Costa Rica
- KTH Royal Institute of Technology
- Escuela Politecnica Nacional, Ecuador
- COPPE- Uniersidade Federal do Rio de Janeiro (UFRJ)
- Tempus Analitica, Mexico
- Evolved Energy Research
- Universidad del Pacifico, Peru

The views expressed in this report do not necessarily reflect the views of any government or those of the institutions of the different authors.

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POLICY LESSONS FROM THE

DEEP DECARBONIZATION PATHWAYS IN LATIN AMERICA AND THE CARIBBEAN PROJECT

DECEMBER 2020

DDPLAC

CROSS-CUTTING POLICY LESSONS

COUNTRY PERSPECTIVES

ARGENTINA

COLOMBIA

COSTA RICA

ECUADOR

MEXICO

PERU

Graham Watkins
Chief of the Climate Change and Sustainability Division
Inter-American Development Bank

Foreword

The COVID-19 pandemic is still raging across Latin America and the Caribbean with large negative effects on peoples' health, jobs, and liquidity. The medical and social emergency is the focus of governments, but they are also looking to the future and to ensuring sustainable economic recovery.

The pandemic affects our region because of pre-existing development gaps. Informal street vendors, for example, cannot work from home or make money if everyone else works remotely and have limited or no access to health care. The pandemic is hitting 50% of such informal workers in Latin America and the Caribbean especially hard. These same vulnerable groups are most affected by the climate crisis, for instance, when heat waves make it too hot to work outside or storms and floods present life-threatening risks. Our recent book, Jobs in a Net Emissions Future, published with the International Labour Organization, highlights why countries need a plan to recover from the pandemic's economic and social effects while getting on track to create net-zero and climate resilient economies by 2050.

This new report showcases the results of the Deep Decarbonization Pathways for Latin America and the Caribbean project (DDPLAC), which has generated important experience in how development banks can help countries design long-term decarbonization strategies. DDPLAC is an academic project designed and executed by the IDB, in partnership with the 2050 Pathways Platform and the French Development Agency (AFD), that draws upon the knowledge and skills of the Institute for Sustainable Development and International Relations.

In this project, academics and think tanks from six countries have confirmed, through rigorous peer reviewed analysis, that technical solutions exist to transition towards net-zero carbon emissions while preserving economic growth. The analysis shows that decarbonization is possible and can bring social and economic benefits. Renewable energy is now cheaper than fossil fuels. Using public transport, walking, and cycling can reduce demand for private transport and the huge economic cost of congestion. Electrifying transport and other energy uses can reduce deadly air pollution. The intensification of agriculture production, a shift to healthier plant-based diets and a reduction in demand for meat can also help reduce deforestation and protect ecosystems.

The transition to a net-zero emissions economy will challenge the social, political and financial status-quo. Even when zero-carbon solutions are available, existing regulations and market design can prevent the private sector from developing profitable business models around them. In another recent report, Getting to Net-Zero Emissions, we showed that countries need a roadmap to navigate these challenges and transition to a net-zero carbon economy. National institutions typically task the ministry of environment to design climate change plans under the Paris Agreement's Article 4. But implementing such plans will be the responsibility of the private sector and line ministries. It is thus essential that we help ministries of environment to reach out to the other sectors and frame their decarbonization strategies in a way that they can each understand and embrace because it advances their own agenda.

Local academia and think tanks can help the design of multi-sector climate strategies. In Chile, Colombia, Costa Rica, and Peru, we are now supporting discussions with stakeholders from the energy, transport, and agriculture sectors, among others, to discuss what a decarbonization plan should try to achieve. Stakeholders share their priorities, such as supplying cheap energy, reducing congestion and air pollution, improving nourishment indicators or food exports, and building resilience to climate effects. To ensure a just transition, governments should make sure they share the gains from decarbonization, and that they address the losses, for instance, by the workers and communities who today depend on fossil fuel extraction. Numerical simulations are key to quantify how sectoral transformations can reduce greenhouse emissions while achieving these other goals.

Our work in Costa Rica has shown how climate strategies can serve as a roadmap for development and mobilize international finance. Costa Rica's National Decarbonization Plan, built using results from DDPLAC, has over 70 targets for 35 different government agencies and ministries to be carried out by 2023 to kick-start a transition to net-zero emissions by 2050. These include regulatory actions (e.g. the rules on how to set electricity prices in electric vehicle charging stations), investments (e.g. to enable public transit), and studies (e.g. assess options to fund an updated payment for ecosystem services scheme). The IDB and French Development Agency then partnered to support the Plan with a USD 380 million loan, and over eight million in grants.

In sum, our experience supporting countries in the region shows successful approaches for other development banks to consider financing greater climate ambition. First, collaborate with local academic institutions to build their abilities to quantify and inform policy debate around climate. Second, bring together discussion groups to discuss synergies between decarbonization and sectoral development priorities. Third, use technical assistance to build a development strategy that achieves carbon neutrality by around 2050, with a roadmap of regulatory reforms and investments needed to enable the uptake of carbon-free solutions by the private sector. Both investment and policy-based loans and more technical assistance are important to support the plan.

I hope this report will contribute to replicating these successes around the world.

Abstract & project summary

Net-zero CO_2 and large reductions in other GHGs are needed by 2050-‘70 to meet the Paris Agreement goals of maintaining +1.5-2°C over preindustrial temperatures. This is technically feasible in Latin America and would have significant air quality, economic and social benefits. The PA, by design, puts countries firmly in charge of how to define and accomplish their contribution to the global net-zero effort, and most of the power to achieve it lies with them. The Long-Term Strategies (LTS) asked for in the Paris Agreement, and the process for creating them, can be helpful for the planning, stakeholder engagement and policy package formation required to deliver the Paris climate goals while meeting other development priorities. From an economy wide point of view, near term 2025-2030 emissions targets and policy need to be realigned with global net-zero emissions by 2050-’70 to guide short-term policy and dissuade investment that locks in GHG emissions. The key physical transformations are: electrification with low GHG electricity of all feasible sectors, including all buildings, light industry, and urban and intercity personal transport; mode shifting in transport nonmotorized transport and high use electric vehicles supported by urban planning; curtailment of most new and existing fossil fuel extraction; and low carbon agricultural intensification combined with reduced deforestation and afforestation. Alternative zero carbon fuels such as hydrogen and biofuels will be required for freight, aviation and parts of heavy industry. All the above will require economy wide and sectoral policies, non-exclusively including reductions in fossil fuel subsidies, general electrification mandates, performance standards, and charging and fuel network building, all of which will require complementary policies. With domestic priorities clear, countries can then see where there are capacity gaps or other areas where international cooperation is both needed and can be more effective. In the short term, to 2025 and mindful of the recovery from COVID, the key activity will be building consensus amongst all stakeholders who will either carry out or be strongly affected by the sectoral changes, and to review existing policy frameworks and regulations for consistency with achieving net zero emissions by 2050-‘70.

Project summary

The Deep Decarbonization Pathways in Latin America Project (DDPLAC), which included teams from Argentina, Ecuador, Costa Rica, Colombia, Peru and Mexico, ran from early 2018 through 2020 with the following goals. 1) Building of energy and emissions models where they did not previously exist to allow the establishment of domestic capacities for analysis of emissions and development goals. 2) Building of a regional modelling community of practice where one did not previously exist, in order to facilitate knowledge sharing across countries and the bottom-up emergence of a regional approach to the deep decarbonization challenge. 3) Formation and modelling of qualitative narrative and quantitative scenario reference cases, Nationally Determined Contributions (NDCs) and Deep Decarbonization Pathways (DDPs), covering the most important emissions sources. 4) Using these capacities, approach and results to conduct a structured and sustained engagement with policymakers and stakeholders for purpose of informing domestic climate policy processes, their Long- Term Strategies and eventually revised NDCs to the Paris Agreement. DDPLAC was initiated by the *Inter-American Development Bank (IDB)*, funded by IDB’s Sustainable Energy and Climate Initiative, IDB’s French Climate Fund, the *Agence Française de Développement (AFD)* and the *2050 Pathways Platform*, and managed by the *Institut du Développement Durable et des Relations Internationales (IDDRI.org).*

CROSS-CUTTING POLICY LESSONS

Chris Bataille
Yann Briand
Johannes Svensson
Henri Waisman

IDDRI

Executive summary

Net-zero CO_2 and large reductions in other GHGs are needed by 2050-'70 to meet the Paris Agreement goals of maintaining +1.5-2°C over preindustrial temperatures. This implies rapid and far-reaching transitions in energy supply and demand; agriculture and land use; urban form, infrastructure, transport modes and buildings; and industrial systems. Most of the current round of emissions reduction pledges outlined in the Nationally Determined Contributions (NDCs) are insufficiently ambitious to achieve the Paris Agreement goals because of their too high absolute 2025-2030 headline goals, their lack of sectoral detail in terms of the technological and economic structural transformation to be pursued, and absence of goals beyond 2030. For all these reasons the current NDC GHG reduction objectives cannot be translated into specific actions on the ground that can be effectively integrated with development objectives to maximise the benefits of the transition.

Net-zero CO_2 emissions systems transitions consistent with strong economic and social development in Latin America are technically possible, with a primary focus on the following strategies.
1) Produce zero carbon electricity (e.g. large-scale roll-out of renewable energy combined with grid flexibility & firm power support measures).
2) Undertake widespread electrification (e.g. using electric vehicles, motors, heat pumps, boilers and cooking stoves), and where not possible, switch to other carbon-free fuels (e.g. hydrogen or sustainably-produced biofuels).
3) Increase the share of public transportation (e.g. bus or train) and non-motorized transportation (e.g. walking and cycling) in total mobility and reduce demand for transport. Finally,
4) encourage lower carbon (e.g. less meat intense) diets, which can help with preserving and regenerating natural carbon sinks (e.g. by reducing cattle related deforestation and promoting reforestation) and restore other carbon-rich ecosystems. All this can be done while increasing the number and quality of jobs and overall well-being.

There are large potential benefits from transitioning to net zero emissions, notably air quality improvements, lower congestion, investment driven macroeconomic acceleration, job creation, improved and preserved ecosystem services, and reduced costs of delayed action (e.g. poorly chosen long lived energy and infrastructure assets that must be scrapped before the end of their functional lifetimes if emissions reduction objectives are to be met). But there are challenges too: fast growing transport and energy needs; challenging land use governance conditions and incentives; current fiscal dependency on coal, oil and gas revenues; and access to finance.

In this regard the Long-Term Strategies (LTS) asked for in the Paris Agreement can be a helpful instrument to inform the creation of more ambitious NDCs. LTS can also support the design of the policy packages required to deliver climate goals and other development priorities. The long-term planning exercise the LTS requires can help anticipate challenges or areas where the transformation to a net-zero future could hurt some areas of society, thus allowing time to envision solutions including through social dialogue. Furthermore, LTS can inform how to maximize development gains, considering technology options and appropriated timeframes for delivery to boost benefits and reduce costs in line with the ultimate target of net zero emissions by 2050. The end goal of an LTS is to create a roadmap for the policy reforms and investment steps needed to reach a decarbonized economy by around 2050. The long-term effects of infrastructure and equipment choices, and the social and economic impacts of transformation policies, need to be carefully anticipated.

The Deep Decarbonization Pathways in Latin America Project (DDPLAC), initiated by the Inter-American Development Bank (IDB), funded by IDB's Sustainable Energy and Climate Initiative, IDB's French Climate Fund, the Agence Française de Développement (AFD) and the 2050 Pathways Platform, and managed by IDDRI, was

designed to help build local capacity to research LTS design grounded on a strong science base and embedded in the national policy dialogue. It brought together academic country teams from Argentina, Colombia, Costa Rica, Ecuador, Mexico, and Peru to: develop energy and land-use modelling capacity, build a modelling community, develop initial NDC estimates and Deep Decarbonization Pathways (DDPs), and start the process of stakeholder engagement, particularly with policy makers, with the goal of helping establish LTS consistent with the Paris Agreement. The following economy-wide and sectoral policy relevant messages emerged from the teams' work.

From an economy wide point of view, near term 2025-2030 emissions targets and policy need to be realigned with global net-zero emissions by 2050-'70 to guide short-term policy and dissuade investment that locks in GHG emissions. Governments can reduce fossil fuel subsidies, reallocate existing fuel excise taxation consistent with fuel carbon intensity, and make finance available for strategic investments such as low GHG electricity and urban transport infrastructure. All sectors should be encouraged to electrify or switch to net-zero emission fuels (e.g. through technology and performance standards and full carbon intensity pricing). Developing an LTS can help identify investment and policy priorities, which can facilitate a more effective over time balance of net government revenues and costs as fossil fuel extraction revenues and fuel consumption subsidies simultaneously decline.

In the short term, to 2025 and mindful of the recovery from COVID, the key activity will be building consensus amongst all stakeholders who will either carry out or be strongly affected by the sectoral changes, and to review existing policy frameworks and regulations for consistency with achieving net zero emissions by 2050-'70. Moving forward to 2030, policy for physical investment in general electrification and clean transport must begin; done right, the transition can bring fifteen million net jobs in the region by 2030 and generate benefits worth several percentage points of GDP just through avoiding the current loss of productivity in congestion and health impacts from pollution, all hopefully speeding the recovery from COVID.

From the point of view of the key sectors studied in our LAC countries, a sincere step towards addressing the climate crisis and limiting the worse of its impacts will require immediate action on the following key areas:

- Given the role of clean electrification for private transport, light industry, residences and commerce, **electricity generation output and GHG intensity must be aligned with the long-term target of net zero emissions by 2050-'70 at the national level, with steps in that direction starting now**. Given the life span of power generation plants this translates into requiring, by policy means appropriate for each country, all new electricity generation to be very low or zero emissions, e.g. solar, wind, closed-loop geothermal, nuclear, clean hydrogen, or fossil fuels with 95+% carbon capture and storage. Other sources with higher emissions, e.g. gas turbines, should only be considered when their express purpose is supporting variable renewables, and there is a long-term plan to transition them to hydrogen or renewable natural gas or replace them with other zero emitting firm power sources. Modern planning and investment for high variable renewables with adequate firm power support must accompany this transition, i.e. 70-80% wind and solar is known to be achievable (40-60% is already being achieved in Europe), but only with good planning, time sensitive end-use price signals, sufficient interties and multi-time interval clean firm power investment. While a transformative change in how the economy is structured and powered, end-use electrification brings very significant local air quality benefits to indoor spaces and congested urban spaces, critical issues in Latin America.
- To meet the goals of the Paris Agreement countries globally will need to phase out their use of coal, oil and gas or use carbon capture and storage by mid-century, imperiling LAC production both for export and domestic use. **New LAC fossil fuel production investment should be curtailed**, **and plans prepared to phase out existing production in a prudent manner, mindful of the impact of the transition on government finances.** Enabling plans to manage fiscal and employment impacts, including tax reform, should be prepared to allow for adaptive policy and contingencies. An LTS can help inform this conversation, which should be

a key short-term priority for policy makers, anticipating challenges and enabling planning ahead for a smoother transition for public finances and jobs.

- National, regional and municipal governments may consider using land use & transit planning to encourage non-motorized, high-occupancy low-emissions travel. A key priority is mandating zero emission motors (battery, fuel cell, or hybrid combinations) for vehicles operating in urban environments as soon as possible, concentrating on high local air polluting buses and trucks first (e.g. Ecuador's requirement that all new buses be electric by 2025). This will require setting standards for charging & fueling networks, building them and financing them, and enabling finance and business models to address the currently higher initial cost of these vehicles.
- Perhaps hardest due to the governance challenges but of vital importance given the relative regional importance of AFOLU GHG emissions (close to half of LAC's emissions) and the biodiversity value of LAC's forests, all levels of government need to help farmers employ sustainable intensive agriculture and assign and enforce land use rights to encourage reduced deforestation, supplemented with commercial afforestation to buffer and expand existing high biodiversity and carbon sink lands. Encouraging a shift to lower carbon diets, i.e. less meat intensive, would reduce deforestation pressures as well. Active participation in international negotiations to create a durable international incentive structure for all countries to maximize their land use sinks is a significant long-term need and enabling condition.

The Paris Agreement, by design, puts countries firmly in the driver's seat of how to define and accomplish their contribution to the global net-zero effort, and most of the power to achieve it lies with them. Most of the necessary technology already exists, especially in transport, buildings and electricity production, is proven, and is rapidly getting cheaper with global economies of scale and innovation. The more countries pull in the same direction at the same time, the faster costs will fall. For most sectors to drive these technologies into the marketplace requires careful policy design and regulation, particularly at the sector level and with consideration of national fiscal policy. With regards to the finance needs for new transport and energy infrastructure, there is sufficient capital and borrowing capacity in the countries; public funds and private money can finance most of it, the challenge will be redirecting existing flows to clean investments and away from high GHG intensity energy infrastructure (coal, oil, gas). With planning, a well-designed LTS can help clarify and prioritize the necessary redirected and marginal investments and policies required. All this, however, will require institutional capacity and strengthened multi-level governance

With domestic priorities clear, countries can then see where there are capacity gaps or other areas where international cooperation is both needed and can be more effective. The most obvious is a collective effort to commercialize or bring down the cost of key technologies, and to make them available to all who need them, e.g. energy storage; low cost clean hydrogen; key industrial technologies for steel, cement, chemicals, mining, etc. Countries may also need guidance on policy instrument design for high renewable electricity system planning, growth and stabilization. Another key area is mobilization of resources to reduce deforestation and increase afforestation. In some instances this is a matter of domestic political will, enforcement of existing rules, and establishment of new land use rights, especially for indigenous peoples, but in others international capital to pay for (or at least value) large scale commercial afforestation would enable forest protection and afforestation programs that are beyond the resources and intrinsic motivation of domestic governments and actors.

To identify pathways to domestic action and the LTS, and what will be needed from coordinated global action, an ongoing dialogue will be required with all those stakeholders who must implement the transition or are otherwise strongly affected by it. Neither the LTS nor short-term policy package formation built on it can be "one-off" exercises; as stakeholders begin to adapt, technologies evolve and new information in general becomes available, the national plan and derivative policy package will need to be revised and revisited.

While the above results are largely consistent across the six countries, there are some country specific results to note. Please note that many of these points also apply to various degrees to our other countries and societies globally.

Argentina

- Unique in Latin America, Argentina has the capacity for a domestic nuclear power industry as an option for firm clean electricity to support variable renewables, but this requires a focussed energy strategy to achieve.
- There is a currently a strong commitment to developing Argentina's Vaca Muerta gas reserves, but this make sense in a low carbon world only if carbon capture and utilization and storage is fully developed at a reasonable cost.
- Amongst its deep decarbonization pathways, the Argentine team developed a unique scenario where Argentina reaches a per capita standard of living comparable with Europe by 2050 and net zero decarbonization through economic restructuring and "upvaluing" from its current export commodities focus.
- Because of Argentina's large methane emissions from cattle under all scenarios (methane emissions need to fall by 50% by 2050 under the IPCC 1.5°C Special Report scenarios), reaching GHG emissions consistent with 1.5° to 2°C requires a focussed effort to reduce deforestation and to do significant levels of afforestation.

Colombia

- The Colombian team highly emphasized that controlling deforestation, which rose after the peace agreement with FARC allowed access to more of the country, is key for lowering its emissions.
- The Colombian team also found that the distinction between CO_2 and non-CO_2 GHG gases (the IPCC 1.5°C Special Report requires roughly -1/2 CH_4 and -1/3 N_2O emissions, both key agricultural GHGs) are important in the context of countries such as Colombia, where the agricultural sector is economically relevant, both currently and as an engine for future growth. Demand side diet changes and reduced fertilizer use have been identified as key to addressing agricultural GHGS. Agricultural emissions are only modestly reduced across their three scenarios, as the sector must provide for food, intermediate, and energy demand in a context in which international trade is important. Domestic policies, international cooperation, consumer awareness and farmer education are all needed to directly address these emissions.

Costa Rica

- Costa Rica is one of the most advanced countries in the world in terms of net-zero decarbonization stakeholder engagement, planning, and policy package formation, as it corresponds with both its existing and aspirational economic structure (tourism and high value agriculture based on biodiversity) and its development challenges (transport congestion and urban air quality challenges).
- Costa Rica is also a model for dealing with land use carbon sinks, having increased forest cover from <30% in the 1980s to almost 60% today, partly to encourage its tourism trade. Its primary decarbonization challenge is now transport, which it primarily wishes to tackle through mode shifting and urban and intercity vehicle electrification, a common strategy across our LAC DDP scenarios.

Ecuador

- While Ecuador has plentiful hydropower today, broad electrification requires diversifying its access to firm clean power sources beyond hydro to supplement future uptake of relatively inexpensive variable renewable sources.
- Developing a bioenergy industry was found to be necessary for deep decarbonisation, specifically for freight and firm clean power.
- An ambitious reforestation program can avoid the dependence on immature, risky and expensive carbon capture and storage (CCS) technologies in the energy sector.
- The Ecuadorian team explored several scenarios with different carbon budgets and the implications of including and excluding AFOLU CO_2 flows. As with all our LAC countries, whether the country includes its typically negative CO_2 land use flows in its carbon budget or allocates them to the global sink has deep policy implications. For the latter to occur, however, international incentive mechanisms are required.

Mexico

- Mexico's current climate change plans and latest energy policy, as highlighted in its NDC (Government of Mexico, 2015), Mid-Century Strategy (SEMARNAT-INECC, Mexico's Climate Change Mid-Century Strategy, 2016), and Energy Transition Strategy (SENER, 2020), aim to reduce emissions intensity per GDP but map out a road towards 2050 which may result in greater absolute emissions than today. The recent focus on long term gas imports from the US, and building of new domestic refining capacity, may lock in unsupportable levels of GHG emissions.
- However, Mexico's very large solar and biomass renewable endowments, industrial base, geographical location, and skilled workforce make a net-zero transformation – which must occur at a global scale – an opportunity to advance towards a high-tech knowledge-based economy, catalyzing economic growth, increased prosperity, less vulnerability to world fossil fuel prices, and greater inclusion.

Peru

- Peru is highly vulnerable to climate change, and its two key contributions are likely to be in minimizing its agriculture, forestry, land use (AFOLU) and personal transport emissions as it develops.
- Peru's current NDC policy actions on AFOLU are pointing in the right direction but need to be considerably strengthened, i.e. 1) Sustainable Management of forest concessions; 2) Improve forest management in native communities; 3) Incentives to native communities for forest conservation; 4) Improve management in Protected Natural Areas; 5) Allocation of rights of use in areas in which they do not exist; 6) Addition of commercial forest plantations.
- There is trade-off between reduced deforestation, afforestation and food production that must be anticipated and planned for.

Introduction

The Paris Agreement's goal of limiting the global temperature rise from pre-industrial levels to 2.0°C and towards 1.5°C requires reaching net-zero emissions of carbon dioxide (CO_2) by 2050-'70, as well as deep reductions in the emissions of other greenhouse gases (GHGs) (Edenhofer *et al.*, 2014; Masson-Delmotte *et al.*, 2018). In this policy report we will focus on the aspirational goal of 1.5°C; the necessary policy actions do not differ as much as the timing of net-zero CO_2 and the scale of the need for net-negative emissions at the global level.

Getting to net-zero emissions of CO_2 is technically possible (Clarke *et al.*, 2014; Fay *et al.*, 2015; Bataille, H. Waisman, *et al.*, 2016a; Bataille, Henri Waisman, *et al.*, 2016b; Davis *et al.*, 2018). Given regional circumstances, net-zero systems transitions in Latin America will have a primary focus on the following strategies: produce zero carbon electricity (e.g. renewable energy combined with firm power support and grid flexibility); undertake widespread electrification (e.g. using electric vehicles, motors, heat pumps and boilers and cooking stoves), and where not possible, switch to other carbon-free fuels (e.g. hydrogen or sustainably-produced biofuels); increase the share of public transportation (e.g. bus or train) and non-motorized transportation (e.g. walking and cycling) in total mobility and reduce demand for transport; preserve and regenerate natural carbon sinks (e.g. by reducing deforestation and promoting reforestation) and restore other carbon-rich ecosystems.

There are large potential benefits associated with a net-zero transition, notably air quality improvements, lower congestion, job creation, and improved and preserved ecosystem services. The transformation to achieve net-zero emissions by 2050 can create immediate and sustained economic opportunities. For instance, OECD (2017) suggests that decisive action taken now towards decarbonization, if accompanied by structural policies, could increase GDP in 2050 by up to 2.8% on average across G20 countries. The International Renewable Energy Agency (IRENA, 2019) argues that a large-scale shift to electricity from renewable energy would boost gross domestic product (GDP) by 2.5% and total employment by 0.2% globally in 2050. Decarbonization does not need to be done at the expense of jobs and growth. By 2030, in a low carbon scenario, structural changes in production and consumption patterns could result in 15 million more jobs in Latin America and the Caribbean compared with a business-as-usual scenario (Saget, Vogt-Schilb and Luu, 2020). The projected gains in employment would largely be the result of changes in diets leading to more employment in the agricultural sector, and to a lesser extent of decarbonizing the energy system.

Delayed or missing action on decarbonization entails high costs. The costs of zero carbon technologies are dropping rapidly whereas business as usual is becoming more expensive and exposed to transition risks including asset stranding; wind and solar backed by short term storage batteries are already the cheapest new generation in many parts of the world (International Renewable Energy Agency, 2020), often lower than the operating cost of coal and gas plants, with costs still falling rapidly at time of writing. At the global level, a pathway immediately aligned with the global goal to reach net-zero emissions by 2050-'70 would require 84% fewer premature retirements of power generation capacity and 56% fewer new capacity additions after 2030 to reach the 2°C target, compared with a pathway based on the current NDCs (Iyer et al., 2015). To meet average carbon budgets from IPCC, 10%–16% of existing fossil-fueled power plants would need to be closed before the end of their technical lifespan (González-Mahecha *et al.*, 2019); building any more fossil-fueled power plants in the region could jeopardize the achievement of the Paris Agreement temperature targets. The IPCC (2018) did not find any pathway that achieves current NDCs and then decarbonizes on time to stay below 1.5°C. In LAC, implementing current NDCs and then correcting course in 2030 to reach carbon neutrality by 2050, would create USD 90 billion worth of stranded assets in the power sector (Binsted *et al.*, 2019). Doing so would also require USD 100 billion more in power plant investments than a transition starting from more ambitious NDC targets in 2020. A rapid and disorderly transition to correct the situation after 2030 would imply grave costs for economies and societies and would likely still not be able to reach the 1.5°C target.

The Paris Agreement operates through iteratively updated NDCs that are to be informed by Long-Term Strategies (LTS). The current round of emissions reduction pledges outlined in the Nationally Determined Contributions (NDCs) submitted around COP21 are insufficiently ambitious to achieve the Paris Agreement goals, partly through absence of goals beyond 2030 (UNEP, 2018). The IPCC (2018) indicates that current NDCs will allow emissions of 52-58 Gt CO_2e in 2030, in contrast to the 25-30Gt CO_2e needed to reach the 1.5°C target. The creation of policies, laws and investments to support the implementation of existing and inadequate short-term targets could erect technical and economic obstacles to achieving the long-term Paris Agreement goals. Inter-American Development Bank (IDB) research shows that, in Latin America and the Caribbean, NDCs fail to put the region on a low emission and economically prudent pathway to achieve the objectives of the Paris Agreement (Binsted et al., 2019).

Country-specific strategies are needed to maximize synergies between deep emission reductions and sustainable development. Deep decarbonisation of energy and land-use systems can complement achievement of national Sustainable Development Goals (SDGs) regarding, e.g., energy security, air quality, equality, and macroeconomic growth (Waisman *et al.*, 2019). But this will be possible only if emission reductions actions are designed with close consideration of each country's goals, challenges, opportunities and national circumstances regarding both climate and development. These global results are true for Latin America and the Caribbean (Inter-American Development Bank (IDB) and DDPLAC, 2019), and the socioeconomic benefits of decarbonization may be even more important in this context given the region's rapidly growing and urbanizing populations. Moreover, the structural social inequalities in this region and the exposure of the most vulnerable population to transition and physical climate risks must be taken into account.

Long term strategies (LTSs) can help guide more ambitious NDCs and policy by establishing a country's vision of specific development outcomes associated with deep decarbonization by mid-century, and identify the sectoral pathways to get there. LTS can also help: inform the re-orientation of infrastructure choices and the design of investment plans to deliver the transition; build policy roadmaps to address regulatory barriers to decarbonization; can help anticipate and manage fiscal impacts; and help governments manage the social impacts of decarbonization to ensure a just and inclusive transition. Not insignificantly, the process of building an LTS can help both solicit critical information from stakeholders as well as build their knowledge base and comfort level with the physical transitions and policies needed.

Several key principles have emerged in recent years to guide the elaboration of long-term strategies (Waisman *et al.*, 2019):

- begin with the net-zero end in mind; from that desirable future work backwards (a.k.a. "back-cast") to identify policies and programs that will connect that specified future to present actions.
- canvass stakeholders, especially those critically affected or who must implement the transition, as well as experts for potential national and sectoral strategies to reach the net-zero goal;
- quantify, compare and contrast these strategies in an integrated way to build common pathways, while using the process to build stakeholder knowledge and consensus;
- and finally, build adaptive policy packages with clear roles and timeframes for stakeholders to achieve the pathways.

These principles guided the design of the Deep Decarbonization Pathways in Latin America and the Caribbean (DDPLAC) project[1] led by the IDB, in partnership with the 2050 Pathways Platform and the Agence Française de Développement (AFD), and drawing on the experience of the Institute for Sustainable Development and International Relations (IDDRI.org). Under this project, domestic universities and think tanks from six LAC countries (Argentina, Colombia, Costa Rica, Ecuador, Mexico, and Peru) investigated national decarbonization pathways. The teams used models describing the energy, agriculture and land-use systems, built a partnership with international experts, created a regional peer-to-peer exchange platform, and discussed decarbonization scenarios with policymakers, civil society, and other stakeholders in their countries.

1 More details about this project can be found in IDB's "Getting To Net-Zero Emissions: Lessons from Latin America and the Caribbean"(Inter-American Development Bank (IDB) and DDPLAC, 2019) as well as a special issue of Energy Strategy Reviews, with a group synthesis paper (Bataille et al., 2020) and associated country papers.

How to revise NDCs to make them consistent with long-term goals

While it is widely acknowledged that current NDCs are not ambitious enough to achieve the objectives of the Paris Agreement and lead to a global warming of around 3°C by the end of the century (Hausfather and Peters, 2020), these high level assessments do not directly inform how to concretely revise individual country NDCs to make them more aligned with the global climate target.

The analysis conducted in the DDPLAC project, where country teams simulated NDC and deep decarbonization pathways using models developed for the purpose, provides such a guide. In **Figure 1** the DDP scenarios describe emissions trajectories consistent with the global climate goal to 2050, and the milestone points in 2030 therefore constitute benchmarks against which the NDCs can be assessed. **Emissions per person in the DDP runs are typically 25-33% less in 2030 compared to the NDC runs;** Costa Rica's original NDC was compliant with 2°C, and they have since revised their ambition to 1.5°C.

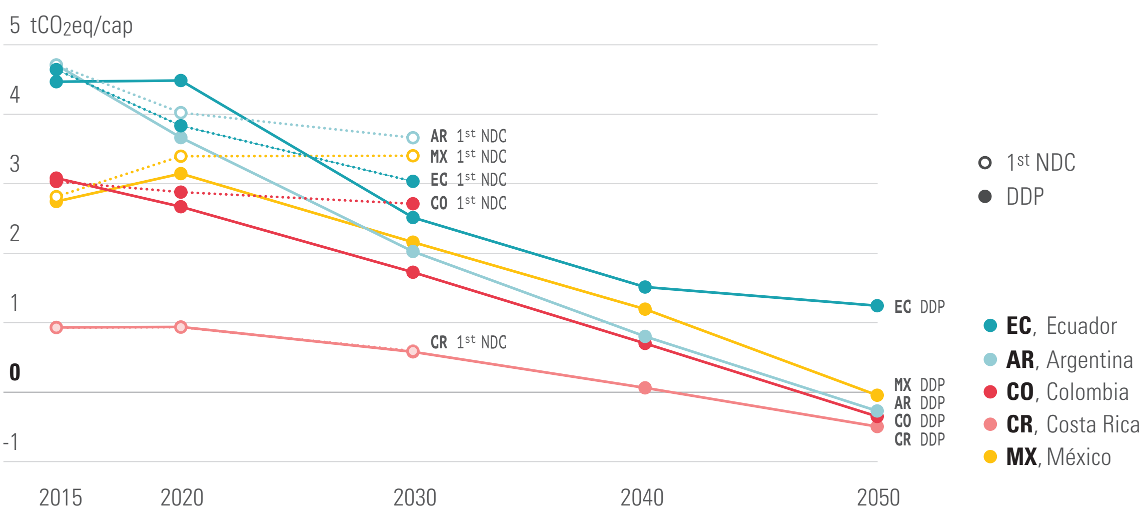
Moreover, the DDP analysis allows the policy conversation to go one step further, by providing a reference for evaluating the scale of the key sectoral transformations that need to happen if the world is to follow a Paris compatible pathway. This information provides a concrete guide for revising the NDCs by indicating where the country effort should be increased; this will be key to facilitating implementation of NDCs.

More specifically, in addition to their sectorally detailed DDP scenarios, most of the country teams have developed a current NDC scenario which provides a sectorally detailed picture of the transformations implied by the current NDC goals. The comparison of this with the detailed DDP scenario can therefore help governments prioritize where sectoral expertise should be sought in order to revise their NDC ambition towards long term compliance with the Paris goals, and policies to achieve this ambition.

To each physical indicator characterizing the transformation, we associate a measure of the "percentage of 2015-2050 effort" calculated as the ratio between the variation of this indicator between 2015 and 2030 and the 2015-2050 variation in the DDP scenario. This comparison of this ratio between the NDC scenario and the DDP scenario helps identify the main dimensions where ambition is insufficient. We present here some illustrations of these comparisons for key indicators in energy, transport and land use.

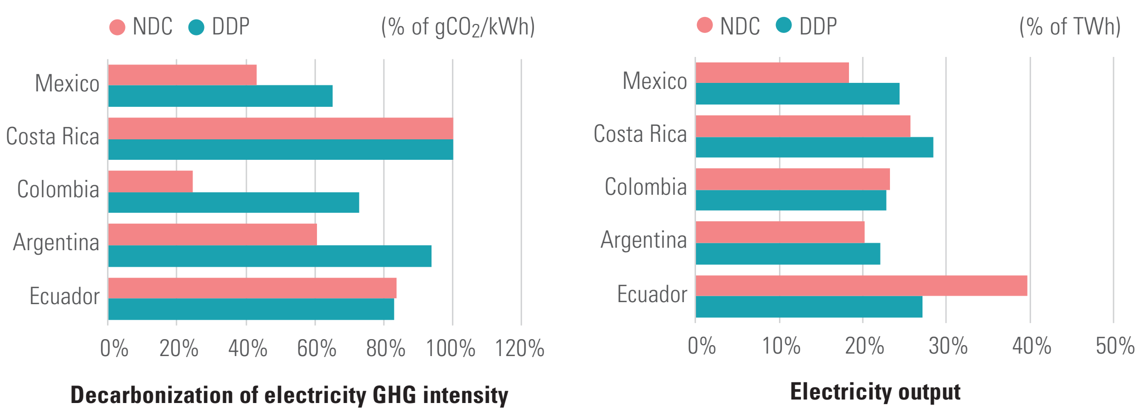
For energy, we focus on electricity production, because electrification is in all cases a key pillar of de-

Figure 1. Projected combustion (not including process) and AFOLU NDC and DDP CO_2 emissions, excluding other GHGs



carbonisation. We distinguish two sub-components: the carbon content and the volume of production (**Figure 2**). The former is supposed to decrease dramatically and the latter to increase substantially in Paris-compatible scenarios. In three countries, Colombia, Mexico and Argentina, it appears that the rate of generation GHG intensity decarbonization implied by the NDC is largely insufficient, implying the creation of stranded assets. In two other countries, Ecuador and Costa Rica, however, the decarbonization of electricity in NDC is well aligned with requirements for DD. In Costa Rica, electricity production is already completely decarbonized (starting from an already very low-carbon basis). In Ecuador the electricity system is also very decarbonized in the NDC, due to recent expansions in its hydropower fleet; it should also be noted from the demand figure, however, that electrification plays a less important role for decarbonization than in other countries. The figure on electricity production shows that, as a first order estimate, demand/power generation projections in the NDC correspond well to the scale to envisaged in DDP, with Mexico as an exception. In sum, the projected amount of power available in 2030 is not an immediate issue - its GHG intensity of production is, however. On this Argentina, Colombia and Mexico vary between only 40 to 60% of the necessary GHG intensity decarbonization by 2030 in their NDCs. Put simply, these countries do not plan to decarbonize their electricity supply fast enough – confirming at country scale the results by Binsted *et al.*, (2019).

Figure 2. Percentage of DDP 2050 electricity decarbonization done in 2030 in the NDC and DDP scenarios



Notes: Figure 2 provides a relative measure of 1) GHG intensity decarbonization and 2) output growth in the NDC and DDP scenarios by dividing, for each indicator, the 2020 through 2030 change in the DDP and NDC scenario, respectively, by the 2020 through 2050 change in the DDP scenario.

Figure 3. Percentage of DDP 2050 transport done in 2030 in the NDC and DDP scenarios

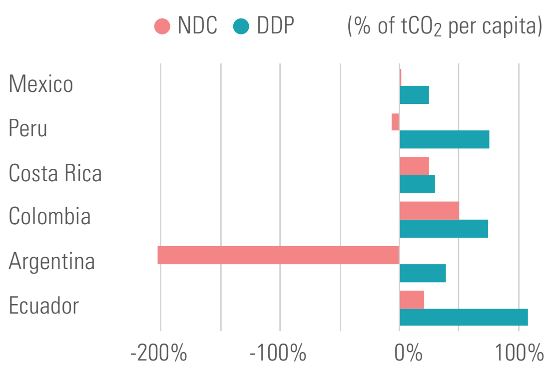
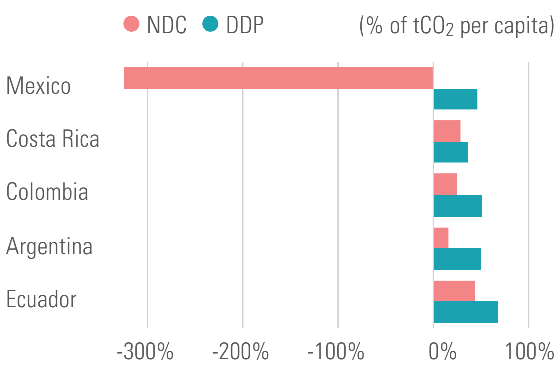


Figure 4. Percentage of DDP 2050 AFOLU decarbonization done in 2030 in the NDC and DDP scenarios



Passenger transport is a big topic for NDC enhancement (**Figure 3**). In almost all countries, except Costa Rica and Colombia to some extent, the rate of effort is largely insufficient or even goes backwards in the NDC in the case of Argentina and Peru. The delay in action in NDC reflects a combination of insufficient measures for incentivizing the diffusion of low-carbon vehicles, notably for road transport, for enabling a modal shift towards low-carbon modes, and to control mobility demand. These actions entail potentially important inertias linked to land use planning and infrastructure deployment; the delay in the NDC results imply high potential emissions lock-ins.

Finally, the Agriculture, Forestry and Land Use (AFOLU, 1/3 of total GHGs) sector is probably the most difficult challenge from a political economy perspective because the issue is not technology but incentives for land use. in that the analysis shows that action is significantly not ambitious enough compared to what would be required (**Figure 4**), and in some cases even directionality is completely absent. Mexico is particularly a problematic case, as AFOLU emissions are rising in the NDC. Unfortunately, Peru, our most advanced AFOLU study, did not have an NDC scenario for comparison. Given path dependencies in this sector, the NDCs create a risk for the long-term natural carbon sink capacity. Given the importance of the LAC region for global land use sink capacity, the enhancement of the AFOLU component of NDCs is a key area for policy application, and given the potential costs of afforestation, global cooperation.

How Long-Term Strategies can help with real-world policy formation

How the LTS development process can enhance buy-in by stakeholders

Notionally, all our LAC countries, in committing to the Paris Agreement, have committed to the goal of global net-zero emissions by 2050-'70 to meet the 1.5-2°C temperature targets, broadly implying national, sub-national and sectoral climate targets and development goals need to be adjusted to include net-zero GHG emissions later this century. But what does this mean for each LAC country and region, and individual economic sectors within these countries? How can LAC countries build the political consensus to trigger the economy-wide net-zero transition and ensure a just and inclusive transition? And what potential mixes of policies can help implement this transition in a way that will be effective, efficient and enjoy sufficient acceptance from all stakeholders that must implement the transition or will be affected by it (e.g. government departments, firms, communities, labour, and other NGO stakeholders)? The capacity of national low-emission development strategies to address these questions will largely depend on the organization of the stakeholder engagement processes to develop them, and the analytical processes used to test the rigour of physical transition and policy propositions from these processes. Some of our LAC teams, especially Costa Rica and Ecuador, have done some of this stakeholder consultation already. Moving forward, specific attention should be given to framing the need for net-zero in the context of other development goals, the ability to apply quantitative rigour to the transition narratives offered by stakeholders, and any specific institutional arrangements needed to enhance stakeholder involvement.

The LTS process "framing" or "scoping" statement should ensure clarity on the objective of the analysis by all stakeholders, i.e. consistency with global CO_2 emissions neutrality in the early latter half of the century. To help keep the net-zero goal in mind, back-casting from a 2050-'70 vision to the present at the sectoral and summed national level helps identify the public policy, planning and investment choices needed to achieve this vision, particularly for long-lived infrastructure, as well as an appropriate sequence of policy actions for a just and inclusive transition. Shared understanding and ownership of this frame is a key condition to ensure buy-in of the challenges and opportunities to be investigated, and active participation in looking for solutions. The scope of the LTS development process should illuminate the challenges and opportunities of long-term low-emissions development in the context of the country. This implies engaging stakeholder concerns as a means to canvass their knowledge and opinions on options, build working consensus, and through testing across many perspectives ensure the robustness of the approach. At the same time, the long-term horizon of the pathways analysis should be forthrightly employed to avoid a focus on narrow or short-term interests (e.g. those who wish to build gas infrastructure must demonstrate how it is consistent with net-zero GHG emissions past 2050-'70). Finally, recognizing the pressing priority of existing development goals (e.g. poverty alleviation, reduction of inequality and unemployment, air quality improvement, and improved power access and reliability), long term transformation options will have to be evaluated in the light of their ability to contribute to synergistically meeting development and climate change goals at the same time. Taking this argument further, development policy that pays for itself while having climate benefits (e.g. electrification of public buses with more frequent and broader service to meet urban air quality goals) will take precedence.

Quantitative analytical approaches and modeling tools should be selected for their ability to use, reflect and produce pathways inputs, assumptions, and results in a way that rigorously and transparently answers the questions of "who does what, when, and who is impacted?" at the appropriate temporal, geographic, and sectoral resolution. The process of matching research and policy questions to analytical tools can help to identify resource and capacity challenges, such as whether current tools are adequate or new tools are needed, or what skills or forms of technical assistance may be needed to perform the analysis. Understanding what data are readily available, what could be made available, and what is not available at all will determines what analysis can be done in a robust manner, what requires simplified treatment, and what should be excluded from the analysis. For governments that lack their own data in key policy areas or sectors, international, sectoral, and proxy datasets from governments with similar conditions can be used in an initial phase.

Specific institutional arrangements are required to structure the involvement of stakeholders in pathways studies. Stakeholders can include other government departments or local governments, public and private companies, non-governmental organizations, think-tanks, institutional investors communities, or trade unions. Co-construction and consultation with stakeholders can help countries build LTSs that are relevant, support multiple development objectives, and have buy-in from stakeholders. Qualitative and quantitative narratives, offered by stakeholders in their own language but translated into common quantitative dashboards, are a key strategy for engaging them in pathways design. The objective should be to organize a two-way communication between the quantitative analysis and the stakeholders to solicit their input and feedback, and report progress and results, at different stages of the process and in particular in the early stages. These iterations are essential to generate robust scientific and technical knowledge reflecting real-world situations, to facilitate assimilation of these scientific insights by decisionmakers, to identify synergies and trade-offs and find ways to manage them, and to help identify areas that are ripe for innovation and transformation and the means to induce.

Once working agreement on one or more net-zero pathways have been established, and the physical transitions (and their potential variations) each sector must embark upon in the short and long run have become clear, then the task of building suitable short and long policy packages must be addressed. Realistically, this will require government initiative and active and constructive stakeholder feedback, making initial buy-in all the more important. Not all policy options will be suitable or available in all countries, and each country's government will have to tailor those that make sense for their transition to their governing system, stakeholders, capabilities, and national circumstances. Explicit or implicit carbon pricing in particular requires a point of incidence, where the charge can be applied or the subsidy reorientated to carbon intensity. In informal economies with absent excise tax structures, the only available point of incidence may be where the final energy form is produced or imported. The same applies for regulations; if building codes either do not exist or are not enforced, energy efficiency and electrification needs to be actualized directly through construction firms and suppliers of construction inputs.

Economy wide and sectoral policies

There is a well-established suite of policy tools from which to build policy packages, including: stakeholder consultation, planning and consensus building (see above sections); removal of regulatory barriers (e.g. buildings codes) to decarbonization processes (e.g. more efficient steel and cement use in buildings; substitution of clinker in cement); regulatory measures, including technology and performance standards; market measures, include direct subsidies, fossil fuel subsidy reduction & carbon pricing; and innovation policy, including support for research, development and commercialization, including early market support. These generic policy tools are typically evaluated against the following criteria in a given context when forming policy packages: effectiveness in achieving the goal; economic efficiency (lowest cost per tonne avoided); distributional effects/equity; transformational potential (i.e. to induce technological or structure innovation); socioeconomic benefits (especially local air pollution and paid employment) and general alignment with broader development goals; interactive effects with each other and other policies in effect; and administrative and political feasibility. The last criteria is perhaps the most challenging, as it includes real world considerations of winning political acceptance, the behaviour and decision making of those who must implement the physical transition actions, managing competing objectives, and the importance of local context in the effective design and implementation of climate policy. Finally, the transition towards net-zero emissions will likely create winners and losers, with negative social impacts if not carefully addressed and planned for. Given all the above we suggest the following key economy wide and sectoral policy package elements, to be administered as appropriate in given sectors, regions and countries.

We will first discuss a set of economy wide policies, then sector specific policies as emerging from the DDP analysis. Each section includes a discussion of any key enabling conditions, capacity building & needs for international cooperation.

Economy wide: Reduce fossil fuel subsidies, reorientate existing fuel taxation towards GHG intensity, and make finance available for strategic investments while planning government revenues and costs

The IEA indicates annual narrowly counted ("price-gap") fossil fuel subsidies at $400 billion USD in 2018 (https://www.iea.org/topics/energy-subsidies). While the removal of fossil fuel subsidies can be very difficult, as Ecuador's recent unsuccessful attempt to reduce diesel, gasoline and LPG subsidies leading civil unrest has shown[2], this will likely be very important for the long run transition to net-zero emission in transport, buildings and industry. Policy makers need to watch for and seize windows of opportunity, like periods of low energy costs, to reduce consumption and production subsidies. Complementary measures are also required to shield the poor and most vulnerable in the transition, for example direct cash transfers to the most vulnerable in response to removal of subsidies or energy or carbon pricing (Vogt-Schilb *et al.*, 2019). Extending the logic of reducing subsidies, reorientation of existing fuel excise taxation towards GHG intensity, as carried out by the Scandinavian countries in the 1990s as part of a broader tax reform, can mimic the effects of a low but effective carbon price. Sweden in particular implemented their carbon tax, currently at \$123/t CO_2e the highest in the world, as part of a major tax reform in 1991, where they introduced carbon pricing as part of a larger reform to reduce high marginal income taxes in exchange for broader value added taxes. "Tax swapping" can also introduce the public to carbon pricing in a relatively neutral way, allowing further increases later; the High Commission on Carbon Prices recommended \$40-80/t CO_2e by 2030 and \$50-100/t CO_2e by 2050 (Carbon Pricing Leadership Coalition, 2017). Carbon pricing, while useful for incenting long term structural changes and innovation in the economy, can be very difficult politically, and even if successful it may be necessary to implement a lower than optimal schedule of prices. Despite economic orthodoxy, policymakers should also not be afraid to impose different prices across sectors, regions and nations – the welfare response to carbon pricing can and will differ (Bataille *et al.*, 2018), and the efficiency of price signals to trigger changes will differ across sectors. California implemented a suite of regulatory policies to deliver most of

2 https://www.npr.org/2019/10/14/770104729/ecuador-reaches-fuel-subsidy-deal-to-end-violent-protests; https://www.petroleum-economist.com/articles/politics-economics/south-central-america/2019/ecuador-reverses-fuel-subsidy-decision

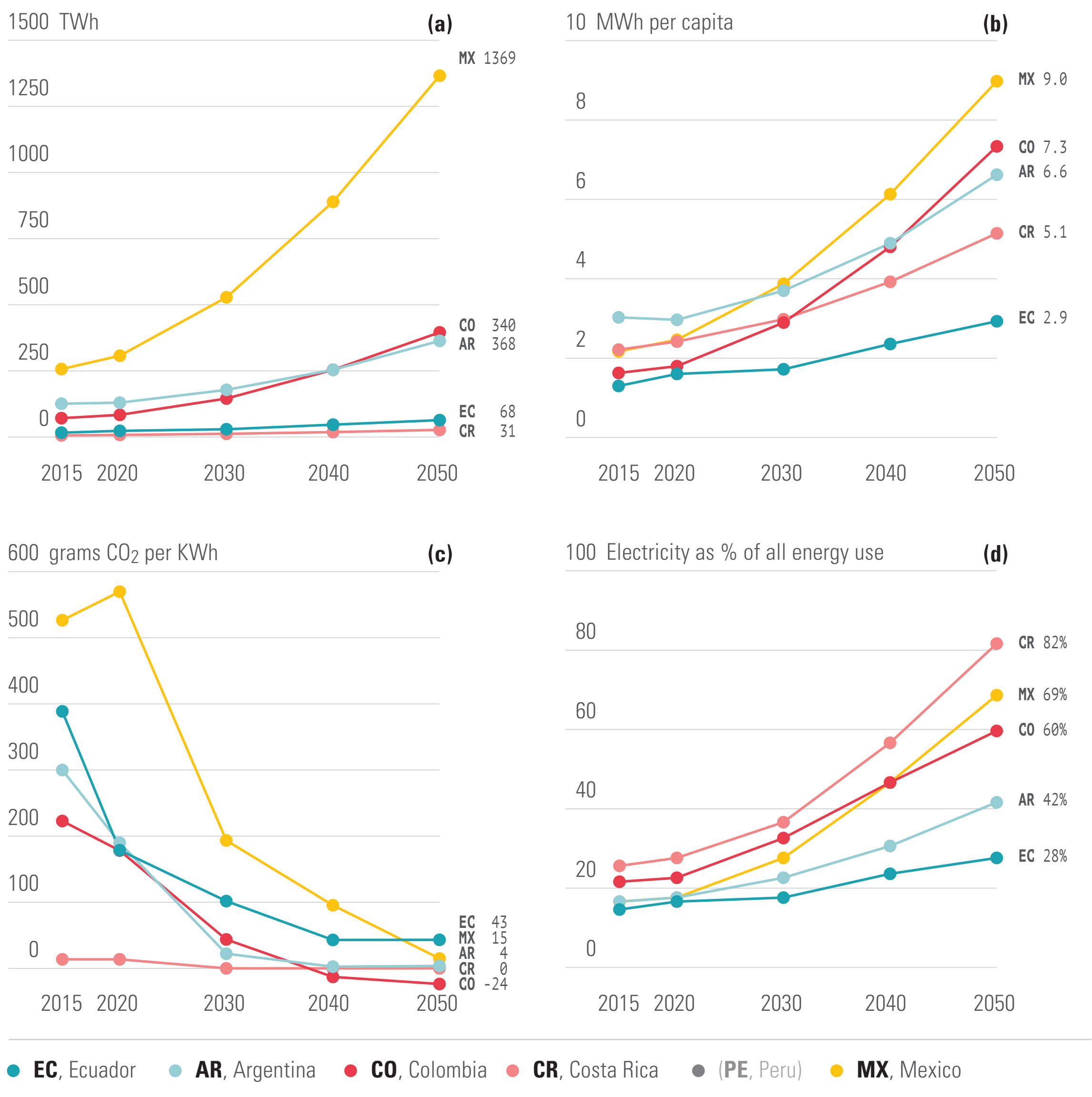
their emissions mitigation goals and implemented its cap and trade system as a backstop insurance policy (Bang, Victor and Andresen, 2017).

Deep decarbonization will also affect sectors that contribute towards a country's fiscal revenues, starting with LAC countries currently receiving oil and gas revenues (Solano-Rodriguez *et al.*, 2019). When reducing subsidies for fossil fuels, providing subsidises for low GHG power generation and EVs, and otherwise employing fiscal adjustments that behave like carbon pricing, careful assessment needs to be made of anticipated net government revenues and costs.

Economy-wide: All sectors must be encouraged to electrify, use local renewables, or otherwise use decarbonized energy where possible

With the caveat that electricity generation must evolve to complete decarbonization, technology or performance standards will be needed to encourage and possibly mandate electrification of energy end-uses, i.e.: cooking; heating; space heating; small and large steam and heat sources (e.g. boilers and heat pumps for commercial and light industrial end-uses); and personal and public transport. To support this electricity generation will need to be decarbonized (next section), transmis-

Figure 5. Total DDP electricity generation in TWh (a), MWh per capita (2015=1) (b), GHG intensity in grams CO2/kWh (c), as % of all final energy use (d)



Source: (Bataille et al., 2020)

sion will need to be improved, and key technologies will need to be available, e.g. induction plates and cooking materials; residential, commercial and industrial heat pumps; solar hot waters and electric boost systems; and electric personal vehicles, buses, and trucks. To meet these needs electricity production per capita rises 4-5 times per capita from today by 2050 in all the DDPLAC analyses, and electricity generation GHG intensity falls to virtually nil (**Figure 5**). Light industry will need education and financial encouragement (e.g. through tax mechanisms) to use direct solar heating, heat pumps, and electric resistance boost heating in place of coal, LPG or NG boilers. Policies will be needed to encourage uptake of best practise industrial direct or indirect (i.e. via hydrogen from electrolysis) electrification when established (e.g. in steel making or nitrogen fertilizer making). Finally, assessment will need to be made of whether a region's electricity and fuel price signals are aligned with deep decarbonization; do they work for or against implicit carbon pricing?

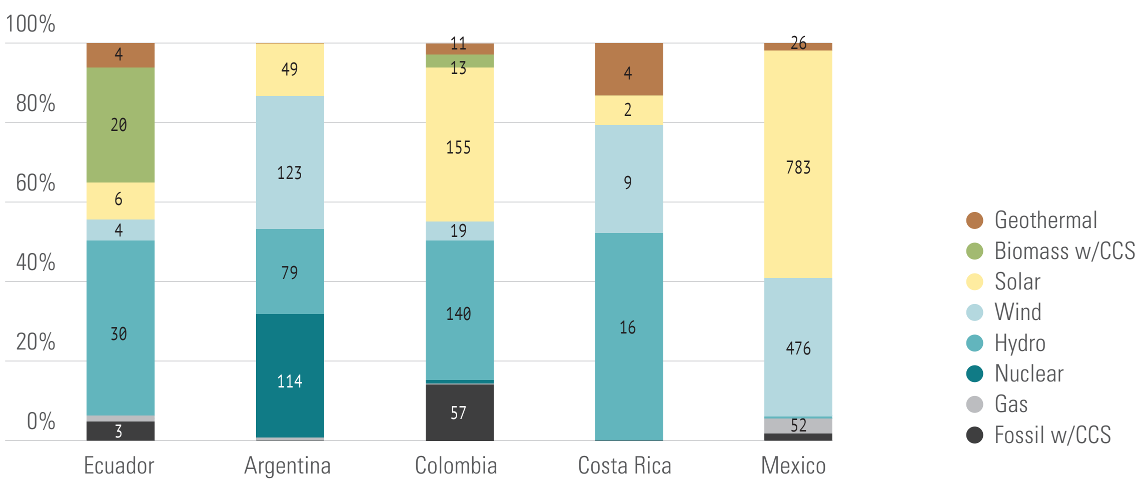
LAC national and regional governments already have most of the governance tools they need to encourage electrification and fuel switching to net-zero carbon fuels (e.g. bio or hydrogen rich synthetic liquids and gases) once they become available. Bio and synthetic fuels will be globally developed technologies, with likely key contributions from Brazil and other LAC countries, and it will be key that LAC countries actively participate in developing the demand side of the market, along with all other jurisdictions.

Sectoral: Energy – All new electricity must be very low or zero emission, and high GHG assets phased out

To support economy wide clean electrification, all new electricity generation must be very low (e.g. -95% CCS or better) or zero GHG emitting, or be for purpose of supporting (i.e. providing "firm" power) uptake of more variable renewables (i.e. solar and wind). This can be imposed through renewable portfolio standards combined with market auctions with maximum GHG intensity standards. Unless mandated otherwise, most new zero GHG generation will come from wind and solar on a cost per kWh basis, which will require intermittency planning and support along the minute, hourly, weekly and seasonal dimensions. Blocks of wind and solar can also be sold into the market combined with integration support. This support can be provided using more planning, regional interties, demand response, energy storage (e.g. batteries, fossil fuels with CCS, gas turbines that can run on a mix of gases or liquids (i.e. methane, propane, LPG, hydrogen), or two-way fuel cells implementing power to hydrogen and back, etc. Finally, the national and regional governance and market structure for electricity and natural gas must be reviewed for dynamics that will work for and against electrification, e.g. legacy reserve margin rules based on probabilistic large coal plant outages.

Countries such as Chile and Mexico have run very successful auctions for renewable power, with recent unsubsidized prices of \$0.029/kWh USD and \$0.021/

Figure 6. DDP electricity generation mix by country in 2050 (TWh)



Source: (Bataille et al., 2020)

kWh respectively and individual projects between \$0.017/kWh and \$0.032/kWh. All these prices are below the cost of coal or gas generation, and inter-regional cooperation can help repeat these successes.

Countries and regions are likely to need planning, market design, and finance for growing and refurbishing their power generation and transmission systems. While most of the finance will need to come from the private market, "derisking" signalling finance from development banks can help attract attention to these projects from the market. Ultimately, however, domestic and international public funds represent a tiny fraction of the investment needed to decarbonize (Fay *et al.*, 2015), and the key for governments is to redirect both public and private investments. A catalytic role for international financial institutions can be to help reshape private and domestic government expectations, financial regulations and institutions towards that goal.

Sectoral: Energy - Carefully reconsider investment in new coal, oil and gas projects for export and domestic use, including exploration, production and transmission

For existing national production of coal, oil and gas, the LAC countries should develop an asset optimization strategy based on GHG intensity (i.e. ramp down coal, oil and gas assets in that order as possible, with consideration for specific investment amortization lives), taking into account how they can be adapted to low carbon energy production. If planned for, some oil and gas infrastructure and facilities can be used to make low GHG hydrogen, bio-liquids and -gases, and other low carbon fuels (Bataille 2019). Public funds for suspended oil and gas works can be redirected into electricity transmission, distribution, and energy storage infrastructure to enable high volumes of renewable generation to be included into the grid.

The early 2019 OPEC price war and the COVID-19 driven fall in demand for fossil fuels has exposed the price uncertainty in global oil and therefore gas markets, and in this light new oil and gas exploration for export should be considered highly risky. Coal, oil and gas exploration that is intended to be tied to use of domestic carbon capture and storage may be less risky under the condition carbon capture and storage is commercialized globally at a reasonable installation and operation price.

Sectoral: Transport - Use land use & transit planning and zoning to encourage non-motorized, high occupancy low emissions travel.

Decarbonizing the transport sector while increasing access to clean and safe transportation options brings opportunities to improve mobility, reduce local air pollution, and improve the quality of life. Many cities in LAC are above the World Health Organization thresholds for the concentration of airborne pollutants. Every year, 50,000 people die prematurely in the region due to air pollution caused mainly by transport (Galarza and López, 2016).

Urban and transit planning is needed to gradually restructure LAC cities towards an urban form that encourages more high frequency transit (e.g. electric buses and trains) and non-motorized mobility. This includes short term efforts, e.g. movement regulations to encourage either non-motorized modes or transit (e.g. raised and separated sidewalks, bike lanes with barriers, removal of parking, land use regulations to concentrate symbiotic businesses and services), and longer term efforts, where city growth and evolution is directed towards encouraging high occupancy low emissions transit and away from car traffic. **Figure 7** shows how total mobility increases in all but Ecuador and motorized individual mobility falls in all but Argentina, mainly due to mode shifting to electrified urban and intercity bus lines.

Sectoral: Transport - Mandate zero emissions for new vehicles, and create the enabling conditions/incentives for innovative transport business models

Battery electric, and hydrogen fuel cell vehicles to a lesser extent, have entered the commercial global transport market, and promise a pathway to eventually eliminate direct GHG and local air pollutants in global cities, if not congestion. Electrification of vkm varies from 6% to 100% by 2050 in our DDPLAC scenarios, with the majority in the 40-65% range (**Figure 8**); while fuel GHG intensity, which includes switching to biofuels, varies from -18% to -100% by 2050 (**Figure 9**). Net-zero emissions vehicles currently cost more than gasoline and diesel-powered equivalents, however, and the availability of recharging and refueling networks can vary from non-existent through limited, while growing quickly in some regions.

According to the IEA Global EV Outlook (Till *et al.*, 2019) policy approaches to promote the deployment of EVs typically start with a vision statement and a set of targets, followed by the adoption of electric vehicle safety and interoperable network charging standards. An EV deployment plan often includes public procurement programmes to stimulate demand for electric vehicles and to enable an initial roll-out of publicly accessible charging infrastructure. Policies to support deployment of charging infrastructure include minimum requirements to ensure EV readiness in new or refurbished buildings and parking lots, and the building of publicly accessible chargers in cities and on highway networks. Measures that provide crucial incentives to scale up the availability of vehicles with low and zero tailpipe emissions include fleet fuel economy standards that tighten to zero emissions through time. Another useful policy measure is to provide economic incentives, particularly

Figure 7. 7 DDP motorized distance travelled per capita (pkm/cap) (a) and motorized individual mobility (Car + two-wheel vehicle) share (% Gpkm) (b)

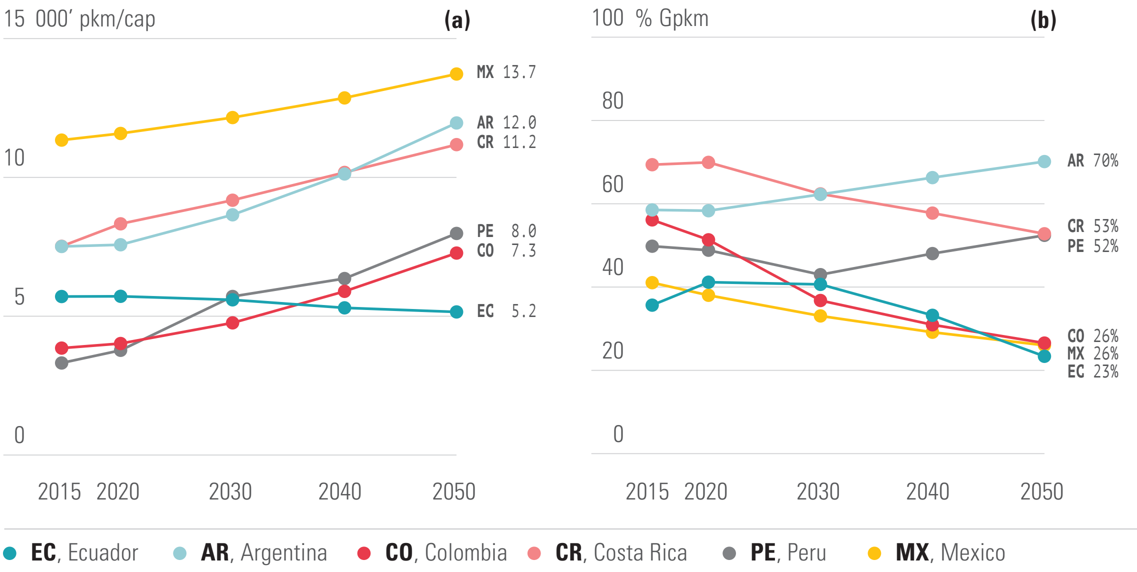
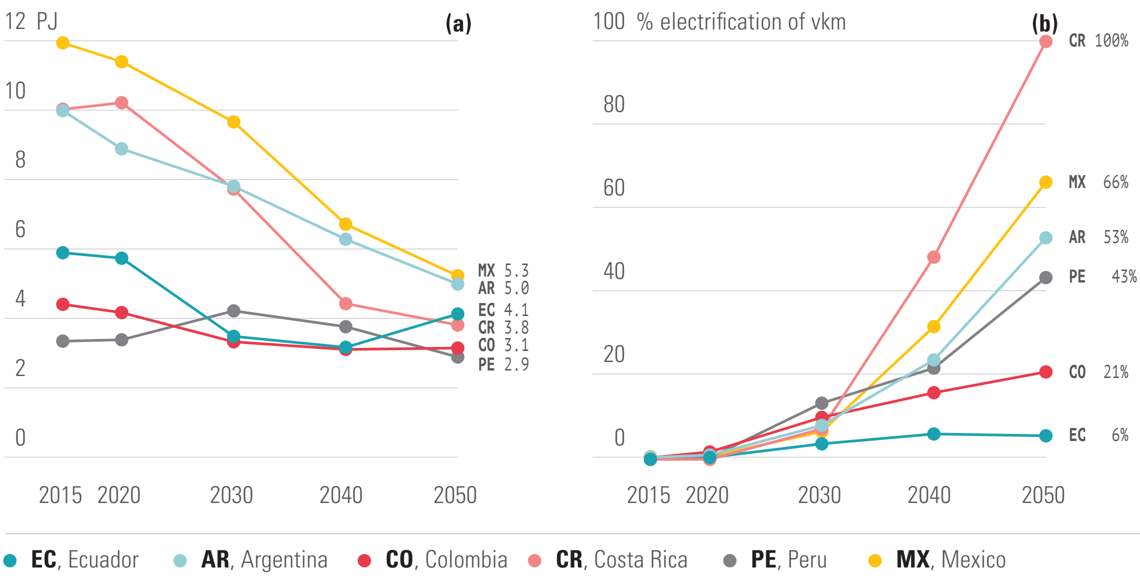
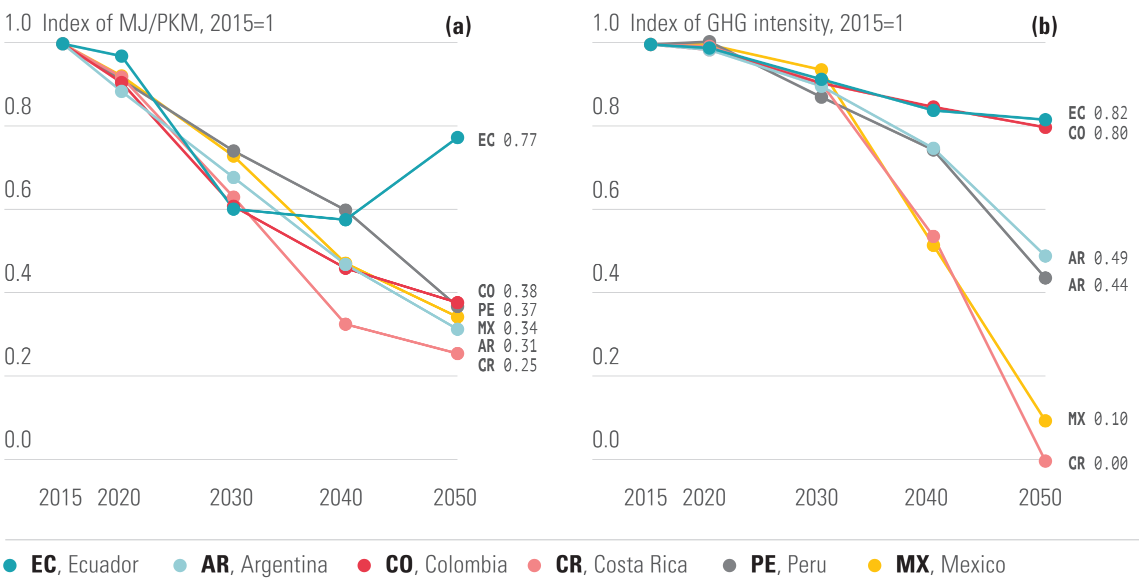


Figure 8. Total energy consumption for passenger transport (PJ) (a) and electrification of all vkm (%) over time (MJ/pkm, 2015=1) (b)



Source: (Bataille et al., 2020)

Figure 9. Passenger transport energy efficiency (a) and overall fuel end use GHG intensity (b)



Source: (Bataille et al., 2020)

to bridge the cost gap between EVs and less expensive internal combustion engine (ICE) vehicles as well as to spur the early deployment of charging infrastructure. These are often coupled with other policy measures that increase the value proposition of EVs (such as waivers to access restrictions, lower toll or parking fees) which are often based on the better performance of EVs in terms of local air pollution.

In the Latin American context, working with the strategy of encouraging high occupancy low emissions urban and intercity travel, business models that help encourage electrification of bus systems (e.g. lease back systems given their high upfront costs) could be transformative. Car, bus and urban freight motorized travel can also be required to transition to zero GHG and local air pollution motors (e.g. electrification and hydrogen fuel cells) via implementation of fleet standards and "clunker" retirement schemes. All heavier and longer-range freight must eventually decarbonize as well, with a mix of electrification, biofuels or hydrogen fuel cells likely depending on the mode, size, route of vehicles and global technological developments.

Again, LAC national and regional governments have most of the governance tools they need for urban planning and vehicle regulations; Ecuador has already mandated all new city and inter-city buses be electric by 2025, and Costa Rica is targeting electrification of the public (30% by 2035 & 85% by 2050) and private (95% to 2050) bus fleets. Where they may require aid and encouragement is implementation of best practises in urban planning, and signalling finance for capital intense urban transit projects to help encourage the participation of the needed private finance.

Sectoral: Agriculture, Forestry and Land Use - Engage sustainable intensive agriculture to reduce N_2O and methane emissions through better farmer practices, and to reduce deforestation pressures

Several of the DDPLAC partner teams (Peru, Colombia, Ecuador, and Argentina) identified sustainable intensification (e.g. more output per hectare) of agriculture and livestock raising as a means to reduce N_2O and methane emissions, including more efficient use of fertilizers and irrigation, dry periods for rice fields, crop and fallow selection to increase soil carbon, etc.

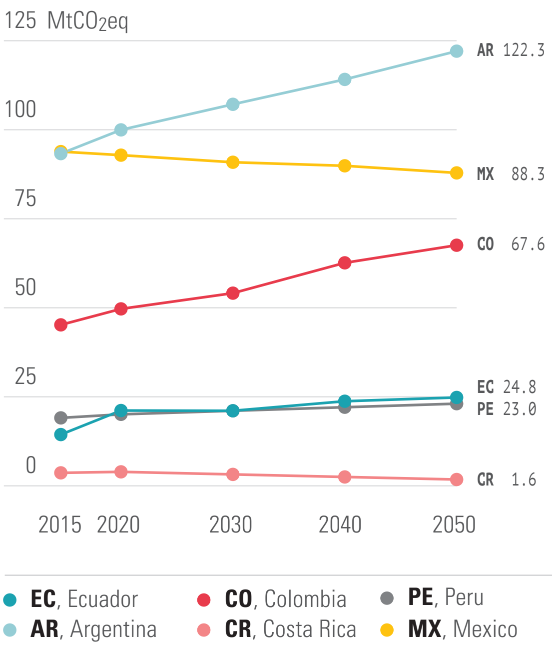
Because nitrous oxide and methane fertilizer and land use emissions outcomes very much depend on the methods farmers use, and will always be difficult to count, these emissions must be reduced through land use regulation, farmer education, and finance mechanisms for the farming community, e.g. fertilizer pricing. Education for farming also often involves a move from subsistence, low productivity agriculture to more professionalized farming. This is within the means of LAC countries but will require a 10-20 year investment in education, and measures to allow currently subsistence farming families to engage with this system.

Nitrous oxide and methane from ruminants (cattle) are proportional to the number of cattle, which is related to human diets, but also the cows' diet. Research is ongoing into vaccines and diet changes to reduce ruminant methane, e.g. by feeding them a small portion of a specific species of seaweed.

While almost all the DDPLAC teams showed flat or increasing agricultural CH_4 and N_2O emissions (**Figure 10**), several noted in their reports that more intensive sustainable agricultural practises could also help reduce pressure to add more farmland through deforestation, and help release previously degraded lands for afforestation.

During the DDPLAC project the teams didn't include large changes in diets, while the subsequent IDB report on jobs (Saget, Vogt-Schilb and Luu, 2020) is premised on a large scale change in agriculture from meat and dairy products to more vegetal production based on diet changes. This has large potential downstream health benefits, and large potential upstream employment and GHG emissions benefits from reduce cattle methane and N_2O (Masson-Delmotte *et al.*, 2018).

Figure 10. Agricultural emissions, CH_4 and N_2O ($MtCO_2e$)



Source: (Bataille et al., 2020)

Sectoral: Agriculture, Forestry and Land Use - Engage assignment and enforcement of land use rights to allow reduced deforestation, supplemented with commercial afforestation

Several DDPLAC teams suggested that that assignment and enforcement of land ownership and use rights (especially for subsistence farmers and indigenous peoples) would help reduce deforestation CO_2 flows and help release agriculturally poor lands for afforestation (**Figure 11**). Creating this enforceable, long term association between communities, agricultural lands, and standing and growing forests produces an incentive to protect and enhance them, as well as longer-term investments in sustainable agroforestry, where forests are "farmed" for high value food, animal, pharmaceutical and other products but left to stand, grow and absorb carbon. This was addressed at some length in the Peruvian DDP work and resulting papers.

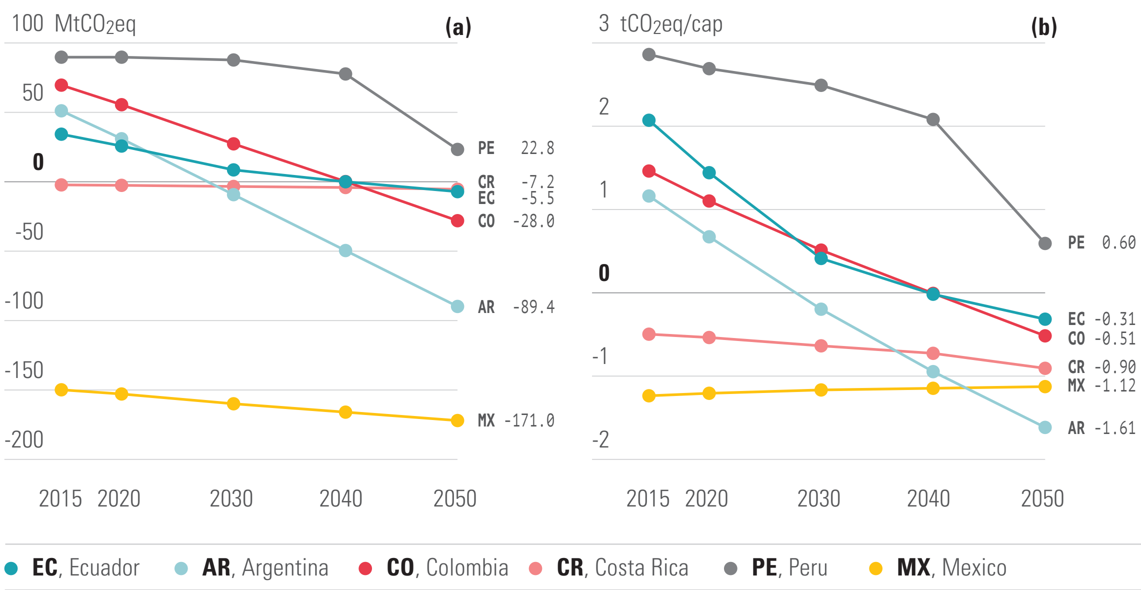
Additionally, large afforestation programs could both protect existing exposed forests and absorb carbon dioxide in their own right. The Peruvian team included a specific suggestion for an afforestation program to buffer existing Amazonian lands that would sequester between 1-2 GtC for \$2 billion, effectively \$1-2/t CO_2. The funds for such a project would have to come from outside the Peruvian government, however.

Land use rights assignment and enforcement are domestic prerogatives, but are one of many development priorities for LAC national and regional governments, and they may not be the highest. Also, as Colombia's experience with the end of their civil insurrection, where the end of violence allowed deforestation to resume in FARC areas, subsistence slash and burn agriculture and illegal land seizure and forestry are hard to avoid if local populations do not have other options. There may be room for funding and logistical support for land use rights enforcement, education for wages labour and sustainable agroforestry, access to higher value-added markets for forest protein and vegetal products, and especially for commercial afforestation programs, all respecting local government priorities. Please refer to "Jobs in a Net-Zero Emissions Future in Latin America and the Caribbean" (Saget, Vogt-Schilb and Luu, 2020).

Sectoral: Participation in structured and intensive innovation and commercialization programs and market pull mechanisms to deal with "hard to abate" sectors, e.g. aviation, freight, and heavy industry.

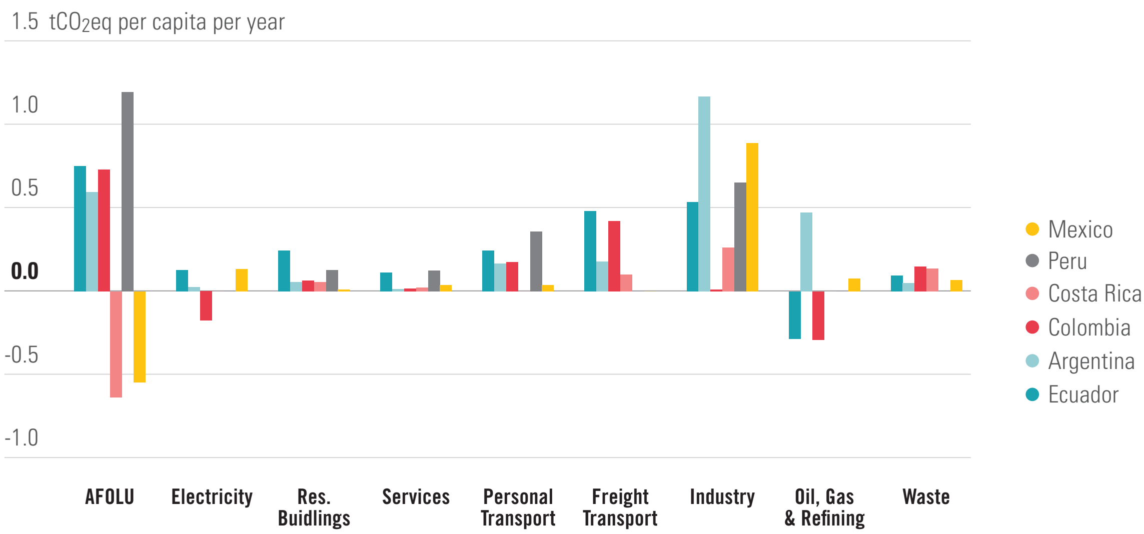
The LAC countries all have substantial aviation, freight, and heavy industry emissions (**Figure 12**), all of which must go to net-zero emissions as well. While the LAC nations have a substantial challenge transforming their electricity, transport and industrial systems, as best available technology improves in the aviation, freight and heavy industry sectors they should also monitor and adopt these improvements, and contribute to global efforts as they are able.

Figure 11. Land use change emissions by country: absolute (Mt CO_2) (a) & per capita (tonnes CO_2 per person) (b)



Source: (Bataille et al., 2020)

Figure 12. Remaining 2050 emissions by sector per capita (tonne CO_2e per capita per year)



Source: (Bataille et al., 2020)

It is not out of the realm of possibility that Mexico's solar resource, Argentina and Chile's wind and solar, and the entire region's plentiful biomass, may be key to producing net-zero materials (e.g. zero emissions iron from Chile using hydrogen reduction) (Armijo and Philibert, 2019), fuels and keystone chemicals (hydrogen, ammonia, ethylene, methanol) (Armijo and Philibert, 2019; Bataille, 2019).

The DDPLAC project has shown that achieving net-zero emission by later this century is technically achievable using known physical and policy pathways mostly well within the capabilities of these countries, and that there are substantial potential macroeconomic, air quality and energy security benefits. Achieving these pathways will require the active participation and cooperation of all stakeholders in the formation of long-term development strategies, strategies which, once established and agreed on, will allow the choice and implementation of economy wide and sectoral policy packages suited to each country and sector to drive the physical transformations. Long-term strategies can also help governments manage the social impacts of decarbonization and ensure a just and inclusive transition (Saget et al 2020). Some key international enabling conditions may be helpful, in the form of key technological advances & commericialization, de-risking "signalling" finance for energy and transit infrastructure, and direct international funding and logistical support for domestically controlled land use rights assignment and enforcement, forest community general and specifically agroforestry education, and very pointedly for direct afforestation programs to protect and enhance existing forests.

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COUNTRY PERSPECTIVES

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ARGENTINA
GETTING TO NEAR NET-ZERO EMISSIONS

Authors:
Franciso Lallana, Gonzalo Bravo, Nicolás Di Sbroiavacca, Gustavo Nadal, *Fundación Bariloche, Energy Department, Argentina*.
Gaëlle Le Treut, *Centre International de recherche sur l'Environnement et le Développement (CIRED)*.

Key policy messages

- Argentina's NDC measures are consistent in direction but not in depth with deep decarbonization.
- Electrification of most final energy demand is necessary for decarbonization.
- Growth of variable renewable energy to 50% of generation by 2050 is necessary across our scenarios.
- The development of a hydro-nuclear program that complements renewable energy development emerges as the favoured option for reaching decarbonization objectives, with the best impact in terms of activity, employment and productive dynamics.
- The availability of a mature and competitive CCS and/or blue hydrogen produced from natural gas technologies are required if *Vaca Muerta* – a major non-conventional hydrocarbons formation - is to play a large and positive role in the Argentinian scenarios, by using its natural gas for electricity generation and eventually for export.
- Paris Agreement compliant per capita emissions goals will be difficult to achieve without afforestation as a core mitigation strategy to offset emissions from agricultural-livestock productive activity.
- The large investment needs required to reach Argentina's Deep Decarbonization objectives will require more substantial, efficient, and cooperative financial resources.
- If decarbonization of Argentina is to be reached jointly with needed national development, a change in the national development model is needed. A comprehensive National Development strategy is needed, accepted by all major stakeholders. Such a strategy should be leaded by an inter-ministry coordination including the private sector; a purely market driven strategy is unlikely to reach the decarbonization objectives.
- Second-order effects of final demand measures need to be explored, in terms of resources and economic uses due to changes in the production structure, e.g. changes in automobile manufacturing arising from the introduction of electric vehicles, or the generalized electrification of energy end-uses by the household and service sectors.

National Circumstances

A central challenge for Argentina is to deeply mitigate its greenhouse gas emissions and at the same time achieve the United Nations' Sustainable Development Goals (SDGs). Exports, mainly from natural resources in both energy and agriculture sectors, played an important role in the country's growth and helped it to recover from the 2001 crisis: they account for a 20% of the share of GDP for the 2001 – 2015 period. For the year 2015, 11% of the GDP comes from exports. Remarkably, 36% of total grains production (oilseeds and cereals) are exported without further value-added steps, while 18% of total beef production went to external markets. (Argentine Government, 2019a).

In Argentina fossil resources contribute significantly to both primary energy supply (88% of the total in 2015) and for final consumption (77% of the total in 2015). Even while Argentina has a diversified electricity matrix (with some hydroelectric power plants, nuclear and intermittent renewables), most electricity is produced through gas and fossil fuel thermal power plants, and the final energy demand of the residential sector is mainly met with natural gas. Since 2010, the Vaca Muerta non-conventional oil and gas formation has boosted the country's fossil fuel independence while providing potential for additional export income. There is widely held vision in the country that the exploitation of these resources can contribute to economic development, the recovery of energy self-sufficiency and repair of the economy´s balance of payments (Dumas, J. y Ryan, D. eds. 2019, Government of Argentina, AGSE 2019). If deep decarbonization goals are to be met, however, this form of non-conventional hydrocarbon development, for both direct use and as blue (methane based with CCS) hydrogen, will require the technological and economic availability of carbon capture and storage.

In its Nationally Determined Contributions (NDC) Argentina has committed not to exceed 483 $MtCO_2eq$ of net emissions in 2030; this is a net reduction of 18% in comparison with its emissions trend in a business-as-usual scenario, but an increase of 33% compared to 2016 level. The large reduction efforts are in the energy and forestry sectors, and, on a secondary basis, in the agriculture, transport, industry and waste sectors. According to the Argentine Government Secretariat of Environment and Sustainable Development (AGSESD), about 70% of the reduction effort in the proposed NDC baseline scenario is to be in the energy production sector and final energy demand (buildings). Yet the Agriculture sector of the economy has received much less attention for developing mitigation measures; together with the food industry, it accounts for 8% of Gross Domestic Product (GDP) in 2015. A brief mention of conditional measures is found in the National Action Plan for the Agriculture Sector and Climate Change, recently launched by the Argentine Environmental Secretariat (2019a). Reforestation stands out as the key lever in terms of increasing absorbed emissions. Transport accounted for 14% of fossil fuel combustion emissions in 2016 (Argentine Government, 2019b) and it is expected to double by 2030 compared to the 2015 level in a business-as-usual scenario. National climate pledges specify a few actions aimed mainly at improving efficiency in road freight transport, prioritizing railroads and public transport, among other unconditional measures that would not reverse the increasing trends (SESD, and MINTRAN. 2017).

Argentina has a National Adaptation Plan process developing mid-term (2030) sectoral strategies for achieving decarbonisation targets that are compatible with its revised NDCs targets, but early indications are these are still far from Deep Decarbonization Pathway (DDP) scenarios in terms of emissions reductions. These strategies are still under review and development, however, and are led by Argentinean Ministries and cover the energy, transport, health, industry, agriculture and livestock, infrastructure and land development and forest sectors (Argentine Government, 2019c).

The currently committed NDC measures (new ones are being developed for 2021) are insufficient to achieve the DDP objectives, especially those associated with final demand, and would imply greater concentrated efforts after that year. Getting to net-zero emissions of CO_2 across the energy and AFOLU systems is technically possible, but the proposed measures to achieve it are potentially highly varying in terms of the uncertainty level involved, potential rebound effects, their cost per unit emissions savings, and their technological maturity. Specifically, mitigation measures targeting the agricultural and livestock sectors, which account for close to half of GHG emissions in Argentina, are generally less developed and more uncertain than those targeting the energy sector. **Furthermore, the development of necessary massive carbon sinks to compensate emissions through afforestation still requires carrying out feasibility and environmental assessments.** Thus, achieving a 2 tonnes CO_2 per capita target for 2060/2070 **from the energy system**, to be balanced with negative emissions from reduced deforestation and afforestation, **has a high level of uncertainty** and poses significant challenges linked to Argentina´s productive structure and its national development goals regarding life quality, equality and energy security.

Project modelling methodology

Building 'backcasting' pathways from the 2050 goals to the present allows identification of the sequence of technical and socio-economic transformations required to reach a deep decarbonization long term objective as well as the underlying drivers, enabling conditions and required policy measures in the context of inertia, lock-ins, and innovation. To build such pathways, a combined qualitative-quantitative DDP method was used (Waisman et al. 2019) which is based on the complementarity between exploratory storylines and the quantification of the storylines as pathways through a set of numerical models: the LEAP (Heaps, 2016) energy model, the IMACLIM-ARG hybrid computable general equilibrium (CGE) model (Le Treut et al. 2019) and the FABLE land-use model (FABLE 2019). The combined tools make it possible to quantify the energy, land-use and socio-economic dimensions of the pathways. Two contrasting pathways were constructed to show how **deep decarbonization could be reached in Argentina** while **meeting other economic development goals,** both involving significant changes to the energy sector and economic system as a whole.

In the framework of the DDP LAC project, the Bariloche Foundation received specific assistance from the French research group CIRED to develop the IMACLIM-Argentina model, a new national version of the IMACLIM-Country model. This modeling capacity aims to study the impacts on Argentina's economic structure of actions to mitigate climate change, aka "decarbonization" (BID y DDPLAC 2019). The coupling between LEAP and IMACLIM at each step of simulation has been achieved which ensure consistency of the analyses. Concretely, key outputs from LEAP scenarios, such as energy content of the economy, the amount of investments for the power sector (by sectors) and the associated costs (basically capital and labour costs), are used to inform IMACLIM-ARG to be able to get an encompassing picture of the DD roadmap implications, and to capture the impacts of contrasted energy systems on the wider economy. Eventually, outputs on production growth levels from IMACLIM-ARG are then used to inform back the LEAP to adapt the energy scenarios. The procedure can be repeated as a loop until convergence of the models.

Using this modelling methodology, **two deep decarbonization scenarios have been built and evaluated** to be compared with the NDC trend scenario. In each of them, the necessary energy re-configuration to reach total emissions tending to 2 tonnes CO_2e per capita by 2050 has been explored. Nearly complete electrification of energy end uses is necessary to achieve the DDP targets in both scenarios. From the energy perspective, the scenarios mainly differ based on the use or not of Vaca Muerta's natural gas. Such use requires the adoption of carbon capture and storage (CCS) technologies. The other DD scenario relies on an intensive development of hydroelectric and nuclear resources instead. In both cases, significant development of variable renewable sources for electricity generation are required, reaching close to 50% of total electricity production levels.

The coupled framework enables the identification of both the macroeconomic impacts and the direct and indirect effects of the DD roadmaps built by the energy model. Indeed, the IMACLIM-ARG model allows highlighting the structural economic changes of contrasted DD strategies. It helps to understand the implications of the transition, according to the initial economic structure it has been given to it, on: GDP structure, sectoral employment and job creation, valued-added structure, and eventually on the enabling conditions in terms of financial or industrial strategies. Ongoing analyses show interesting preliminary results.

Despite a lack of precise updated economic structure data to inform IMACLIM-ARG at the base year, we went through the model calibration. To ensure greater robustness of the modeling framework, access to more recent national statistics would greatly aid this effort. More detailed information would also give an opportunity to disaggregate key sectors hidden into aggregates (such as heavy industries) and thus to deepen the sectoral analysis.

Key policy findings

One of the main conclusions of the Argentinian DDP study is that despite considering a significant set of mitigation measures in both the energy and the LULUCF sectors in the modeling, it will be necessary to resort to an increase in afforestation if it is desired to reduce net emissions to less than 2 tonnes CO_2 per capita per year. Although there is a high level of uncertainty and risk associated with this measure and no detailed feasibility analysis has been carried out yet, under adequate circumstances and an State-led integrated land use planning framework this could result in the preservation and increase of forest stocks (both natural and planted), with potential benefits from ecosystems services provision (e.g. soil erosion prevention, and water basin and ecosystems protection), which in turn can have tangible economic and health benefits for the society. These potentially positive outcomes also align with several National SDGs.

The scenarios modelled reduce the energy fraction of per capita emissions to practically zero by 2050. However, it is not possible to extend the goal to all sectors due to the impossibility of concurrently reducing non-energy land use CO_2, livestock methane (CH_4) and agricultural N_2O emissions. In this sense, **afforestation** acting as CO_2 sink arises as a requirement for Paris Agreement compliance, which requires net-zero CO_2 by 2050 for 1.5°C, and by 2070 for 2°C, and -50% CH_4 globally by 2030 to 2040. Remarkably, this highlights the distortion produced by the undifferentiated accounting of emissions from different sources and activities, an ethically disputable issue given that a country producing grains and livestock destined for export cannot achieve the required goals by compensating with its energy emissions. Additionally, the implementation of National policies in these primary sectors has been historically challenging and changes in production patterns and methodologies have been led mainly by short term productivity and market prices.

Concerning the energy system, Argentina´s DDP scenarios also highlight the **role of both hydro and nuclear power in zero energy emissions scenarios**. This is consistent with former sector strategies that provided the country with reliable power to stimulate development, increase energy security, reduce dependence on fossil fuels, help develop strategic industrial sectors and, in the case of nuclear power, also produce knowledge and technological spin-offs. Additionally, this strategy is **compatible with a higher share of variable renewable sources** in the electricity mix, development that would require an active and leading role of the National State.

Furthermore, from the preliminary analysis carried out with LEAP-IMACLIM, **DD strategies** based either on gas production with CCS or on the hydropower development together with nuclear energy **do not incur a significant macroeconomic cos**t but **do induce sizeable changes on the GDP structure, contrasted impacts across sectors in term of sectoral employment and production, and a strong shift in the sources of valued-added, compared to the NDC scenario**. A DD based on hydro and nuclear energy requires more investment which weighs more on GDP compared to a roadmap based on gas with CCS, but requires less offsetting with negative emissions in the long run. Both DD scenarios require sizeable construction which leads to an increase in job creation for the sector up to 2050. The energy sector production drops off but as it becomes more labor-intensive, jobs are created, especially in the DD scenario with hydro and nuclear development. These conclusions seem robust but they are also sensitive to the industrial strategies. The DD roadmaps should come with discussions and recommendations on the production location of the goods needed to meet mitigation goals. Relocations or relying strongly on imports could harm the economy. Additionally, other policies that couple the energy system to the productive one (such as the restructuring of the national automotive manufacturing complex towards electric cars) could be incorporated. This kind of analysis was not approached since there were no differences among both scenarios in terms of the final demand measures. However, the use and availability of economic resources or inputs required by these changes could affect the comparison due to second-order effects.

The costs of some zero carbon technologies, linked mainly to the energy sector, are dropping rapidly whereas business-as-usual is becoming more expensive and exposed to transition risks including asset stranding. Although there are potentially high costs to inaction, a comprehensive assessment of costs and benefits should compare the **long-term costs of different scenarios from a social point of view**, internalizing impacts on employment and health, avoided accidents, congestion, among other issues. This kind of analysis is very complex and highly uncertain for a long-time frame, but some insights can be achieved through integrated energy-economy modelling.

Regarding **key demand side measures**, improvements in refrigerators, air conditioning and lighting (light emitting diodes) respective efficiencies, as well as in thermal envelope (insulation), penetration of electric heat pumps for heating, and penetration of solar collectors for hot water, are outstanding in the household and services sectors. Additionally, given an almost total penetration of electric vehicles and already foreseen actions (NDC baseline) for improving efficiency in road transport of loads, prioritizing railroads and public transport are proposed as necessary actions for the transport sector.

Livestock and agriculture land use area projections imply that the sum of pasture plus agriculture remains constant. A reduction in emissions per head of livestock of 30% to 40% by 2050 is assumed compared to the trend scenario (achieved through diet modification and other measures, e.g. tannins, lipids, pasture management, food processing). However, there is still high uncertainty regarding the levels of enteric methane reduction and their permanence in time. Agriculture in turn, reduces its emissions by 20% to 30% compared to the NDC base line scenario, explained by increased crop rotation, incorporation of its residues into the soil, nitrogen use efficiency improvement (e.g. nitrogen release inhibitors, biological nitrogen fixers) and increasing the share of cereals relative to oilseeds.

Finally, the development of Vaca Muerta non-conventional oil and gas deposits clearly conflict with DDP strategies unless carbon capture and storage and/or blue hydrogen production were to be used. However, since it is considered to be a key to Argentina´s long term development strategy, it cannot be disregarded unless a suitable alternative can be found. This implies that in order to meet the goal of zero deep decarbonization energy emissions while continuing the development of Vaca Muerta, international financial efforts supporting local research projects and the promotion of pilot CO_2 capture and storage projects are necessary.

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COLOMBIA
OPTIONS FOR MID-CENTURY DEEP DECARBONIZATION STRATEGY

Ricardo Delgado[3], Thomas B. Wild[4], Ricardo Arguello[5], Leon Clarke[5]

Key messages

- We find that an extension over time of current and announced policies is insufficient for achieving the desired outcome of reaching carbon neutrality by 2050. Deep decarbonization requires major changes to be fully implemented by 2050. There is still time to plan a smooth and economic transition. Lowering ambition in the short term might not only reduce the effectiveness of decarbonization but also increase unnecessarily the transition costs and reduce the benefits.
- To help inform revision of Colombia's NDC, Colombia should construct its LTS within the context of its unique circumstances and societal goals while meeting the goal of net-zero emissions later this century. Poverty alleviation requires use of currently available resources to support the early transition towards a low carbon economy.
- Energy efficiency is important yet decarbonization is mainly reached using cleaner energy, i.e. switching to very low and zero carbon fuels. The transition could be smooth if it starts soon and with incremental and sustained efforts.
- Electricity will be the dominant fuel for decarbonization. Hydro, wind, solar and sustainable biomass-based generation will need to provide most of the power demanding the exploration of grid improvements and backup options (power to gas, batteries, pumping hydro, demand response programs).
- The power sector will increase its activity and is required to do the transformations that enable it to provide a reliable, affordable and net-zero emissions service. Anticipation is key to take advantage of the new business possibilities within this sector. We have 30 years to plan, build and design the operation of a larger than now and net zero CO_2 emissions power system. We shall not forget, however, that 30 years might be the useful life of a new power plant, so planning the next few years investments is key for the longer-term goal.
- In a deep decarbonization scenario, there is an increase in the production of agricultural products (including bioenergy) and exports. Stopping deforestation is a must and there is the need to enable lands to produce additional food and biomass by intensifying crops and cattle.
- International markets of oil and natural gas will still be active by 2050 with lower demands and highly uncertain prices. Decarbonization in Colombia will not eliminate domestic oil and gas industries but their competitiveness by mid-century would depend largely on international circumstances.
- Transportation has two lines of action towards decarbonization. Firstly, public transportation needs to support the growing passenger demand in the upcoming years, eventually switching to net-zero emissions vehicles. Private modes should stabilize its participation at current levels, and also switch to net-zero emissions vehicles. Overall, the transportation energy mix needs to be transitioned to the use of biofuels of second and third generation, electricity and hydrogen, with a focus on the latter two energy forms in urban settings due to local air quality needs. Regarding freight, there is the need for using alternative modes such as rail and water transport lowering the emissions by introducing heavy duty trucks powered by advanced biofuels, LNG and hydrogen.

3 School of Engineering. Universidad de los Andes, Colombia
4 University of Maryland, Maryland, USA
5 Universidad del Rosario and Universidad de Ibague, Colombia

Where Colombia stands

Like all countries around the world, Colombia must construct its LTS within the context of its unique circumstances and societal goals, and in the short term with a mind to recovery from the COVID pandemic. Colombia's current economic context is characterized by a high share of the services sector in GDP, followed by lower shares for manufacturing and agroindustry activities, and mining. However, both the external and fiscal fronts have a marked dependence on fossil fuels exports. Total Colombian emissions in 2014 were 214.3 Mt CO_2e, which makes the country relatively low per capita emitter (4.56 ton CO_2e per capita). The Agriculture, Forestry, and Other Land Use (AFOLU) sector is the largest emitter with net emissions amounting to 50% of the total, followed by energy, which represents 39%. Within the AFOLU category, land use change is responsible for 60% of the emissions while, within energy, the largest emitter is the transport sector, which represents 36% of the category's emissions (IDEAM, et al., 2017).

Controlling deforestation is key for lowering emissions. The country has large areas of unmanaged forest, which raises concerns about deforestation that accounts for the vast majority of land use change and associated emissions. On the other hand, **current electricity production has relatively low emissions** due to a large share of hydroelectric production [(IDEAM, et al., 2017; UPME,2016; XM, 2015), and the country shows low per capita energy consumption. However, even at moderate economic growth rates, within the span of the following three decades Colombian GDP should increase at least two-fold and the energy sector will grow substantially. As for other countries, broader concerns about prosperity are the ultimate goals for Colombia and, to be successful, mid-century development strategies must identify appropriate synergies between climate protection and a prosperous and sustainable future.

Goal and scope of the study

The development of mid-century strategies is challenged by the uncertainty associated with understanding the future several decades from now. It is also challenged by the complexity of the underlying technological and societal systems that must evolve to reduce emissions and limit temperature change. Despite this fact, there is increasing evidence that a net-zero emissions is possible.[6] While there is no way to fully manage these challenges, formal energy-economy, integrated assessment, or similar models have been used extensively to produce self-consistent scenarios of the future and to inform planning (Winkler et al., 2017; Raubenheimer et al., 2009; Winkler,2009). With such an aim, in this study we use the Global Change Assessment Model (GCAM) to develop three representative pathways toward deep emissions reductions by mid-century in Colombia.

We explore what might happen: 1) under Colombia's current policy trajectory, 2) in a context of a 30% reduction in CO_2 emissions by mid-century, and 3) in a 90% reduction scenario (the last two ones are consistent with two-degree and 1.5 degree rises in global temperatures, respectively). These stylized climate policy scenarios are not intended to serve as high-fidelity representations of how Colombia's low carbon development strategy will be. The Colombian LTS would potentially consist of hundreds of measures implemented across numerous sectors and sub-sectors. However, as they will have to be guided by overarching, common sets of strategic and articulated interventions, our goal is to contribute to identify and delineate them in a way that is clear in providing insights for decision-making at the heart of long-term climate and economic planning.

6 https://publications.iadb.org/en/getting-net-zero-emissions-lessons-latin-america-and-caribbean

Main findings

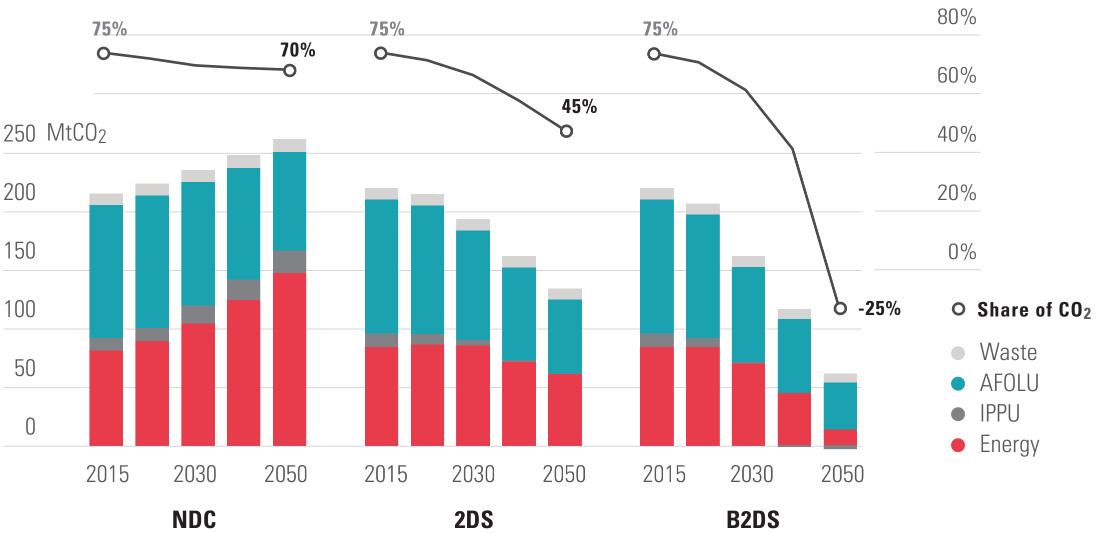
We find that an extension over time of current and announced policies is insufficient for achieving the desired outcome of reaching carbon neutrality by 2050. In fact, despite these efforts, emissions will continue to grow if no additional and more ambitious measures are implemented. **We also find that the distinction between CO_2 and non-CO_2 gases are important in the context of countries such as Colombia, where the agricultural sector is economically relevant, both currently and as an engine for future growth.** Indeed, agricultural emissions are only modestly reduced across our three scenarios, as the sector must provide for food, intermediate, and energy demand in a context in which international trade is important. This also leads to significant increases in agricultural land, that the country has the potential to accommodate without increasing deforestation (which requires appropriate agricultural intensification).

Early action is required to successfully reach this mid-century goal. Although the AFOLU sector is currently the largest source of emissions in the country, mitigation efforts are required in all the other sectors. Deforestation must be controlled, and energy sector CO_2 emission and their growth should be addressed early by any LTS. This mandates that energy be generated by non-emitting sources, that end users switch as much as possible to energy carriers that will support the use of these sources (e.g., electricity, biofuels), and that energy use is constrained as much as it is feasible. Rapidly declining electricity emissions that ultimately serve as a sink for CO_2, using bioenergy coupled with carbon capture and storage (CCS) technology is a possibility. However, **CCS could be explored as an option with large caution due to the uncertainty of its future commercial availability**. The country should not rely on the availability of CCS and such expectations should not stop the required transformations to have a 100% renewable power sector.

Clean electricity is required to support energy consumers. Clean electricity would provide typically difficult-to-decarbonize sectors, such as freight transportation and industry, more room to limit their emissions. Recent advances in battery technology also make feasible for the transport sector, including

Figure 13. Yearly Colombian greenhouse gas emissions and share of CO_2 in the three modeled scenarios

Current policies (NDC), 2°C Scenario (2DS) and 1.5 °C Scenario (B2DS)



freight, to be another potential component of Colombia's decarbonization strategy, intimately linked to electricity sector emissions reductions.

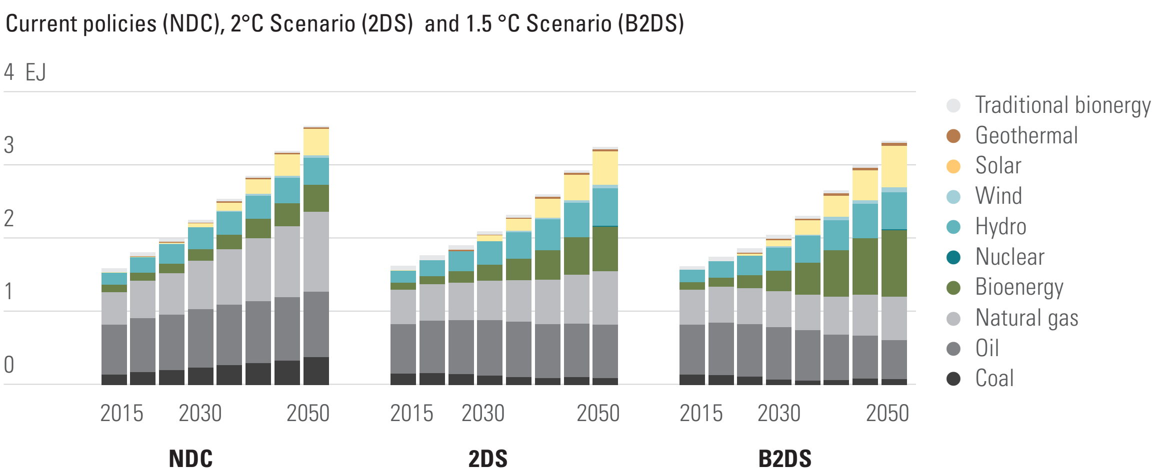
As expected, final energy demand grows rapidly, driven by population and income growth. Emission reductions are reached by improvements in energy intensity as well as in the carbon intensity of energy used. Reductions in energy intensity primarily reflect technological changes such as more efficient devices, use of public modes for passenger transportation, modal shifts for freight, but also some changes in end-user behavior. Nonetheless, these improvements, while sustained, are not the main driver of change. This role is reserved for the carbon intensity of energy, through less carbon intensive or renewable sources substituting for carbon intensive fuels.

Decarbonization implies major adjustments in the fuel mix. Sources include solar, wind, hydroelectric, geothermal, nuclear, bioenergy, and fossil or bioenergy power coupled with carbon dioxide capture, utilization, and storage (CCUS). While the mix cannot be foreseen with certainty today, our results allow for pointing towards three important issues in the Colombian context: the role of renewable resources; the role of second and third generation biofuels, given the emphasis on the agricultural sector and the potential to use bioenergy both domestically and internationally; and the manner in which fossil resources might still be deployed in the Colombian energy mix and the implications for CCUS.

For decarbonization to take place, **the share of renewables in the primary energy mix needs to more than double by 2050** and it mainly occurs through substantial increases in bioenergy utilization and solar power. Hydroelectric power keeps its importance but increases at a slower rate through time. The increase in solar and wind penetration and the substantial use of biofuels calls for investments and strategies to manage an electricity grid that is more dependent on intermittent resources and long-term planning, particularly in the context of a changing climate that could impact the seasonality and availability of hydroelectric power to balance the expanded variable renewables fleet. On the other hand, fossil fuels are a critical piece of the puzzle, not only because of their role in the domestic energy system but also because of their current and project economic importance. In this case, the future of the fossil fuel industry may depend, to a large degree, on the international market demands and prices and on the availability and cost of CCUS technologies that are currently under development (and possess a high uncertainty on it effectiveness and techno-economic feasibility).

The potential use of CCUS calls for increased understanding of the potential for, and the limits to, CCUS in the future Colombian energy system (Williamson, 2016). Any alternative will require greater use of other low emissions electricity sources, including solar, wind, bioenergy, and potentially

Figure 14. Primary energy consumption by energy carrier in the three modeled scenarios



nuclear power, as well as a more aggressive use of bioenergy and electricity in transport and industry. Electricity will be the dominant fuel for decarbonization, while natural gas consumption declines, and coal is virtually eliminated in end use sectors. Therefore, final energy sectors should avoid expanding use of natural gas and coal, and instead focus on increases in electricity and liquids from biomass to be on track for reaching climate stabilization.

Transportation is currently the largest energy sector contributing to CO_2 emissions, and activity is expected to grow. We estimate the road transportation will grow 2.2 times between 2015 and 2050, while decarbonized transport services will need to be provided for public transport systems that grow to serve over 70% of total road mobility demand by 2050 (reversing the trend toward private vehicle use as income per capita increases). Furthermore, we estimate by 2050 64% of the public transport systems need to be powered by electricity, while the rest of power will be a mix of natural gas, fossil liquids, and biofuels.

Strategies to address deforestation are a critical component of any Colombian LTS. For this study, given the complexity of the underlying dynamics of deforestation, its behavior was developed exogenously to GCAM. The deforestation trajectory was selected to remain consistent with the land requirements for

Figure 15. Power generation by source in the three modeled scenarios

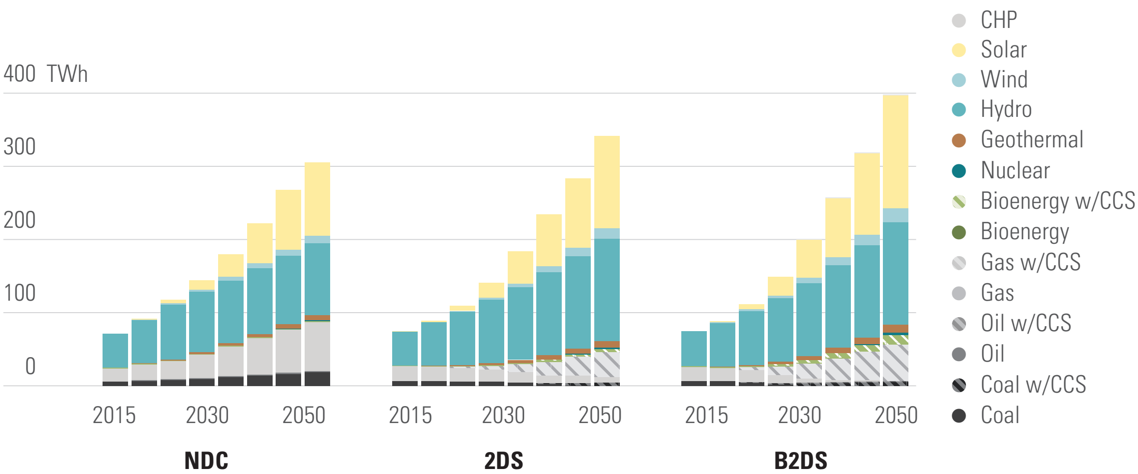


Figure 16. Yearly motorized km travelled by passengers and energy mix for passenger transport in the 1.5 °C Scenario

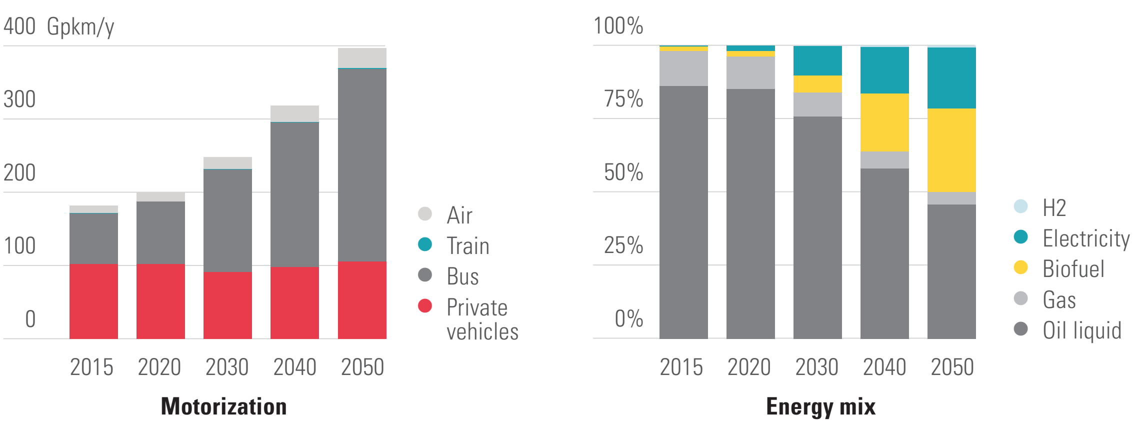
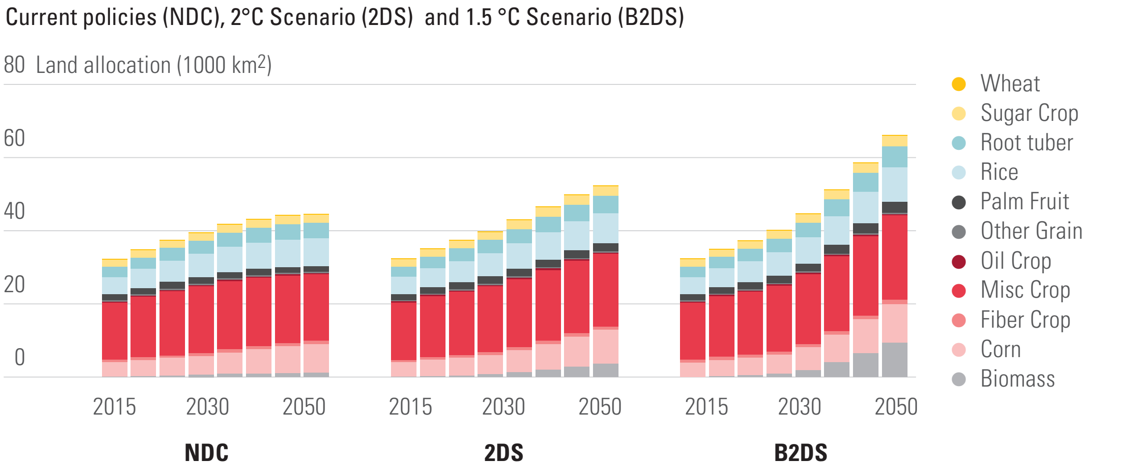


Figure 17. Agriculture land allocation by crop in the three modeled scenarios



agricultural and bioenergy production. We project a large increase in agricultural activities and their associated land demands because of higher production of biomass for energy as well as food. Such a development would be consistent with an improvement in rural activities and a broader economic opportunity for the national economy. However, enabling additional land for food and biomass production while reducing deforestation, and even increasing reforestation, is a fundamental challenge.

Intensification of livestock production is key for freeing up areas that can be used for increased crop production, with an emphasis on biomass. Moving from a current animal density of about 0.8 heads per hectare to 2 heads per hectare could free about 12 million hectares for other agricultural uses (allowing for more than doubling currently planted areas), and also helping to end pressure on natural forests in some critical regions and to increase afforestation and ecosystem restoration. Further development of appropriate livestock technologies, provision of technical assistance to ranchers, and streamlining and strengthening marketing practices, can be important tools in achieving this goal. Reducing deforestation and making better use of land resources for agriculture (a key component for improving rural household income) may be facilitated through appropriate land planning processes and agricultural intensification (especially in the livestock sector). This allows for a partial reallocation of agricultural activities and for increasing production in a manner that is both compatible with zero net emissions and with food and intermediate goods affordability.

Conclusions

The scenarios in this study show that current and announced Colombian policies are not compatible with compatible with deep decarbonization. Following them could imply technological choices that would raise the risk of stranded assets and increase the challenge of climate mitigation.

Planned decarbonization trajectories with early actions might reach the climate stabilization goal, enhance the national economy, and help Colombia reach the SDGs at the same time. In terms of timing, the only required near term action indicated by all the explored scenarios is that there be quick phase out of coal for internal consumption, indicating a just transition strategy for this sector should be implemented as soon as possible. All the other transformations give more space for the transition, but there is no time to waste. Other than coal, there is still time to use current fossil fuel capital stock and resources within the length of their useful lives . However, new investments would require to be done acknowledging the mid-century decarbonization goal. Clear signals to markets are required regarding the Colombian commitment to the mid-century deep decarbonization goal. This clarity would unlock new business opportunities such as the intensification of the agricultural activities, the deployment of an advanced biomass industry, the development of a more advanced and modern power sector, opportunities for the local industry in the development of the electromobility and its infrastructure, among others. A planned pathway towards deep decarbonization is not incompatible with the successful completion of current business (after the end of asset and projects useful life) and might imply new business opportunities for the mid and long term. This might be a way to couple current efforts for poverty alleviation with longer-term options for sustaining these efforts. None of them should be dismissed, poverty needs to be alleviated now and permanently.

The scenarios in this study articulate several key actions and issues that are of sufficient potential importance to warrant further consideration as part of a LTS development. These include the following: (1) stopping deforestation, including enabling lands to produce additional food and biomass by intensifying crops and cattle; (2) use of solar and wind power in electricity generation with associated exploration of grid improvements and seasonal backup; (3) electrification of transportation and industry; (4) the potential to increase public transportation as a means to constrain transportation emissions and enhance urban lifestyles; and (5) the critical potential role of bioenergy in transportation, electricity generation, negative emissions, and possible exports, and its broad implications for agriculture and energy policies and dynamics and, with high caution due to the inherent uncertainties (6) CCUS as an option to allow for continued use of natural gas in electricity generation and potentially to support bioenergy with CCS.

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COSTA RICA
GETTING TO NET-ZERO EMISSIONS: SUMMARY FOR POLICYMAKERS ON THE LESSONS FROM THE ENERGY AND TRANSPORT SECTORS

Authors:
Jairo Quirós-Tortós[1*], Guido Godínez-Zamora[1], Luis Victor-Gallardo[1], Jam Angulo-Paniagua[1], Eunice Ramos[2], Mark Howells[2], Will Usher[2], Felipe De León[3]

[1] School of Electrical Engineering, University of Costa Rica, San José, Costa Rica.
[2] Division of Energy Systems Analysis, KTH Royal Institute of Technology, Stockholm, Sweden.
[3] Climate Change Directorate, Ministry of Environment and Energy, San José, Costa Rica.
[*] corresponding author: jairohumberto.quiros@ucr.ac.crs

Getting to net-zero is necessary to limit the temperature rise to 1.5 °C, it is technically possible, and it brings benefits to development.
The Paris Agreement establishes a mechanism to fight climate change by contributing to mitigation of Greenhouse Gas (GHG) emissions caused by anthropogenic activities [1]. Starting in 2020 and every 5 years thereafter, countries of the United Nations Framework Convention on Climate Change (UNFCCC) must update their progressive commitment towards decarbonisation through their Nationally Determined Contributions (NDCs) for holding global warming well below 2°C above pre-industrial levels while pursuing efforts to limit it well below 1.5 °C. While NDCs will support the transformation, countries are encouraged to define Long-Term Strategies (LTSs) to guide this transformations with economic and social goals [2].

Reaching net-zero emissions is technically possible. There is an international agreement that net-zero emissions of carbon dioxide (CO_2) by 2050 and a deep reduction of other GHGs can be accomplished through actions around four central pillars: (i) producing zero carbon electricity (and other liquid and gaseous fuels); (ii) undertaking massive electrification and switching to net-zero fuels; (iii) increasing the share of public and non-motorized transportation; (iv) halting deforestation and protecting and regenerating natural carbon-rich ecosystems. Technological solutions are already available for each pillar.

Costa Rica has made progress. Different policy packages put in place have resulted in an almost 100% renewable electricity [3] and 60% of the national territory being covered by forest [4} (compared to less than 30% in the 1980s). These two milestones represent the first two pillars of the country's decarbonization process.

Efforts are still needed in the energy and transport sectors. The latest GHG inventory (reported to the UNFCCC5) highlights that the energy sector accounted for 67% of the country's gross emissions (10.88 $MtCO_2eq$), with transport representing 51% of the total. This not only produces health issues, but also serious traffic congestion and accidents. Thus, decarbonizing through limiting urban growth, promoting a modal shift to non-motorized transport, reducing demand due to digitalization of jobs and teleworking, and adoption of low-emissions technologies like electric personal and public transit vehicles are key strategies towards the mid-century goal.

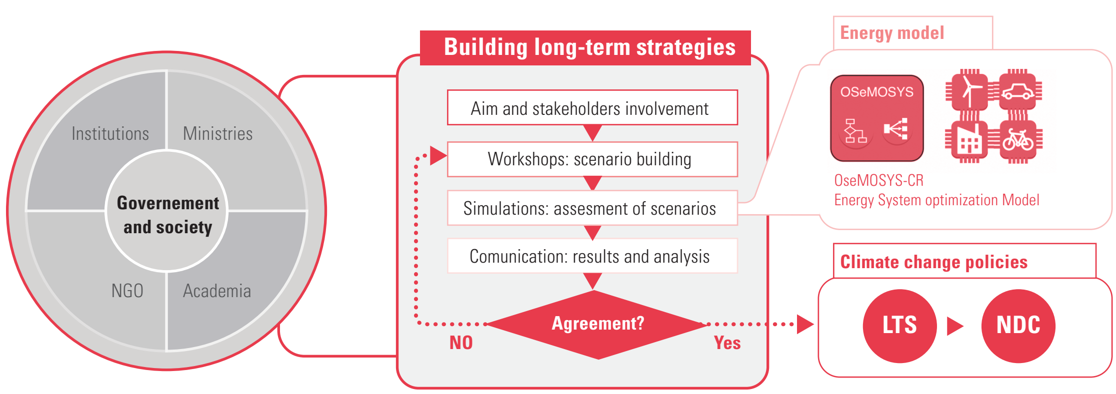
Measures in other sectors will also be needed to meet the mid-century target. Improvements in efficiency and reduction of waste across all sectors, particularly from energy and food consumption, and switch to less carbon-intensive industrial processes, building materials and diets, will also help meeting the 2050 target.

A regional project supported visioning the Costa Rica of mid-century. Costa Rica took a leading role in the Deep Decarbonization Pathways in Latin America and the Caribbean (**DDPLAC**) project. Coordinated by the Institute for Sustainable Development and International Relations (IDDRI) and the Inter-American Development Bank (IDB), the project provides a framework for the definition of an LTS to six Latin American countries emphasizing the need for stakeholder consultations and co-identification of mitigation measures [1]. The Costa Rican team was formed by members of the University of Costa Rica (UCR), the Royal Institute of Technology (KTH) and the Directorate of Climate Change (DCC) of the Ministry of Environment and Energy. The team developed and used an energy system optimization model (OSeMOSYS-CR) to support the national strategy process.

Efforts made during DDPLAC supported the creation of the LTS. The National Decarbonization Plan (NDP_ of Costa Rica [6], launched in early 2019, maps out a comprehensive transition to net-zero emissions by 2050. Designed by the Climate Change Directorate (DCC) through a backcasting participatory process illustrated in Figure 18, the NDP was communicated to the UNFCCC as its long-term, low level GHG strategy. The NDP describes a transformational change structured in ten lines of axion -transport, energy, buildings, industry, waste and AFOLU sectors- with policy targets defined using the analytical framework of the DDPLAC project.

A structured stakeholder consultation approach was deployed to produce the LTS. The process to produce the LTS started with a stakeholder engagement process as an essential step in the design, assessment, and implementation of decarbonization pathways. This ensured that the perspectives of all the relevant actors were considered while accounting for different development goals, understanding what changes could be viable, and what the barriers are to decarbonizing the country. This engagement also strengthened the ownership of the LTS amongst stakeholders and their support during implementation. The process consisted of meetings to define common aims and engage with stakeholders. This led to structuring the Plan into ten lines of actions, eight cross-cutting strategies and three stages for the implementation. Through a participatory process, a scenario building exercise was carried out in which narratives, formulation of technical

Figure 18. Integration of Government and society in the backcasting participatory process



considerations, and restrictions were defined. Then, the assessment of scenarios involved the modeling of targets within OSeMOSYS-CR (and a precursor model) for the energy sector and simple linear models for other sectors[7]. Finally, the DCC provided feedback to stakeholders through the presentation of results which not only included the main outcomes, but also methods, techniques, and sectorial results to ensure a transparent communication of results through graphs and tables.

A systematic approach to produce decarbonization pathways was stablished. The narratives and other inputs provided by stakeholders were then modeled in OSeMOSYS-CR. A decarbonization scenario towards mid-century was developed: a 1.5°C scenario that is compatible with a goal of net zero emissions by 2050. Costs and benefits were compared to a business-as-usual (BAU) scenario that projects the

7 OSeMOSYS-CR contains the entire Costa Rican energy sector based on the best available data. The model includes cost and capacities of multiple technologies such as power plants, vehicles, buses and variables such as the sale of fossil fuels and electricity, or the relation between the average distance traveled and energy consumption for transport. A module for co-benefits, linked to fossil fuel uses, calculates the effects on health, congestion, and accidents.

Figure 19. Key objectives in the decarbonization of the energy sector in Costa Rica

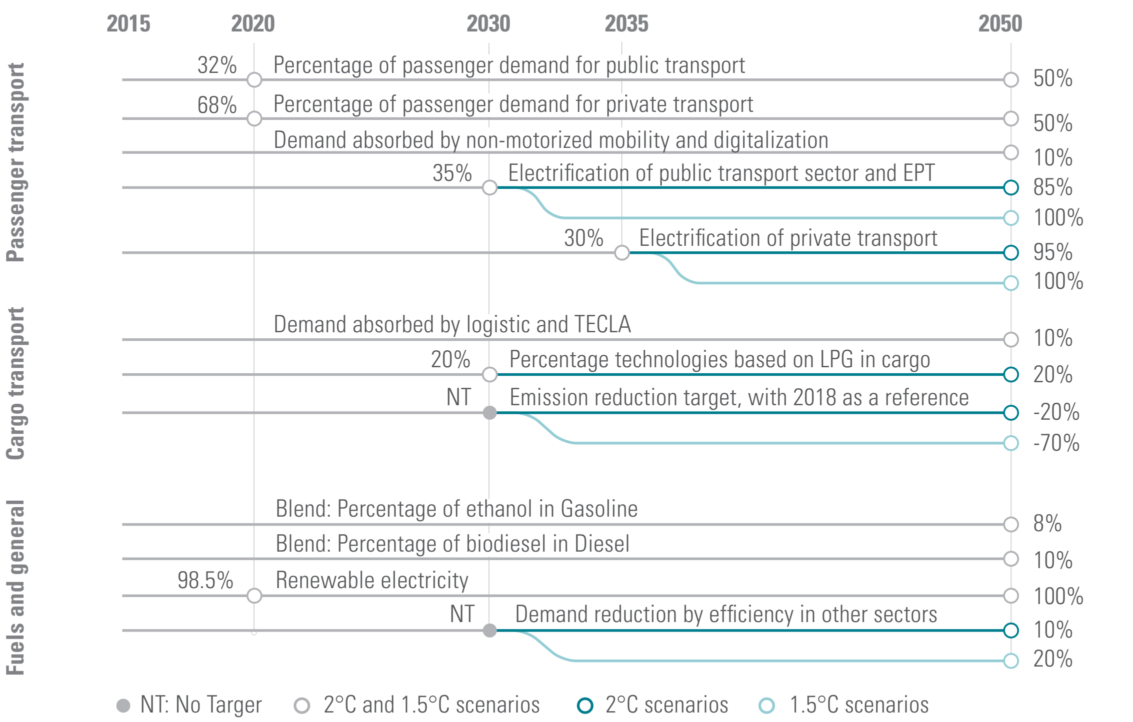


Table 1. Main strategies in the decarbonization pathways in the Costa Rican energy sector

Urban planning and mobility	Switching fossil fuel technologies	Switching energy carriers
✔ Costa Rica implements a mass rapid transport system with an Electric Passenger Train system as a backbone. ✔ A modern public transport scheme is deployed. ✔ Urban planning practices, including densification of the city, building bikeways, and the integration of environmental elements that promotes walkability and sustainability. ✔ The use of light-duty vehicles is reduced, and modal shift occurs towards public transport. ✔ Teleworking and the digitalization of businesses reduces energy consumption improves efficiency.	✔ The import and purchase of electric vehicles, not only for private use, but also in buses and cargo occurs as a result of better market conditions and incentives in place. ✔ The Limón's Electric Cargo Train (TELCA) operates with a load transfer center for the main cargo route in the country to reduce carbon emissions from heavy freight. ✔ Flexibility, intelligence, and resilience of the electric system is consolidated under the concept of smart grids.	✔ Biofuels produced locally are in place and they help to replace imports promoting local business. ✔ Green hydrogen (from electrolysis), particularly for heavy duty vehicles (cargo and buses), is in place after 2030 to reduce emissions from the sector.

behavior of the emissions without considering policy interventions (i.e. following the historic trends). The main strategies in the 1.5°C scenario are described in **Table 1** and the objectives presented in **Figure 19**.

Getting to net-zero is possible in the transport and energy sectors of Costa Rica. The modeling of the objectives (**Figure 20**) allows understanding that emissions in the energy and transport sectors can be reduced by mid-century by 8.4 $MtCO_2eq$ (**Figure 20**). The reduction occurs primarily through a replacement of fossil fuels used in the transport sector with renewables in the energy mix that will then feed the electric vehicles, electric buses and enable the electrification of other sectors.

A deep decarbonization scenario implies modal shifts and reductions in distance travelled. The decarbonization pathway for Costa Rica involves a transition to public transport that represent from 45% to 70% of motorized kilometers travelled by 2050 compared to often significantly lower figures (down to 30%) in scenarios without climate change policies. The Plan envisions that, by 2050, public transport should cater for most of the demand in metropolitan areas, and that non-motorized modes (including walking and cycling and reduced demand due to the digitalization of jobs and teleworking) should increase their contribution to 10% of mobility by 2050.

Figure 20. Annual emissions in the energy sector

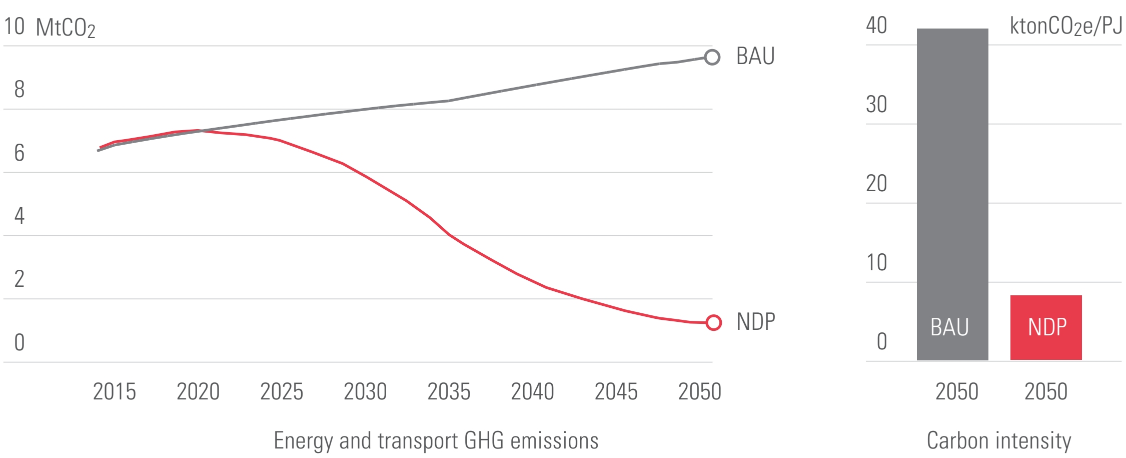
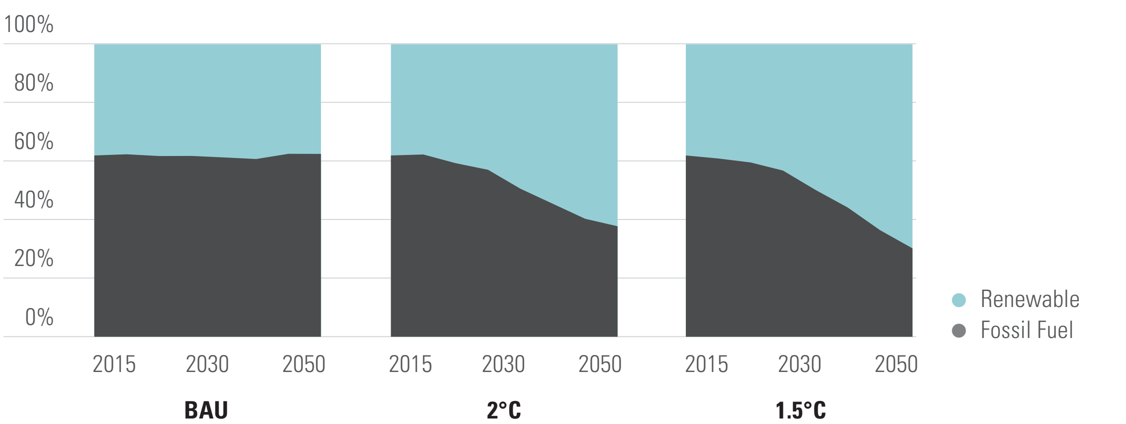


Figure 21. Distribution of energy



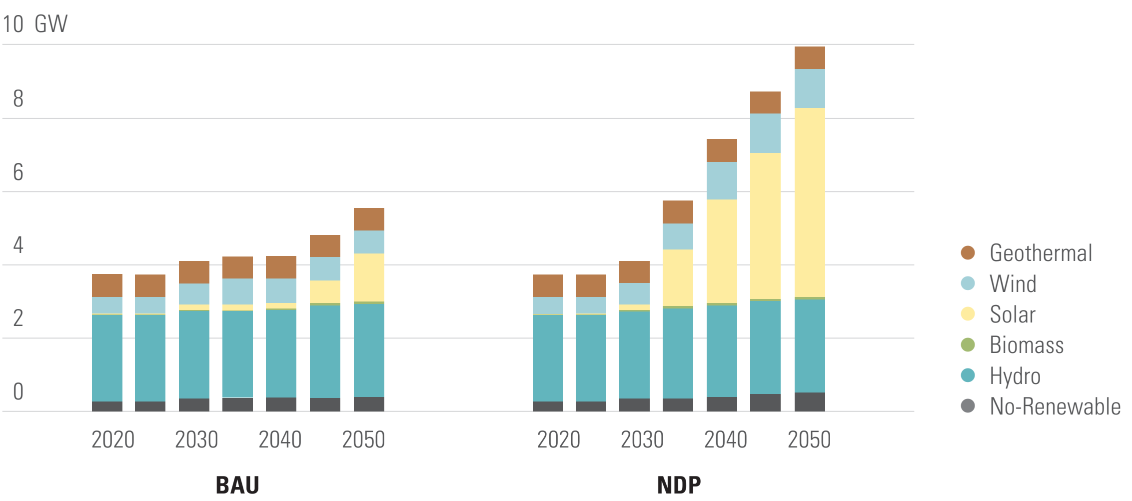
New renewable power plants and higher efficiency to produce electricity will enable the electrification. The Expansion Plan of the Generation defined by the Costa Rican Institute of Electricity (ICE in Spanish) runs until 2034. Some plants will be built to meet the growing existing demand, currently with a 2% growth approximately. The electrification of the transport sector, however, may require additional plants. More efficient processes to produce electricity may also be needed to support this transition. Compared to the BAU scenario in 2050, the study found that a deep-decarbonization requires about 4.4 GW of additional installed capacity (**Figure 22**). Their operation is, nonetheless, needed primarily after 2035 given that the massive deployment of electromobility starts to take place. This implies that investments may not be significant as the cost of low carbon generation technologies are expected to be much lower in the future[2,7}.

The decarbonization process requires investments that are compensated with reduced operational costs. Deploying zero or low emission technologies may lead to higher investment costs today, but their operation is in almost all cases cheaper. In addition, the costs of zero carbon technologies are dropping rapidly whereas business as usual is becoming more expensive and exposed to transition risks including asset stranding. The cost of batteries for electric vehicles has also seen a six-fold reduction in just eight years, which is expected to continue. Compared to the BAU scenario, the study finds that the decarbonization requires additional investments of US$ 26.7 billion by 2050 that are contrasted with savings of US$ 29.7 billion by the same period [**Figure 23**], thus leading to a positive net financial benefit of US$ 2.9 billion (approximately 5% of current Costa Rica's GDP).

Co-benefits could exceed the decarbonization investment costs. Decarbonizing the transport sector brings opportunities to improve mobility, reduce local air pollution, and improve the quality of life. Time lost in congestion and the cost of accidents is also an expensive problem. In Costa Rica, it is estimated that time lost due to congestion, accidents, and the health impacts of local air pollution cost the country 3.8% of GDP annually[8]. Moving to efficient public transport systems and to electromobility vehicles could be one of the greatest opportunities to support the transition to net-zero emissions while bringing substantial benefits to the economy and society. An effective urban transport system based on electric buses can cut congestion, accidents and local pollution while taking advantage of renewable electricity and saving money. Results from the DDPLAC team[8] highlights that accounting for these aspects can increase the economic benefits

8 Supported by another project that assesses the cost and benefits of decarbonizing the transport sector.

Figure 22. Installed capacity per technology and scenario



of decarbonizing the transport sector to about US$ 20.6 billion [**Figure 23**(c)], which represents almost 35% of current GDP.

Investments made today enable the benefits in the mid and long-term. The timeline of these socioeconomic benefits (**Figure 24**) indicates that investments surpass savings in the short-term (2020-2030). The investments are related mainly to the initial roll-out of electric vehicles in the private fleet, the electrification of light freight transport, the first phase of the passenger train deployment, and new renewable power plants. While investments are still needed in the mid and long-term, operational savings (highly related to lower fossil fuel consumption) always compensate capital costs; thus, bringing net financial benefits. In these two periods, the investments in low carbon freight trucks are predominant. Furthermore, it includes the second phase of the electric passenger train and the transition to more efficient public transport, while continuing the electrification of buses and private vehicles. In the energy sector, renewable energy infrastructure continues to support the technological transition. If we add up the benefits in terms of health, congestion, and accidents, the socioeconomic benefits in the mid and long terms represent almost 13 and 26% of current Costa Rica's GDP; thus highlighting that benefits are greater as the mid-century goal is reached.

Figure 23. Cost comparison by scenario

Values are discounted at 5% up to 2050

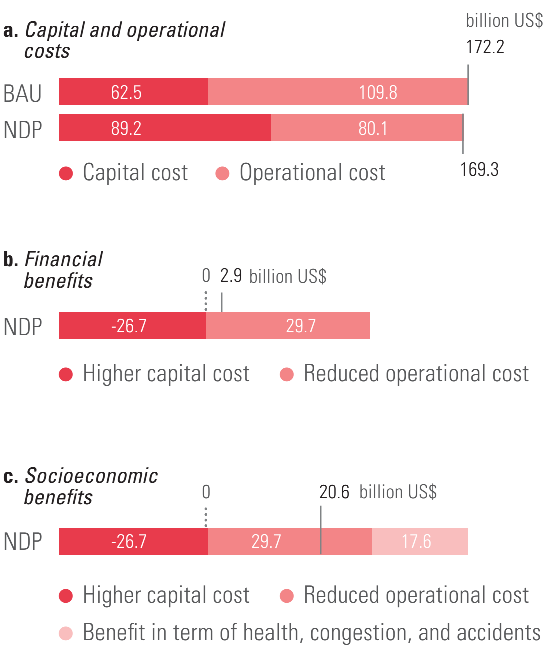
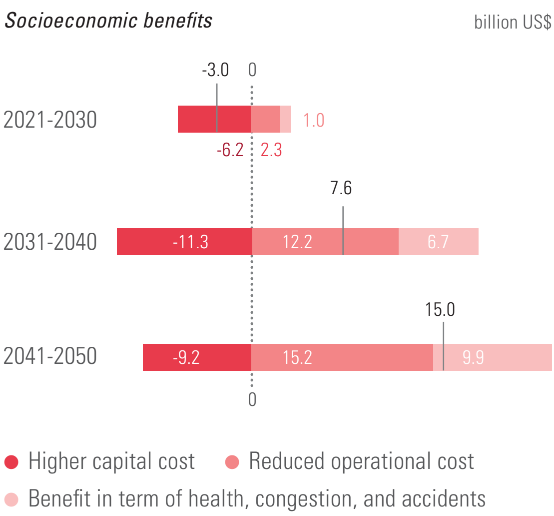


Figure 24. Timelines of socioeconomic benefits.

Values are discounted at 5% up to 2050



The decarbonization process is likely to create winners and losers. The transition towards cleaner energy sector can have an impact on consumers, workers, communities and businesses related to phasing out or downsizing economic activities that are inconsistent with net-zero emissions, e.g. the commercialization of fossil fuels. The short-term impact of removing energy subsidies or introducing environmental taxes that increase the cost of food and basic services are also important issues. Anticipating, minimizing, and compensating them by targeted policies and complementary measures are as critical. Furthermore, international evidence suggests that the social acceptability of reforms requires the consultation of stakeholders and communication campaigns before implementing reforms.

Fiscal revenue will also be affected. Fiscal sustainability is essential to the political feasibility of the reforms needed for transformational approaches. Government income from the transport sector represents about 20% of the total revenue in the country [9]. The adoption of electric vehicles will reduce revenues from gasoline and diesel taxes. With Costa Rica's LTS in place, the government is now able to anticipate these changes, which are being studied by the country with support of the DDPLAC team to allow for identification of alternative fiscal measures to be planned and implemented. To manage the potential impacts, the Plan can be used to progressively adjust the rate of taxes on gasoline, electricity and vehicle ownership and operation based on the targets in the Decarbonization Plan.

The LTS leads the development of Costa Rica. Costa Rica committed to decarbonize its entire economy by 2050. This transformational change will need to overcome multiple challenges. To study them, local and international experts will be needed to produce technical studies that support the transition, bringing robust evidence of the most cost-effective path towards a decarbonized Costa Rica in 2050. The NDP also places the decarbonization at the heart of multiple government and autonomous institutions, which will need to adapt their plans to the new normal. Coordination between institutions to coherently articulate efforts becomes critical. Fortunately, there is a great opportunity today to execute the so-called green recovery post-covid which will bring multiple additional benefits for its population.

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ECUADOR
GETTING TO ECONOMY-WIDE NET-ZERO EMISSIONS

Authors: Rafael Soria, DSc., Daniel Villamar, MSc, Pablo Carvajal, PhD (**EPN**). Pedro Rochedo, DSc, Alexandre Szklo, DSc, Roberto Schaeffer, PhD, Mariana Imperio, DSc (**COPPE/UFRJ**).
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Key policy messages

- Ecuador's NDCs are not enough to set the country in a pathway towards a well-below 2°C world. Ecuador still needs a long-term integrated strategy (LTS) aligned with the Paris Agreement.
- International cooperation could help create the enabling conditions for moving in the direction of deep decarbonisation through financing, training, technology transfer and institutional capacity building.
- Diversifying the electricity generation system with non-hydro renewable energy is key to reduce the dependency on large hydropower generation (5 GW today), which could worsen in climate change scenarios with less precipitation. Up to 2050 the power system would require a total 4.4 GW of solar PV, 3 GW of biomass-fired thermal power plants with carbon capture and storage (BECCS), 900 MW of on-shore wind and 500 MW of geothermal plants. It all adds up 9 GW, which is 17 times more than 2020 non-hydro installed capacity. Additional 3GW of hydro power plants would be required up to 2050. Total installed capacity in 2050 would be 18 GW.
- Developing a bioenergy industry is necessary for deep decarbonisation. Planted crops may be sustainably managed to provide woody biomass to bio-refineries and thermal power plants. Around 500 thousand hectares of sustainably managed planted forest would be required by 2050. In 2015 forest area in Ecuador was 12.8 million hectares (51% of the continental territory).
- Ambitious reforestation could avoid the dependence on risky and expensive carbon capture and storage (CCS). Reforestation and conservation of additional 300 thousand hectares, in comparison to the 2015 base year, would provide enough negative emissions to avoid the deployment of an additional 900 MW of BECCS.
- Electrification of passenger transportation is crucial to reduce emissions. By 2050 70% of buses, and 33% of private cars would need to be electric. Around 10% of passenger transportation demand may be supplied in a non-motorized way (walking, biking, skates and skateboards) in urban cities. This requires actions to improve urban planning and municipal integrated transport systems.
- Emission reduction in freight transport is challenging, it requires electrification and use of advanced bio-fuels. By 2050 40% of light and medium trucks fleet could be electric, while only 10% of heavy duty trucks. Approximately 25% of transport final energy consumption would be supplied by biorefinery diesel, while around 4% would be supplied by traditional biodiesel.
- Energy efficiency may play an important role to decarbonize the energy system. In the industrial sector, an energy intensity reduction of 14% up to 2050, in comparison with 2015 base year, is possible by implementing state-of-the-art technology (boilers, drives, etc.) and increasing electrification. Electrification rate in the industrial sector may increase to 30%, with large potential in Food and Beverage companies. In the residential sector the electrification rate may increase from current 25% to 32%, especially for cooking and water heating applications.
- Research and Development (R&D) and pilot plants must be cross-cutting policies throughout the decarbonisation process.

National circumstances and findings

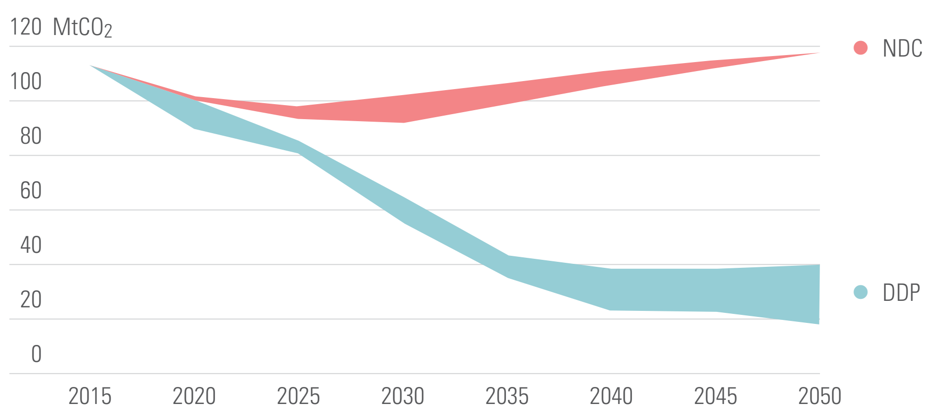
This policy brief presents and discusses the results from the Deep Decarbonisation Pathways in Latin America and the Caribbean (DDPLAC) project for the Republic of Ecuador. This two-year project developed a series of long-term energy and land use scenarios for Ecuador's pathway towards a low-carbon energy and land system by 2050. The project was developed by local and international energy modelling experts and is part of a broader project comprising of six countries in the LAC region: Mexico, Costa Rica, Colombia, Ecuador, Peru and Argentina (IDB and DDPP-LAC, 2019). Climate change (CC) is a global issue that requires action from every country in order to allow for a "well-below" 2°C world (closer to 1.5°C) above pre-industrial levels by the end of this century (IPCC, 2018). In 2016 Ecuador emitted 98.6 $MtCO_2eq$ (CAIT Climate Data Explorer, 2020), and is committing to voluntarily reducing its emissions levels while working to overcome socio-economic development barriers. In March 2019, Ecuador submitted to the United Nations Framework Convention on Climate Change (UNFCCC) its first National Determined Contribution (NDC), both conditional and unconditional to international support, with objectives up to 2025. Later, in August 2019 the Ecuadorian Government declared its NDC to be State policy of mandatory compliance (Gobierno de Ecuador, 2019). This policy brief finds that Ecuador's current NDC is not aligned with a long-term global pathway towards a "well-below" 2°C by 2100, and suggests which measures could be taken for Ecuador towards 2050 to shift its course towards that direction. Further explanation of the methodology used in the study is presented in Annex 1 and in (Villamar et al., 2020).

Ecuador's NDCs are not aligned with a long-term deep decarbonisation trajectory; a long-term integrated strategy (LTS) aligned with Paris Agreement is needed.

Greenhouse Gas (GHG) emissions from energy and land in a scenario aligned with the current Ecuadorian NDC shows a growing tendency that is far from the decarbonisation requirements aligned with a global 1.5°C level by 2100. Ecuador's current NDCs, both unconditional and conditional to international support, are not aimed at long-term deep decarbonisation trajectory. The current NDCs would guide the country towards a slight reduction by 2025, but without further long-term strategies would cause emissions to reach around 120 $MtCO_2eq$/year in 2050. To achieve the Paris agreement, Deep Decarbonisation Pathway (DDP) scenarios shows that GHG emissions would need to be in a range between 20 to 40 $MtCO_2eq$/year[9] in 2050 (**Figure 25**).

9 In the academic publication from Villamar et al., (2020) all the modelling details and scenarios definition are presented. Some DDP scenarios were modelled, using carbon budgets (cumulative emissions up to 2050) for Ecuador between 1.46 and 1.25 $GtCO_2eq$, which are compatible with a global 1.5°C level by 2050. These carbon budgets were estimated with the global COFFEE model (Rochedo et al., 2018).

Figure 25. GHG annual emissions up to 2050 for NDC and DDP scenarios



NDC put Ecuador on a track towards 120 $MtCO_2eq$ by 2050, while DDP scenarios need to be in a range between 20-40 $MtCO_2eq$ by 2050.

To achieve this more ambitious GHG mitigation scenario, Ecuador needs a Long-Term Strategy (LTS) that guides country' transition to more ambitious targets in the energy and Agriculture, Forest and Land Use (AFOLU) sectors as will be explained below.

International cooperation and private investment could help create the enabling conditions for moving in the direction of deep decarbonisation.

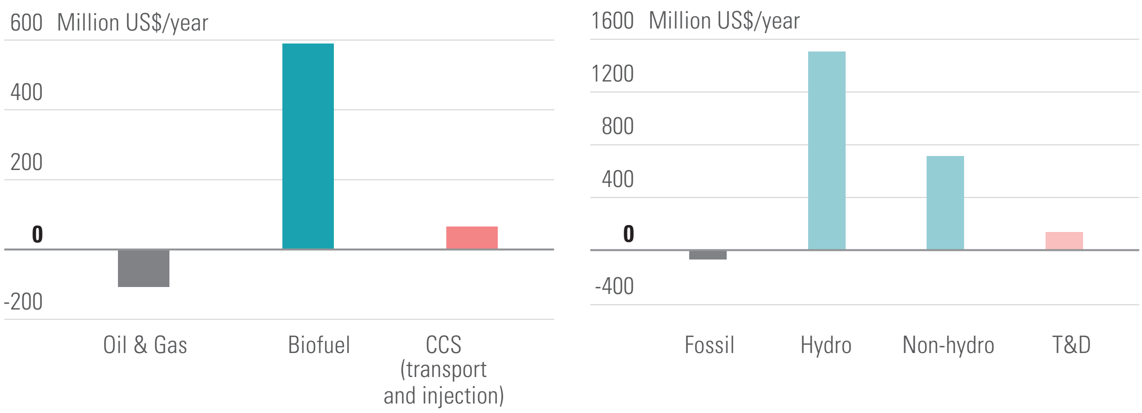
Up to 2050 there would be less investment in Oil & Gas sector and much more in biofuels (590 million USD per year) and transport and injection infrastructure to make CCS possible (65 million USD per year) (See **Figure 26**, left). In the power sector investment in fossil fired power plants would drop, while higher investment would be required for hydro (1,500 million USD per year), non-hydro (715 million USD per year) and transmission and distribution (T&D) (140 million USD per year) (See **Figure 26**, left).

Diversifying the power matrix with non-hydro renewable energy is key to reducing the dependency on large hydropower generation.

Ecuador should diversify its electricity generation system with non-hydro renewable energies to reduce the dependency on large hydropower generation, which could worsen in climate change scenarios with less precipitation (P. Carvajal et al., 2018; P. E. Carvajal, 2019). Up to 2050, our modelling suggests the power sector needs to deploy at least an installed capacity of 4.4 GW solar PV (utility scale and distributed generation), 3 GW of biomass-fired thermal power plants with carbon capture and storage (BECCS), 900 MW of on-shore wind and 500 MW of geothermal plants (See **Figure 27**). This adds 9 GW, which is 17 times more than 2020 non-hydro installed capacity. Hydro power plant would remain as the most important generation source with a total of 8 GW of installed capacity in 2050, including an additional 3 GW from 2020. Electricity generation installed capacity in 2050 would be 18 GW. Although there is still an important remaining techno-environmental hydropower potential in the Amazon region (13 GW), its additional deployment based on run-of-river plants would lead to operational problems in the electricity sector, especially at the time of low hydrology, coincident in the Amazon and Pacific basins, at the end of each year. Storage biomass capacity would allow supplying firm electricity with biomass thermal power plants during this period. Thus, thermal power plants fuelled with biomass is a suitable option for Ecuador, a country with large potential for bioenergy.

Natural gas (local and imported) may be an option to fuel around 600 MW of combined cycle thermal plants to provide firming power to support intermittent renewable energy sources. CCS could be

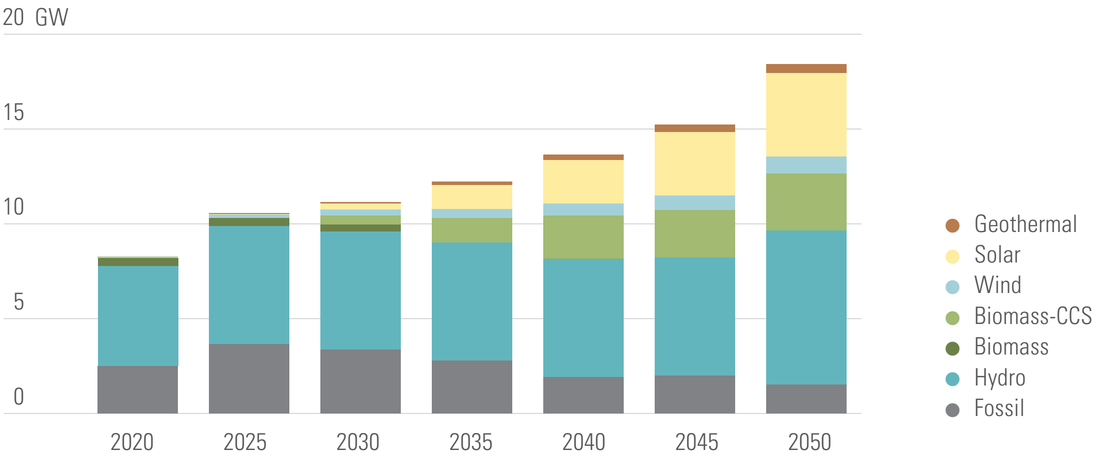
Figure 26. Additional annual investment required for DDP scenario, in comparison to the reference case, 2020-2050



a. shows Oil&Gas, refineries and bio-refineries, and transport and injection for CCS

b. shows power plants and transmission and distribution (T&D)

Figure 27. Evolution of power generation installed capacity in a DDP scenario up to 2050



partially applied to the remaining fossil fuel thermal power plants. The deployment of the above-mentioned technologies would lead to 94% of renewable electricity generation in 2050.

The expansion of the power sector up to 2025 is aligned with the Ecuadorian Master Electrification Plan (PME 2027), which already proposes 1.1 GW of combined cycle thermal plants with imported liquefied natural gas (LNG); and, non-hydro renewable options (600 MW) including solar PV, on-shore wind and geothermal (MERNNR, 2020). The PME also shows an expansion of 2.4 GW between 2020-2027.

This is a challenge that remains not only for the Strategic Public Company Electric Corporation of Ecuador (CELEC EP) but also for the private sector. In the short and mid-term, the Government should create the appropriate enabling framework to allow private investment participation in the power sector.

The development of the bioenergy industry is key for a deep decarbonisation.

Wood from managed forests, mainly from reforestation programs on degraded land, could be an important fuel for thermal power plants (with or without CCS). Biomass will not only be important for the power sector, but to decarbonize the whole primary energy supply matrix for the whole economy. Biomass could also be used as raw material for the production of advanced liquid fuels and sophisticated chemicals in bio-refineries. An installed capacity growing to approximately 45 thousand barrels of oil equivalent per day in bio-refineries would be required by 2050. Around 25% of freight transport's final energy consumption could be replaced using advanced biofuels in the medium and heavy truck fleet. In addition, to face the imminent exhaustion of Ecuador's petroleum resources, which would happen before 2040 at current production rates, the development of bio-energy crops from 2030 onwards is an alternative key activity to both decarbonize the energy matrix, and to generate income and jobs in rural areas. Ecuadorian oil depletion brings challenges not only for the energy sector, but also consequences in terms of trade deficits. If a bioenergy industry is successfully developed, it would be able to provide around 80 million barrels of oil equivalent in woody products to the energy sector (bio-refineries and thermal power plants) in 2050, which assumes the sustainable management of around 500 thousand hectares of planted forest. This option can help mitigate risk in the energy sector and set Ecuador on a track for sustainable development and socio-economic growth. In 2015 forest area in Ecuador was 12.8 million hectares (51% of the continental territory), of which 27% was protected forest.

These outcomes may help to strengthen and direct the National Bioenergy Strategy (PNUD/MAE, 2018) and the Proposed Plan for a National Biodigester Program (IIGE/MERNNR, 2020) that are being developed by the Ministry of Environment (MAE) and Ministry of Energy (MERNNR), respectively. These policy instruments should foster both thermal power plants fuelled with biomass products (solid, liquid and gas) and biorefineries. Agro-industrial residues, especially from oil palm, rice, sugar cane and banana, also present a significant energy potential that could be used in the short-term for electricity distributed generation.

An ambitious reforestation program can avoid the dependence on immature, risky and expensive carbon capture and storage (CCS) technologies in the energy sector.

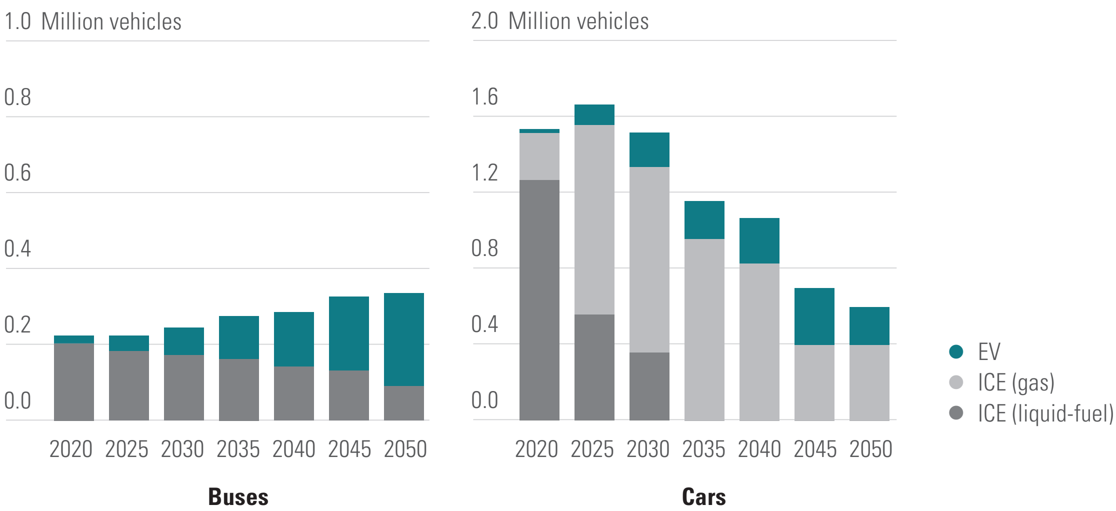
There is a trade-off between bioenergy carbon capture and storage (BECCS) in the energy sector and reforestation/forest conservation in the AFOLU sector. While BECCS is an option to have negative emissions in electricity generation, in the mid-term, BECCS remains as an expensive and risky technology due to its commercial immaturity. On the contrary, reforestation appears as a short-term suitable option for a country like Ecuador, a country rich in fresh water sources and with large biodiversity due to its climate and location. Reforestation (with forest and grassland) and conservation of additional 300 thousand hectares, in comparison to the 2015 base year, would provide enough negative emissions to avoid the deployment of an additional 900 MW of BECCS. In fact, reforestation brings some positive co-benefits related with keeping ecosystem services, additional tourism for example.

The considered reforestation goal is larger than the goal established by both the National Forest Restoration Program (40,000 ha) and by the Ministry of Agriculture forest plantations for commercial use program (120,000 ha). On the other hand, the proposed goal is significantly less ambitious than the 'Socio-Bosque" program (conservation of 3 600,000 ha) (MAE/FAO, 2019).

Electrification of the passenger transportation is essential to reduce emissions in the transport sector.

Deep decarbonisation by 2050 demands an increase of public transport use, as well as an increase in its electrification rate. At national scale, electric buses in 2040 should represent half of the bus fleet and by 2050 over 70% (See **Figure 28** left). Around 20,000 electric buses would be operating in 2050. This important change responds to the Organic Law of Energy Efficiency, issued in 2019, which mandates that "from 2025 all vehicles that join the urban and inter-parish public transport service in continental Ecuador should only be electrically powered" (*Asamblea Nacional de la República de Ecuador, 2019)*. Thanks to the increased use of public transport from 2030, private mobility demand should decrease. Ambitious goals are required from 2030. By 2035 fossil liquid fuels should no longer be part of the private passenger transport energy matrix, except for justified cases. Instead, the private car fleet would be powered by natural gas (local and imported) and electricity (See **Figure 28**, right). Although a significant reduction of electric vehicle prices is ex-

Figure 28. Passenger transport demand for public transport (left), and private transport (right)



pected in international markets leading up to 2050, our modelling finds they remain relatively expensive in comparison with internal combustion engines (ICE), leading to a 2050 car fleet composed one third by electric cars. Electric trains (metro in Quito, tramway in Cuenca) and electric motorcycles will play an important role in a DDP scenario to increase the use of public massive transport systems.

GHG emission reduction in the transport sector does not depend only on electrification; there must be a switch from personal to public mobility, and a reduction of motorized mobility. In 2015 buses supply 56% of passenger motorized transportation demand, cars 33%, motorcycles 3% and airplanes 8%. In a DDP scenario, in 2050, buses would supply 63%, cars 14%, motorcycles 9%, airplanes 10% and trains 3%. Policies should foster non-motorized mobility (walking, biking, skates and skateboards) in cities. Around 10% of total passenger transportation demand could be supplied in a non-motorized way (**Figure 29**). Urban planning and social misconceptions of transport need to be addressed in order to improve urban mobility. Electrification of the public transport system should be associated with improvements in security, travel time, comfort, particulate matter emissions, etc. The private fleet could be electrified, but if complementary policies formulated with a holistic view do not take place, the mobility problem will remain.

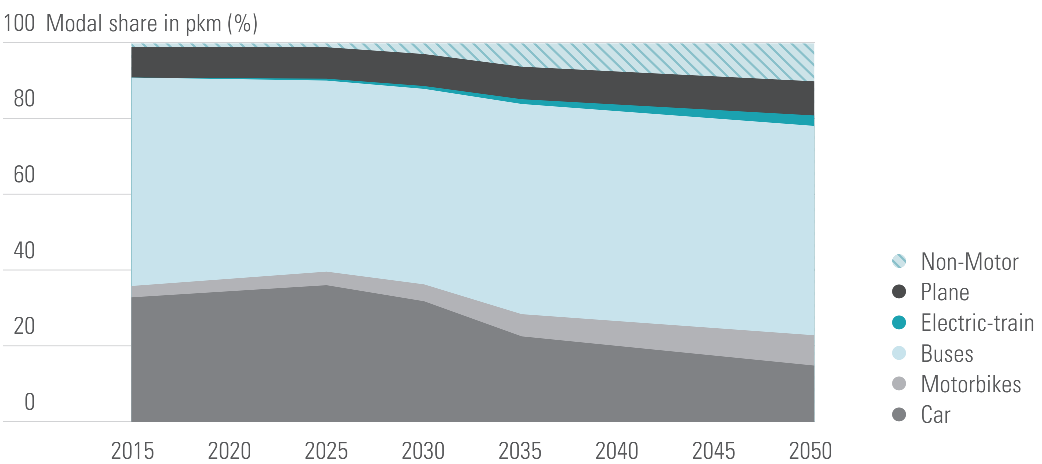
The Strategic Mobility Plan 2013 -2037 developed by the Ministry of Transport and Public Works (MTOP, 2016), which is strongly focused on infrastructure construction (roads, ports and airports), should be updated to set goals in the above mentioned axes too, looking to activity, energy intensity, energy mix and environmental problems (local and global) too.

GHG mitigation in freight transport is challenging, it requires electrification and use of advanced biofuels.

Final energy consumption of freight transport is estimated to be 127 million barrels of oil equivalent in 2050 in our DDP scenario. GHG mitigation in this subsector is the most challenging as these activities require large amounts of energy concentrated in a small volume. Thus, one option to decarbonize freight transport is the use of advanced fuels produced from biomass in bio-refineries. By 2050 approximately 25% of the sector's final energy consumption is estimated to be supplied by biorefinery diesel, while around 4% would be supplied by traditional biodiesel. These biofuels could be used by existing medium and heavy trucks with minor adaptation to their combustion engines. Complementarily, the light and remaining medium truck fleet could be partially electrified. By 2050 only 10% of the heavy truck fleet may be electric, while this value increases to 40% for the medium and light trucks fleet.

Electric trains for freight transport remain as important options in the mid and long-term. In our DDP scenario electric trains could meet 10% of freight transport demand by 2050. The Ecuadorian Government has evaluated electrifying the Quito-Guayaquil train (MTOP,

Figure 29. Evolution of modal share for passenger transport in a deep decarbonisation scenario up to 2050



2016), and the Daule-Guayaquil-Posorja-Manta train (MTOP, 2018) projects, and making these large-scale projects a reality involves significant participation by private capital and international cooperation.

Energy efficiency may play an important role to decarbonize the energy system.

In the industrial sector, an energy intensity reduction of 14% by 2050 in comparison with 2015 base year, is possible by implementing state-of-the-art technology (electric boilers, efficient drives, solar low and mid-temperature heating, etc.) and increasing electrification. The electrification rate in the industrial sector may increase from current its 25% to 29%, especially in Food and Beverage companies. In addition, higher electrification in the residential sector is possible, especially for cooking and water heating. In our DDP scenario the electrification rate in the residential sector increases from its current 25% to 32%. However, this energy efficiency potential is limited by the current levels of energy subsidies (Schaffitzel et al., 2020).

Although the study did not assess industrial cogeneration and solar industrial heating, other studies show their significant contribution to the energy matrix and environment. The installation of industrial cogeneration technologies (600 MW) in 555 companies may decrease at least 30% of diesel consumption in heating applications (CELEC EP/ UCUENCA EP/MERNNR, 2017). In Imbabura, Pichincha and Loja provinces there are several industrial plants with ideal conditions for the application of concentrated solar for heat industrial process, replacing diesel and bunker (Soria et al., 2020). In addition to the presence of fossil fuel subsidies, another barrier for cogeneration is the low electricity tariff for this electricity generation, while for solar heating, research and development funds to nationalize Fresnel concentrating solar technology are required to make cheaper solar heat.

Research and Development (R&D) and pilot plants must be cross-cutting policies throughout the decarbonisation process.

The Academy, as well as national research institutions (IIGE, INIAP, etc.) should be involved in the decarbonisation process. While reducing GHG emissions, economic development and quality of life improvements should also be sought. Thus, in the mid and long-term the country should be able to domestically produce knowledge and to some extent, technology. Some of the disruptive technologies to achieve decarbonisation are highly demanding of theoretical and applied knowledge, which the country should develop in order to avoid falling into technological dependency with developed countries.

Findings show that DDP scenarios are challenging, but do not compromise socio-economic development. Decarbonisation is possible without affecting Gross Domestic Product, population growth, food and energy accessibility. On the contrary, the DDP scenarios were built over premises that considered modern energy services access and sustainability in the land and energy systems. The main challenges for Ecuador are in the transport sector, where electrification of light vehicle fleet will not be enough. Additional efforts to promote mass public electric passenger transport system and replacement of diesel by advanced diesel from biomass in the heavy cargo transportation are required.

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ANNEX 1: METHODOLOGICAL NOTES

The Ecuador Land Use and Energy Network Analysis - ELENA model developed by the *Escuela Politécnica Nacional* (EPN), with the technical assistance of the *Federal University of Rio de Janeiro* from Brazil, during DDPLAC project, is available to assess decarbonisation pathways for Ecuador. ELENA model is used to assess the expansion of the energy system, possible land use changes and evolution of GHG emissions up to 2050. This is an integrated optimization model that considers the whole energy conversion chain, from primary energy to useful energy, for each of the economic sectors. ELENA also models the land use system; it calculates the land use changes according to the food demand and deforestation/reforestation scenarios up to 2050. Useful energy and food demands are exogenously calculated, as well as deforestation/reforestation scenarios.

A set of scenarios describing demands perspectives and the evolution of technological parameters up to 2050 were used to determine different energy and land use pathways for the coming decades.

A total of six scenarios were analysed. First, a scenario that describes the business-as-usual tendency (Reference case based on least cost decision). Two scenarios model Ecuador´s National Determined Contributions unconditional and conditional, achieving specific goals in 2025. Finally, three scenarios modelling Deep Decarbonisation Pathways (DDP) are used. DDP_{High} scenario includes a maximum value of cumulative emissions until 2050 of 1.46 $GtCO_2eq$. A stricter constraint was considered in DDP_{Low} scenario, allowing only 1.25 $GtCO_2$ eq. These emissions limits were calculated with the support of COFFEE global model (Rochedo et al., 2018). Finally, the DDP_{High_Refo} scenario has the 1.46 $GtCO_2eq$ limit, but includes a mandatory reforestation policy. The use of these GHG emissions restrictions ensures that by 2050 considered DDP scenarios are compatible with a global 1.5°C level.

A complete description of ELENA model, its data base and the modelled scenarios are available in the academic publication of (Villamar et al., 2020).

MEXICO
STEERING TOWARDS PARIS: POLICY INSIGHTS FROM A WHOLE-ECONOMY DECARBONIZATION PATHWAY ANALYSIS

Authors: Jordi Tovilla and Daniel Buira of Tempus Analytica, Ltd.

Key policy messages

- Implementation of Mexico's current climate and energy policies, including the NDC of 2015 and Mid-Century Strategy published in accordance with Article 4.19 of the Paris Agreement, will be contrary to the achievement of the Paris Agreement goals.
- Whole-economy decarbonization planning tools can provide practical insights on how to shift Mexico's sectoral and development pathway towards Paris.
- Major energy sector restructuring is urgently required to achieve a rapid wholesale substitution of oil and gas by renewable electricity as the main source of primary energy across all sectors including transportation, buildings, agriculture, as well as much of industry.
- Rapid uptake of measures to change both urban dynamics and transport fleet technologies can radically curb the demand for private vehicle use and energy, with clean electricity further reducing emissions of today's fastest-growing sector.
- The potential for forestland to contribute the significant negative emissions required to achieve net-zero by 2050 not only calls for rigorous ecosystem stewardship, but also for deep technification of agricultural practice across livestock and crop management to reduce ongoing agricultural emissions.
- These profound structural transformations can only come about within a re-casting of Mexico´s social and economic development pathway to 2050 and beyond, which has clear policy and investment implications for the short and medium term.

Introduction: Mexico's current plans will not achieve the Paris Agreement

The Paris Agreement, adopted in December of 2015, is seen as a watershed in international climate negotiations. Although the goals stated in Article 2 align with the science of minimizing the adverse effects of climate change, the actions taken by countries to achieve them are nationally determined. Success or failure will therefore depend on the aggregate effects of disparate national policies, as opposed to the mechanics of the Agreement itself.

In 2018, the Intergovernmental Panel on Climate Change – charged with identifying the best available science to inform policy – published its Special Report on Global Warming of 1.5°C. In this, the IPCC states categorically that the Nationally Determined Contributions communicated by countries until that date are not only insufficient to achieve the Paris goals, but are in fact contrary to the Agreement. If countries implement their NDCs as they stand, they will lock in so many emissions as to make the Paris goals impossible to achieve (de Coninck, y otros, 2018). The IPCC advises countries to develop transformation pathways to 2050 with a view to reducing global emissions by half in 2030 and achieve net-zero emissions in 2050. Mexico's climate change plans and latest energy policy, as highlighted in its NDC (Government of Mexico, 2015), Mid-Century Strategy (SEMARNAT-INECC, Mexico's Climate Change Mid-Century Strategy, 2016), and Energy Transition Strategy (SENER, 2020), aim to reduce emissions intensity per GDP but map out a road towards 2050 which may result in greater absolute emissions than today. Sadly, this problem is not unique to Mexico, but a result of the planning paradigm within which national policy has been developed. Although the IPCC is clear that deep structural change is required, most countries have generated policy in the usual manner, identifying incremental improvements which are inadequate, thereby committing to unacceptably high future emissions. For Mexico, this could result in failure to achieve its national climate commitments, while further betting economic prosperity and financial stability on a fossil fuel economy which must drastically decline by the middle of the century.

Methodology: Decarbonization tools can map out pathways towards net-zero emissions

This project uses the Deep Decarbonization Pathways method (Waisman, 2019) which sets out a process for designing country-driven visions of transformation to achieve climate goals and sustainable development. Core methodology elements include setting an ambitious target for 2050 (net-zero or well on the way to net-zero in a manner compatible with the Paris goals), "backcasting" from the target to the present, a "whole-economy" focus so all (or as many as possible) sectors and GHGs are considered, and a "dashboard" tool to allow meaningful integration of results generated in different ways to create a holistic picture. The method highlights trade-offs and synergies while recognizing the inextricable relationship between social and economic development and emissions goals. Detailed physical transformation pathways are then created for each sector, identifying short, medium and long-term actions and policies to ensure these transformations can happen.

Projecting pathways into the long-term future allows us to outline a transition towards zero-carbon while considering the natural life cycle and turnover of equipment and infrastructure, modifications in behaviors of people, and aspirational socioeconomic goals. In addition, it identifies and avoids solutions that may offer apparent short-term benefits but are obstructive in a longer timeframe – e.g. by leading to locked-in emissions or stranded assets – thereby directly addressing the challenge faced by most country NDCs today. This feature is crucial when planning

capital intensive infrastructure, and also when making decisions that determine future market dynamics.
Planning the decarbonization process should be guided by conceptual pillars which must all be pursued at the same time:

- Rapid decarbonization of electricity systems through rollout of renewable energy and clean firm power to support it.
- Widespread electrification of energy use, driving the uptake of low-carbon energy.
- For energy uses not easily electrified, switching to alternative zero-carbon fuels.
- Widespread pursuit of efficiencies in products and processes to improve energy intensity across all sectors (e.g. transportation, industry, agriculture etc).
- Improving urban structure to reduce people's footprint and improve their quality of life.
- Boosting natural carbon sinks through good management of forests and other ecosystems.
- Transforming agriculture to reduce emissions from crops and livestock and increase carbon sinks.

We projected two scenarios of Mexico's economic development to 2050 based on the same economic and population growth. The first assumes NDCs will be implemented to 2030 and similar ambition extended continued to 2050, providing a Reference Scenario (REF). The second or DDP Scenario was developed explicitly to achieve the Paris goals using the conceptual pillars highlighted above. Modelling both pathways across seven sectors while tracking emissions of three greenhouse gasses allows direct comparisons to be made, thus highlighting the key differences which must be addressed if Mexico is to correct its course.
We employed a multi-tiered approach to pathway analysis. For electricity and transportation, detailed modelling was carried out using **Energy PATHWAYS** (Evolved Energy Research, 2019). This bottom-up energy accounting tool models the energy economy with detailed granularity and allows a backcasting approach to demonstrate what physical infrastructure changes are required to reach set goals. The evolution of electricity generation technologies (and their coupling of other energy sectors) were modeled with **RIO,** the Regional Investment and Operations platform (Evolved Energy Research, 2019). This optimizes the cost of expansion of capacity for electricity generation, fuel production, and the transmission infrastructure required, with detailed sequential hourly system operations, enabling the analysis of the energy system as a whole.
The transformation of all other energy sectors is described at the "dashboard" level, specifically by modification of Kaya identity drivers (activity, energy and carbon intensities) in each sector. Non-combustion emissions from industrial processes are also tracked at dashboard level. Non-energy sectors and emissions (AFOLU, Waste) have been included at a preliminary dashboard level, as the tool used is still under development.

Results: Sectoral decarbonization can underpin economic and social development pathways

Our work resulted in sectoral narratives of change with clear differences from current Government of Mexico (GoM) plans.

Electrification will transform all energy sectors. This will significantly increase demand for electricity – mirrored by a correspondingly rapid fall in fossil energy demand – which in turn must be provided by zero-carbon technologies. Our detailed technical analysis gives confidence that an accelerated, large-scale rollout of decarbonized power generation will provide reliable, competitive zero-carbon energy for other sectors to use in their own rapid transitions. Concretely, **Figure 30** shows the difference in power generation and storage rollout by technology in the two scenarios, with an example of the resulting DDP hourly power dispatch in 2050 (seen in 31) demonstrating the viability of this very high renewable approach.

Passenger transportation is currently the sector with largest and fastest-growing emissions. Further growth is expected as the population becomes wealthier, aggravated by uncontrolled urban expansion. Hence, a core narrative element of this work is that urban development should happen in a different way, not only to reduce emissions growth, but to increase public health and wellbeing. Changing urban structure will distribute services and opportunities more fairly within the citizenry, while building a robust public transport system to improve passenger comfort, safety, and travel times. At the same time, rapid rollout of decarbonized trams, busses and cars will be required (**Figure 32**), powered by renewable electricity instead of fossil fuels. This will significantly increase overall demand for electrical power while reducing demand for oil.

Oil and gas demand reduction (**Figure 33**) is a necessary part of deep decarbonization: as personal mobility in Mexico decouples from fossil fuels, export opportunities will also diminish since other countries will undertake similar decarbonization measures. This is in stark contrast with stated GoM policy to invest in increased oil production and refining capacity. Mexico's demand for fossil gas, currently from both power

Figure 30. Installed electric capacity (GW)

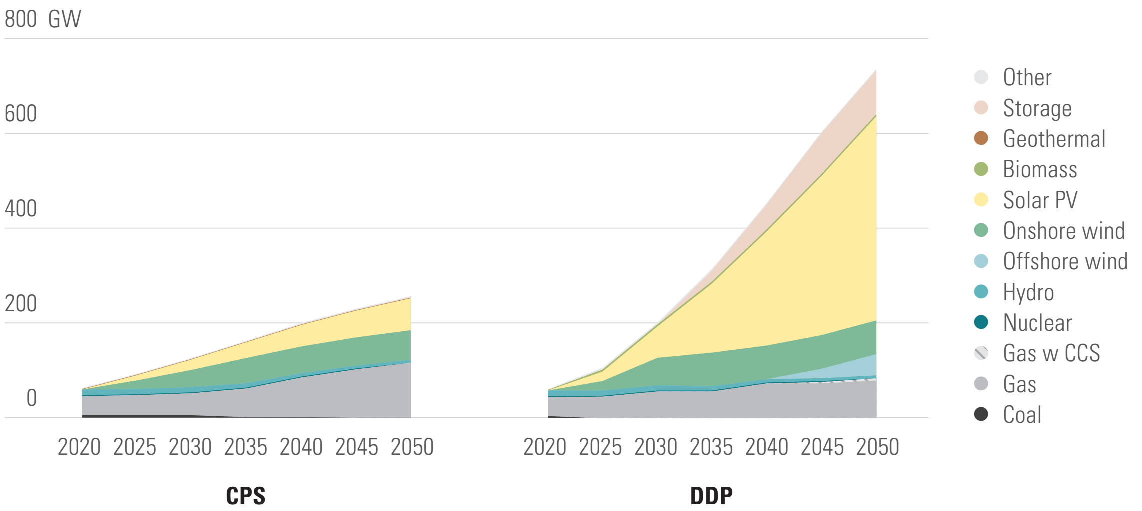


Figure 31. DDP hourly electricity dispatch in 2050 by region (GW)

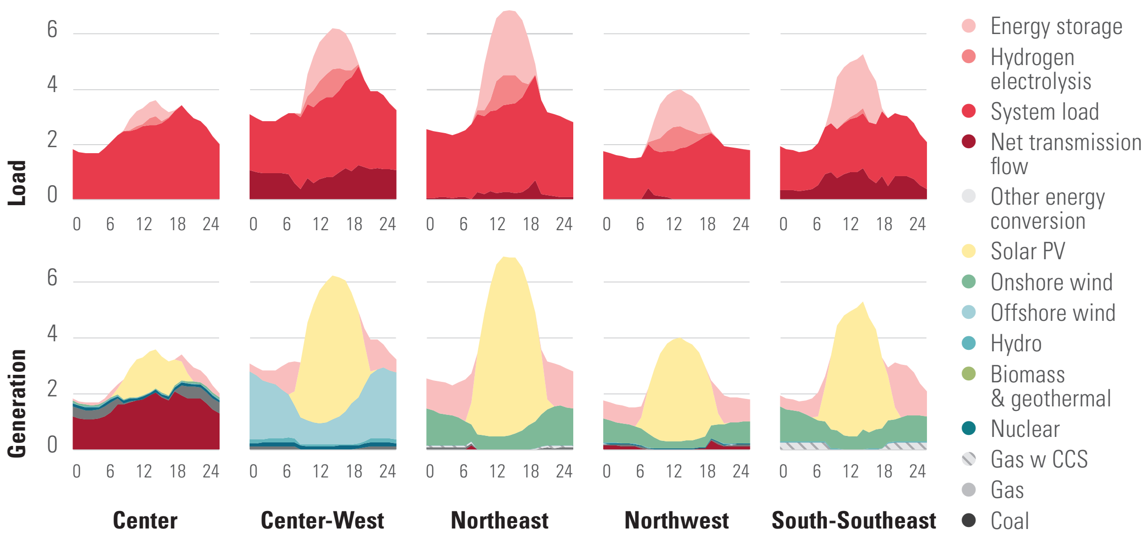


Figure 32. LDV transition to EVs

(a) sales (%); **(b)** annual service provided (billion vehicle-km); **(c)** energy demand (EJ)

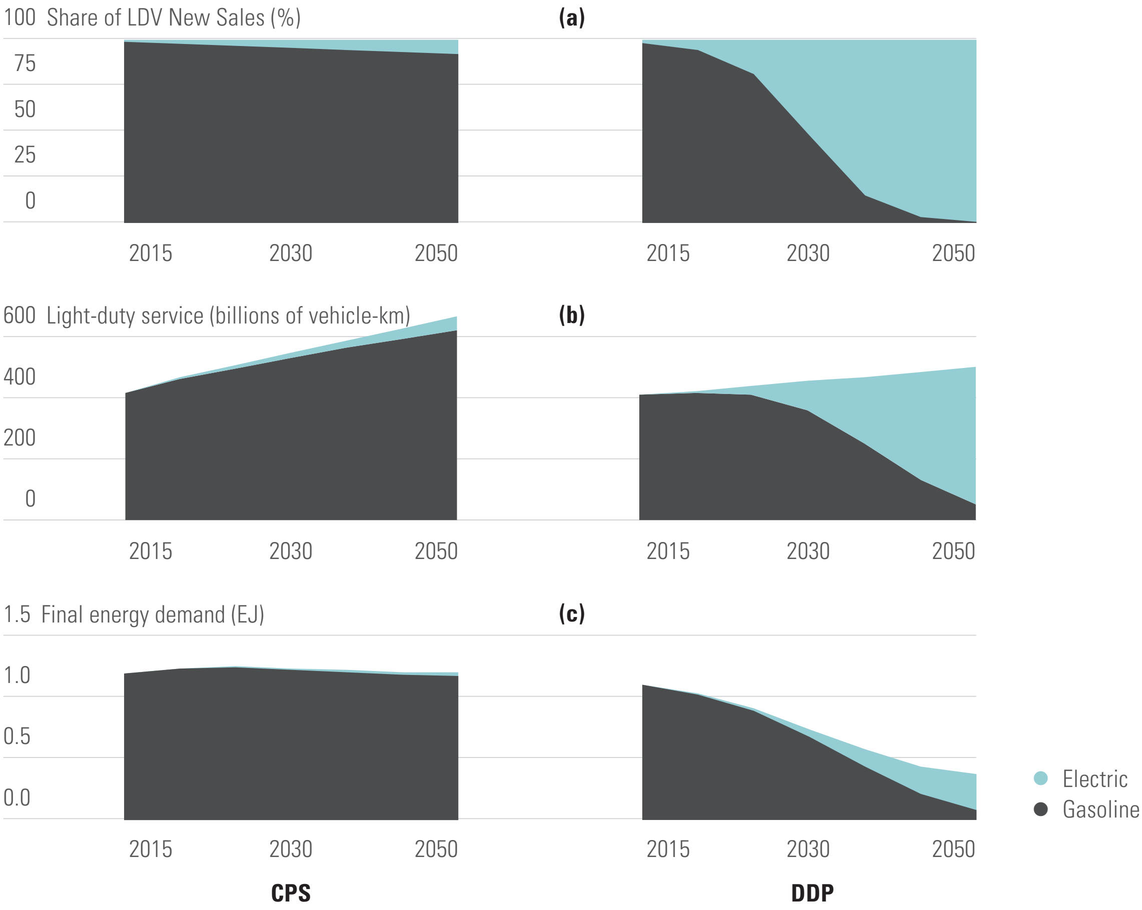
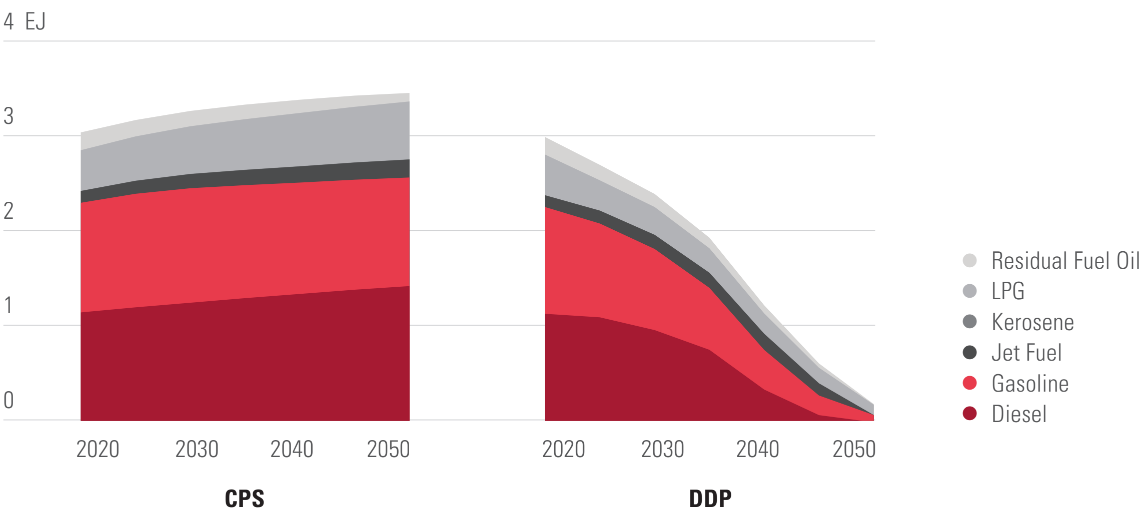


Figure 33. Demand for petroleum-derived fuels (EJ)



generation and thermal use by industry and buildings, will phase out more slowly. However, this fuel is largely imported from US low-cost shale production, making its substitution by renewables a driver of greater national economic activity and energy sovereignty.

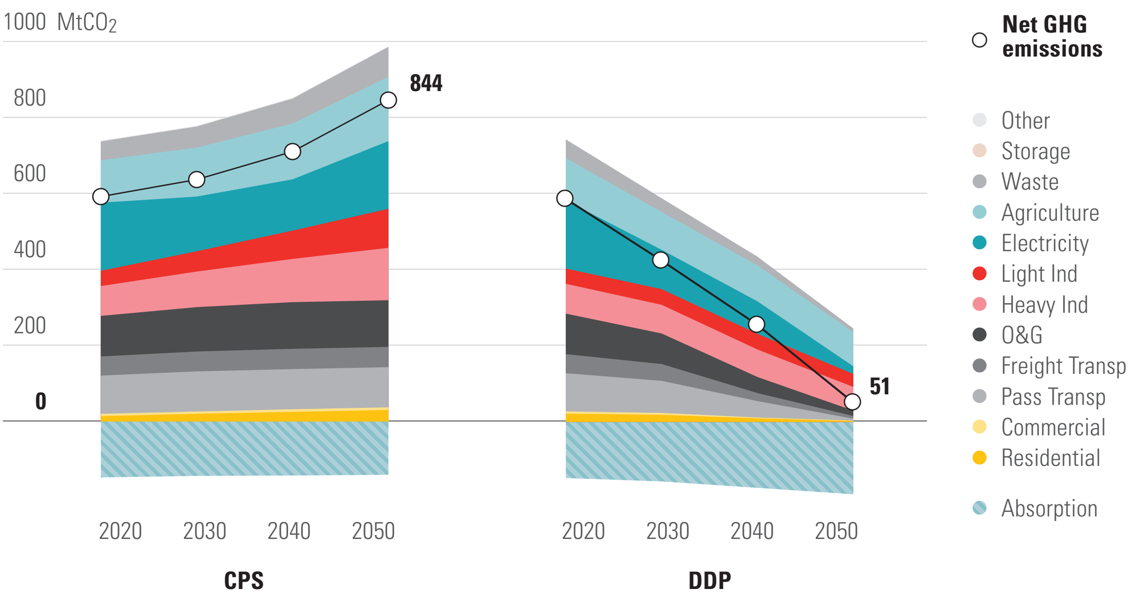
Freight transportation and industry will see both efficiency improvements and direct electrification proceed rapidly where practical, while step-change modal shifts in some high-demand corridors of freight transport, and process innovation for industry, will further reduce emissions. Significant energy needs will remain, however, for which over time, additional zero-carbon fuels will be generated through a range of technological pathways, powered either by biomass, waste, or renewable energy. These will gradually phase out fossil fuels, with the substitution well underway – but not completed – by 2050. The industrial transformation to deliver zero-carbon fuels presents additional opportunities for post-oil investment and economic activity.

Buildings emissions, which gradually grow in the current policy scenario as increasing prosperity outpaces continuous efficiency improvements, can be rapidly reduced through a combination of solar heating (which is a widespread solution across similar latitudes along the world) and electrification, coupled with upgraded standards for construction, equipment, and appliances.

Distributed power generation presents another important economic opportunity, particularly in the residential sector for which electricity used – largely generated from fossil fuels – is currently subsidized. Investment in distributed solar PV technology can simultaneously cut emissions and reduce government costs.

AFOLU is crucial as Mexico must increase GHG absorptions from this sector to meet its targets. Improved forestland management will be combined with intensification of farm productivity (which releases land for afforestation) to grow the sink. This will be complemented by gradual reductions in emissions from fertilizer use as well as enteric fermentation and manure management, largely decoupling agriculture growth from emissions growth. While our analysis does not detail the AFOLU transformation, it highlights the requirement for deep technification of the sector from a whole-economy perspective, emphasizing emissions drivers of historic importance which policy should focus on.
The net result of these sectoral transformations can be seen in **Figure 34**. While current policy is estimated to lead to net 2050 emissions of 844 $MtCO_2$, net DDP emissions become 51 $MtCO_2e$, 94% lower. Per capita emissions will have fallen from 4.2tCO_2e in 2015 to 0.3tCO_2e in 2050, in line with a global temperature rise of between 1.5 and 2°C. The most dramatic reductions will come from changes in energy use, with

Figure 34. GHG emissions pathways by sector, including absorptions, for CPS and DDP scenarios ($MtCO_2e$)



a resulting sharp decline in oil and gas activity. Forests slightly increase CO_2 absorptions from present values, while food systems' GHG footprint is stabilized and gradually managed down. Since our analysis of agriculture and industry is less detailed than for other sectors, further work may reveal additional opportunities for emissions reductions.

Conclusion: Rapid and profound policy shifts are needed if Mexico is to succeed

Mexico can achieve the Paris Agreement goals while improving the life of its citizens. However, this will require a shift away from the current development pathway and the narrative that has been central to the public policy debate for the past generation. A different planning paradigm and a significant redirection of investment will be needed to implement this new development vision. Mexico's renewable endowments, industrial base, geographical location, and skilled workforce make this transformation – which must occur at a global scale – an opportunity to advance towards a high-tech knowledge-based economy, catalyzing economic growth, increased prosperity, and greater inclusion.

Single policy measures will not be sufficient. Suites of complementary policies, or "policy packages" across different sectors will be required to work together, and they will be most effective combining cross-cutting policies with sector-specific measures. Below we present a number of cross-cutting policy changes which will be needed to enable sectoral change:

- **Planning:** The federal government should formulate as soon as possible and in collaboration with stakeholders from productive and social sectors, an integrated long term plan for decarbonization by 2050 which sets ambitious long-term targets and clear milestones along the way. From this, the sequence of necessary changes must be identified, as well as concrete policy actions to achieve them. In this manner, the urgent short-term actions required to reach a long-term transformation can be undertaken quickly from 2020. This strategy should update the existing Mid-Century Strategy (MCS) and feed into the NDC update process.
- **Labor:** A just transition should be a cornerstone of the transformation if it is to succeed while driving social and economic development. Ensuring this will require clear institutional arrangements with roles and responsibilities. The federal government should consider the establishment of a multi-stakeholder council or similar body to provide broad direction and oversight to just transition activities, while leading voices from within growth sectors should identify and communicate the scope for growth and creation of new jobs. Worker representatives and unions, particularly from sectors set to decline, should collaborate with growth sectors to identify the training and other support that will be needed for those individuals seeking to change sectors. Joint investment from central government, local communities and the private sector, together with international collaboration, should be sought to support this transition, which can simultaneously achieve additional social and economic objectives. For example, the sustained investment and training involved can provide means to ensure more Mexicans join the formal economy, increasing their productivity, social protection, and fiscal contributions.
- **Regulatory standards:** Carbon intensity and performance of products and behaviors should form key criteria of regulatory approval across all sectors, ranging from building codes, industrial equipment, vehicles, home appliances and consumer products, as well as guidelines for public procurement and spend. Agreed phase-ins of standards over time, following a calendar of increasing stringency, must be established early on across sectors to give clear signals to the marketplace, with key market players collaborating with the relevant authorities through organized schemes which ensure transparency in terms of alignment with the Paris goals. This will naturally feed through to prices, resale values, and product launches, modifications, and market withdrawal of products and services which are not compliant.

- **Public prices:** Ministries of finance around the world will have to play a decisive role for the low carbon transition to take hold, and for Mexico this will be no different. Taxes, tariffs, incentives and subsidies should evolve to increase the cost of those activities which must rapidly reduce in volume, while supporting the uptake of new technologies and practices. The timing of these measures could be gradual or tiered to facilitate market acceptance, however support for new alternatives options should ramp up at the same time (or preferably before) high-carbon alternatives increase in cost to accelerate change while avoiding hardship.
- **Fiscal sustainability:** The ambitious economic and social development program required to achieve national goals calls for the state to provide vision and leadership while fostering education and investment. Managing this change will need strengthened skills and systems within the public administration at all levels of government. Within this context, Mexico's historical dependence on oil revenue for fiscal stability – which is not representative of the diverse, service-led economy – will become rapidly inadequate as oil activity declines globally to avoid the catastrophic effects of climate change. Mexico must therefore set out a new vision of fiscal sustainability. A stronger link between fiscal take and national economic activity will lead to a virtuous circle as investment in the transition stimulates activity which in turn leads to increased intake, enabling further investment. As new opportunities generate jobs, it will become easier for citizens to join the formal economy. The trajectory of the tax burden over time must align with national and local goals and the overall technology pathways. Furthermore, most resources for states and municipalities currently trickle down from federal sources, meaning local revenues and tax systems will need to be strengthened to fund long-term ambitious projects suitable to local needs.

Sector-specific policy changes are also needed, including:

- **Cities:** The role of the urban structure as a driver of citizen quality of life must be given a central place in national planning, particularly for efforts seeking to improve equity. A holistic view including job opportunities, access to services, public health, quality of building stock and availability of quality transportation (including safety, reliability, comfort, and journey times) should drive planning efforts, regulation, and investment.
- **Transportation technology:** Achieving modern public transport networks which serve a far higher percentage of the population must be a core pillar of the Mexico's urban development. Within this, the urban transport fleet – both public and private – must be electrified rapidly, effectively increasing EV sales from 2020 to overtake ICE sales before 2035.
- **Energy:** Future national prosperity and sovereignty must become rooted in Mexico's abundant renewable resources which, capitalizing on the country's manufacturing and work-force strengths, should become the main recipient of energy investment. Rapid roll-out of renewable generation capacity will be needed to satisfy increasing demand while also replacing current fossil generation. Therefore, investment focus must turn away from the oil and gas sector, which bets future prosperity on uncertain international commodity prices while compromising public health and making climate goals impossible to achieve.
- **Industry:** The opportunities created by the renewable electricity surge and electrification of transport should guide the direction of future industry growth, even while reducing dependence on fossil fuels and re-tooling where appropriate for zero-carbon fuels from renewable sources (waste, bio, synthetic from zero-carbon electricity). As other countries also pursue decarbonization, the loss of income from oil exports should be replaced by increased activity in low-carbon technologies such as clean energy, EVs, and sustainable building materials.
- **AFOLU:** Stewardship of forestlands should continue to improve, seeking to maintain or increase the current carbon sink for decades to come. However, this will only benefit the national transition if farming emissions are simultaneously reduced by changing practices in both crops and livestock, as well changes in customer demand. Should farm emissions growth follow recent trends, these increased emissions will cancel out any absorptions from forestry to 2050, suggesting the need for policy action which links agricultural prosperity with good forest management.

PERU

GETTING TO NET-ZERO EMISSIONS AND CREATING FURTHER OPPORTUNITIES IS POSSIBLE: THE CASE OF THE AFOLU AND TRANSPORTATION SECTORS

Daniel De La Torre Ugarte, Carlos Heros, Mauricio Colado, Willy Mak, Fernando Requejo (Universidad del Pacifico, Lima, Peru), and Yann Briand (IDDRI)

Key policy messages

- Peru is highly vulnerable to climate change, and its two key contributions are likely to be in minimizing its agriculture, forestry, land use (AFOLU) and personal transport emissions as it develops.
- Peru's current NDC policy actions on AFOLU are pointing in the right direction but need to be considerably strengthened. i.e. 1) Sustainable Management of forest concessions; 2) Improve forest management in native communities; 3) Incentives to native communities for forest conservation; 4) Improve management in Protected Natural Areas; 5) Allocation of rights of use in areas in which they do not exist; 6) Addition of commercial forest plantations.
- There is trade-off between reduced deforestation, afforestation and food production that must be anticipated and planned for.
- Peru needs to form a national plan and implementation policy package for transport, including land use for more transit and mode shifting with a focus on urban and inter-city electric buses, and more general electrification of vehicles. More policy work is warranted.
- The estimated DDP pathway results show a 75% reduction from AFOLU, and an 80% from BAU transport emissions, -50% from today, with reduced congestion and local air quality benefits

A path to net-zero emission is possible for Peru

The Paris Agreement has established a compromise between countries to mitigate the greenhouse gases (GHG) emissions in all socio-economic activities. Through voluntary National Determined Contributions (NDCs) each country adopts measures for progressive decarbonization to hold global warming below 2°C above pre-industrial levels.

In Peru, the decarbonization of AFOLU[10] and passenger transport sectors are essential as GHG emissions will increase by 1.5% and 4% respectively each year if no action is taken. The modelling of decarbonization on AFOLU policies shows that reducing emissions by 116.6 $MtCO_2$ eq. in 2050 compared to Business as Usual scenario, a reduction of 71.4% and an additional 4.06 million hectares of primary forest are preserved, and that this reduction occurs primarily through a decrease of the rainforest deforestation, sustainable forest management, property rights allocation and sustainable management of forest concessions. In addition, the modelling of decarbonization policies in the passenger transport sector shows a reduction of emissions by 25.8 $MtCO_2$ eq. in 2050 compared to Business as Usual scenario, a reduction of 85.6%. This reduction occurs primarily through an increase in public transport infrastructure and an electrification of transportation. Passenger transport emissions are reduced, even though the total kilometres travelled increases through time. Overall, the analysis suggests Peru would be on the path to the net-zero emission by 2050.

The forest represents an opportunity for growth and economic development. There are 73 million hectares of forest in Peru, the ninth-largest forest area in the world, representing priceless biodiversity. However, 144,000 hectares are deforested every year. Still, the forest sector and the timber industry contribute less than 0.5% of GDP and one out of three people in the rainforest region is poor. Profound changes are needed to create opportunities for the communities and to conserve the rainforest. Obtaining sustainable value from the rainforest would be an excellent opportunity to show how a deep decarbonization path could provide new income opportunities and preserve the primary forest.

Peru has committed to reduce up to 30% of GHG emissions by 2030. The Nationally Determined Contributions (NDC) involves actions in all sectors and by all actors of society. It is a grand first-step in addressing climate change (and it is a reference baseline). Still, it may not be enough, so it needs to build a reliable road leading to the decarbonization of the economy by 2050.

Efforts are needed in AFOLU to deeply reduced emissions. AFOLU is the highest emitting sector, and it is responsible for 44.9% of total GHG emissions. Rainforest deforestation is the principal source of GHG emissions in AFOLU (81.9%), so efforts must be focused on reduction of the deforestation drivers. Agricultural and livestock expansion is responsible for 76.5% of the annual deforestation.

Producers are increasing their cultivated area by preying on the rainforest. Among small scale and mostly migratory agricultural producers, forest burning is the preferred and cost-efficient practice to deal with the loss of nutrients in the Amazon forest soils. Unfortunately, this practice drives the conversion of primary forest into areas of cultivation. It is estimated that to get one hectare of cropland, farmers removed and burnt 4 hectares of primary forest. The lack of financial and technical capabilities of smallholder farmers results in practices that create erosion and reduce land management efficiency.

Generating value from the forest is the key pathway for decarbonizing the AFOLU sector. To reduce deforestation and enhance forest sinks, efforts need to be made to induce stakeholders to value the sustainable use and conservation of an ecosystem that took centuries to develop. Stopping deforestation by adding value to the long-term use of the forest and the ecosystem services it provides is the main purpose. For a community that is facing development challenges such as poverty, poor health, lack of education and

10 AFOLU sector includes Agriculture and LULUCF (Land use, land-use change, and forestry)

food security, etc., it is challenging to prioritize the long-term value of the forest so creating a short- and long-term value to the standing forest is highlighted as the pathway to stop forest loss.

Deep decarbonization of AFOLU could be achieved with 5 group of actions. To meet the Paris Agreement, rainforest can be decarbonized through: (i) allocation of property rights on non-categorized forest in the Amazon; (ii) increase of sustainable management in forest concessions; (iii) promote of good practices for forest management and conservation in Native Communities; (iv) increase of commercial, protection and restoration forest plantations and (v) improve Natural Reserves management.

Property rights allocation on non-categorized forest in the Amazon is assigning some type of right or entitlement over currently uncategorized forest areas. This is really important because the deforestation rate is led by forests without rights allocation, 36.1% of the annual deforestation, the goal by 2050 is to allocate property rights to 15.3 million hectares. The financial requirement for rights allocation (including titling, monitoring, control and incentive fund) is $536 million dollars (a net present value of $328 million with a discount rate of 10%).

Increase of sustainable management in forest concessions. Sustainable forest management in forest concessions allows forest harvesting activity while not affecting the capacity of the concessioned forests to continue providing their ecosystem functions. The goal by 2050 is to reach 7.4 million hectares of new sustainably managed forest concessions. According to the data of SERFOR, the accumulated financial requirement of sustainable forest management reach $4 billion (a net present value of $2.7 billion with a discount rate of 10%) in 2050. This calculation includes timber transformation in sawn wood and logistics. However, public investment in roads is required because transportation represents more the 60% of the total costs.

Commercial incentives for afforestation and restoration of forest plantations. These are required to induce recovery of deforested land, and as a consequence promote the restoration of forest ecosystems; the goal by 2050 is to reach 2.4 million new hectares of forest plantations. The lack of adequate financial mechanisms and infrastructure gap to overcome the region´s geography are the biggest obstacles for investors. We estimate accumulated investment of $27 billion (a net present value of $3.4 billion with a discount rate of 10%) for 2.4 million hectares of commercial reforestation. These costs include the best technology available in Peru and do not include logistics, timber transformation and additional Government expenses to improve roads. The financial requirement is great for commercial reforestation, but it is the most accepted intervention if we consider that recent studies indicate the sustainable management of primary forests may have important negative impacts in local ecosystems, like nutrient losses from old trees. In addition, recent research indicates that the Amazon rainforest faces a tipping point. In this context, some experts started to recommend aggressive reforestation campaigns and economic activities with the standing forest.

Forest management and conservation by native communities. Paradoxically, most deforestation in the most environmentally rich areas occurs near native communities that have the most to lose from lost traditional agroforestry, but they lack the physical and legal capability to stop it. These communities also tend to be very poor and lack basic services. Forest conservation agreements, along with enforced use property rights associated with use, have been shown to have a positive impact on the standard of life of native communities and reduce the rate of forest loss on native community lands. These agreements, to be effective however, require education and logistics support to encourage the evolution of a combination of businesses based on: sustainable forestry, furniture, sustainable tourism, biotechnology, pharmacy, and high value foods (nuts, etc.). There are also opportunities for biodiversity research and payment for ecosystem services. The goal in our DDP is to reach 11 million hectares managed by native communities. Incentive payments for native communities will require an accumulated sum of $1.5 billion (a net present value of $355 million with a discount rate of 10%) for an accumulated land of 3.8 million hectares by 2050. The challenge is that this intervention is funded 100% by the public budget. It is difficult to foresee the Peruvian Government increasing this budget for this intervention, especially if we consider that the net present value represents half of the Ministry of Environment's current budget.

Isolated interventions have less effect on the GHG emission reduction. Though 2050 each of the above mentioned interventions have the potential to reduce emissions significantly: allocation of rights reduces 620 $MtCO_2$ eq., forest concessions 290 $MtCO_2$ eq., forest plantations 423 $MtCO_2$ eq., improved management by native communities 347 $MtCO_2$ eq. and natural reserves management 857 tCO_2. Rights allocation and sustainable forest management synergistically augment their effects if they are applied together. For example, if more lands are allocated under sustainable forest management with better techniques to improve productivity, the forestry profitability will disincentivize the expansion of croplands in forestland. Just reclassifying land is not enough without efficiency and good management, and good management has a limited impact if there are no more available lands. The synergies permit an additional emission reduction of 6.5 $MtCO_2$ eq. (not including the isolated effect of policies). In this context, property rights allocation and Forest Management and Conservation in Native Communities provide an accumulated reduction of 35 $MtCO_2$ eq., property rights allocation and Natural Reserves management reach a reduction of 55 $MtCO_2$ eq. Finally, all the synergy interventions together provide an additional cumulative reduction of 5.6 $MtCO_2$ eq.

The integrated analysis of AFOLU (LULUCF and agriculture) allows us to assess their production and food security impacts on the agricultural sector and address the possible unintended effects of LULUCF interventions. The reduction in the conversion of primary forest to cropland implies a drop in the area harvested for crops. Rice, tubers, legumes, fruits and yellow corn are highly dependent on the cropland available in the rain forest. In the year 2050 there 268,000 harvested hectares less than in the BAU scenario. This includes a loss of 124,000 hectares of rice, 44,000 of tubers, 8,000 legumes, and 2,000 fruits. Yellow corn, a Peruvian staple, drops 90,000 hectares. While an increase in imports is not necessarily negative, the political consequences of importing about half of the local consumption of rice may not be acceptable to authorities and the population. On the other hand, for the case of the non-tradable products like tubers, legumes, and fruits the reduction in harvested land would triggers an increase in prices. Given that legumes and tubers are produced by smallholder farmers, mostly in the highlands, the price increase becomes a positive impact on their income as it also drives a higher level of output.

It is necessary to recognize that agriculture cannot continue to grow at the expense of forests. Both the necessary technical improvements and institutional framework for environmental monitoring and the intensification of agriculture must be sought and strengthened. To start addressing these challenges, we present two additional interventions. First, the introduction of a system of rice intensification (SRI) in the coast. The SRI system offers advantages for the farmer and the environment. The yield per hectare of SRI is higher (12%) than the traditional method and has a lower water consumption and generates fewer emissions (-10%). Previous analyses indicate the adoption of the SRI technology requires financing resources and extension support for farmers, and an adequate supply of labor, particularly when smallholders are predominant. The second intervention is a drive to change consumer preferences from rice to tubers and legumes; a natural shift to substitute carbohydrates from rice towards tubers and legumes is a promising long-term trend. Introducing SRI technology and promoting tubers and legumes over rice helps mitigate the reduction of cropland in the rain forest. Price trends for tubers and legumes favor smallholder farmers, the overall quality of the diet improves as tubers and legumes provide additional nutrients to rice, and domestic demand is sourced locally. In summary these interventions allows a reduction in agricultural emissions of 1.7 $MtCO_2$ eq. compared to BAU.

Future research agenda on AFOLU. Given the importance of reforestation and the diversity and heterogeneity of the Amazon rainforest, it is important to have a finer assessment of the areas with potential for commercial plantations. Based on existing GIS data is it possible to locate the extensions of land with potential for reforestation, based on access to markets and availability of labor. The microclimate and soil

Figure 35. LULUCF emissions

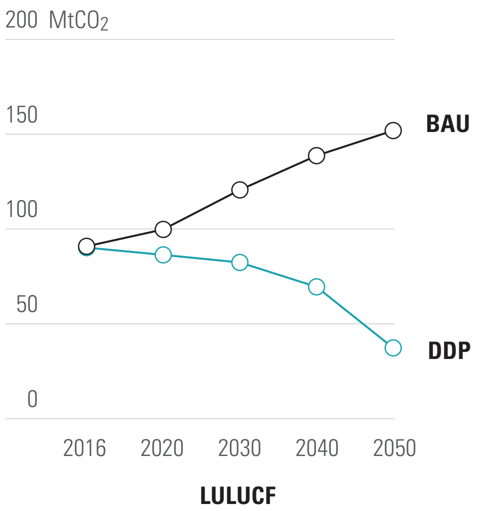
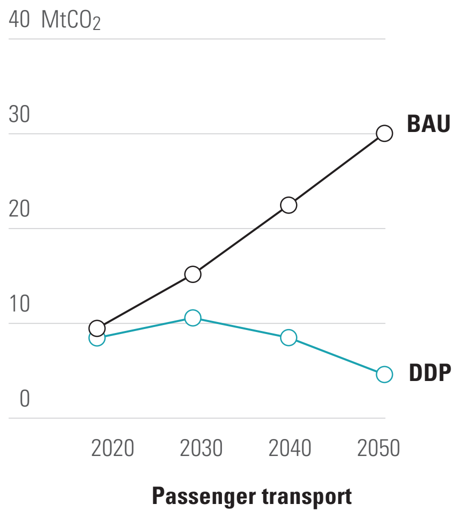


Figure 36. Passenger tranport emissions



characteristics are also to be considered to identify the potential species for reforestation. This detailed analysis is a must to actually confirm the potential that commercial reforestation and sustainable managed of forestry concessions have to contribute to the DDP towards zero emissions.

The decarbonization of the transport sector is key and brings co-benefits. The latest GHG inventory highlights that the energy sector accounted for 25% of the country's gross emissions (4.46 $MtCO_2$ eq), with transport representing 40% of the total. This represents the second sector with the highest emissions report. Also, considering that the passenger transport sector has a high growth rate in emissions within the energy sector, it is imperative to structurally prepare its deep decarbonization. At the same time, these structural transformations could contribute to improving the quality of life by increasing access to new opportunities, enhancing mobility by reducing travel time and distance, reducing local air pollution, reducing traffic jams, and increasing labour productivity.

Transport sector has many decarbonization challenges. Total travelled kilometres will grow in line with the population and household income growth; if transport fuel remains fossil fuel based, sectoral emissions will grow. Furthermore, the gap between adequate public transport infrastructures and services contributes to the adoption of private cars and associated traffic jams. According to national surveys, there is a preference for private cars rather than public transport due to feelings of insecurity. In addition, the lack of public refuelling stations for alternative fuels limits the penetration of new technologies of vehicles, especially electric vehicles. Finally, the presence of informal collective transport services by microbuses, collective taxis and two wheelers taxis increases the traffic congestion and has a lower energy efficiency due to the average age of the vehicles. So, there is a clear need to migrate towards a transportation system based on cleaner energy such as electric power or net-zero gases, as well as changes from private towards public transportation and enable people to avoid unnecessary kilometres.

Decarbonization of the sector will be achieved with 4 groups of actions. To accomplish the Paris Agreement, Peru passenger transport sector can be decarbonized with: (i) an increase of adequate public transport services; (ii) a mass electrification of vehicles; (iii) a cleaner supply of fossil fuels and electricity; (iv) and a change of the behaviour of transport sector development.

Peru has already taken some steps. The introduction of urban train and bus rapid transit (BRT) services has reduced the public transport infrastructure gap. While the increase of compressed natural gas stations shifts has allowed the demand of new vehicles with cleaner transportation. At 2020, pilot programmes of electric vehicles and scrapping bonus has started in Lima, which reduce the informality and increase fuel efficiency.

Improvement of quality in public transport services. An ambitious goal could be that at least 50% of the modal shift participation is done by public transportation since 2030. Many infrastructure investments are needed. BRT (Bus Rapid Transit) could be developed more rapidly. For example, 12 news BRT systems could be introduced in each 5 year period through 2020-2030 starting with the main cities of the country: Piura, Arequipa, Chiclayo, and Trujillo. Then, this could be further expanded nationwide. Lima's public transport could also be enhanced with the development of 4 new Metro lines. We estimate accumulated investment of $9 billion (a net present value of $5.5 billion with a discount rate of 10%) for the infrastructure building and the development of enabling conditions by 2050. Beyond the development of new public transport infrastructure, the quality of service should be improved to create a model of public transport as attractive compared to private vehicles. Only a combination of infrastructure development and service quality improvements ensuring better safety, higher speed and lower cost than personal car is able to change the population transport preferences.

These actions will allow cheaper, safer and more energy efficient transportation, which will have a growing demand as shown in the first experiences of BRT and Metropolitan train.

Change of vehicle technologies: electricity as a new fuel. It is possible to electrify the car stock; we project 85% battery electric and 10% plug-in hybrid cars by 2050. For other road vehicles, we target 70% of electric buses and 80% of two wheelers. Pilot programs for electric cars and two wheelers will be developed in Lima, then it will be scaled to the other main cities by 2030, and later will be developed nationwide. We estimate a necessary accumulated investment of $15.5 million (a net present value of $8.6 million with a discount rate of 10%) for the development of the policy and pilot programs by 2050. The penetration of electric motorization will depend in the reduction of fixed costs of these kinds of technologies. Also, it will differ in each Peruvian state due to the household's revenues and the presence of electric charging stations. So national incentives schemes should be promoted, such as a scrapping bonus, to assure the competitive prices of these technologies with respect to fossil fuels vehicles. For buses, the concessions could be an efficient tool to ask for the operation of vehicles with low GHG emissions, e.g. powered with electricity or fuelled with biofuels. Furthermore, the existing old collective taxis and microbuses need to be retired and

Figure 37. Passenger Transport Emissions by Type of Energy

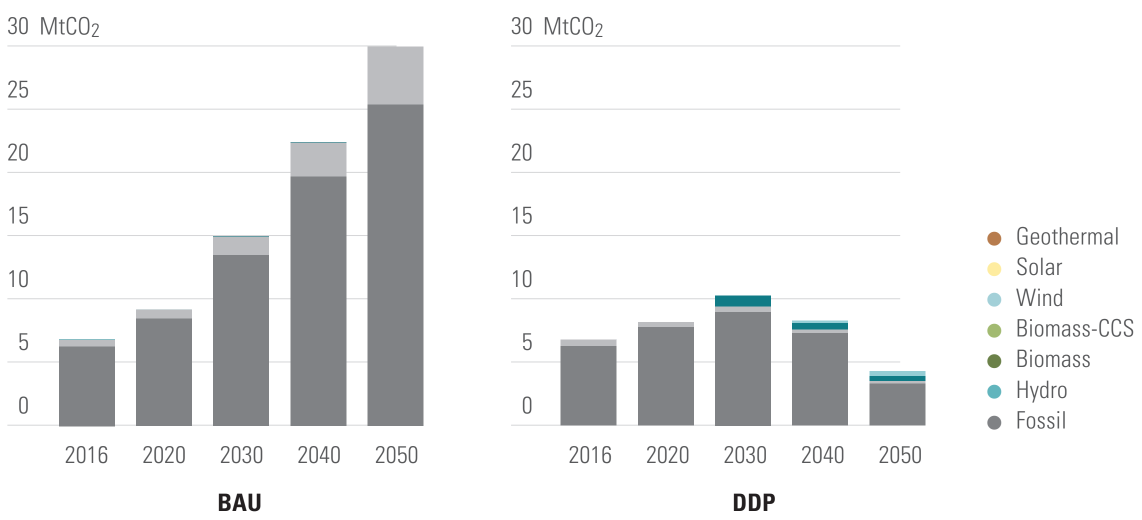
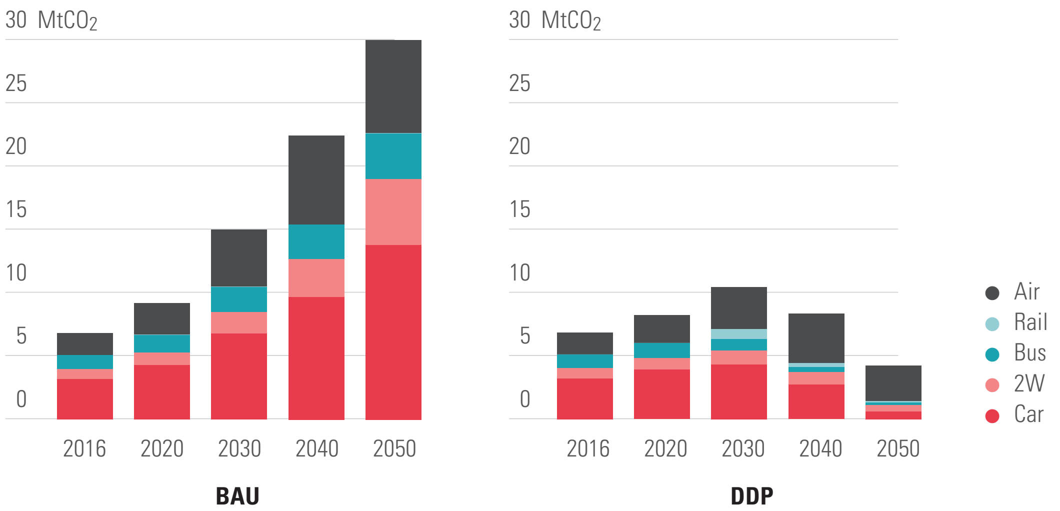


Figure 38. Passenger Transport Emission by Type of Transportation



this could be supported with a specific company-registered scrapping subsidy to buy low-carbon vehicles. At the same time, this could also help regulate this current informal form of public transport. As planned already by ATU, the retirement of collective taxis and microbuses in Lima will start from 2020 and will be extended in the rest of the country after 2030.

Energy alternative: Biokerosene and decarbonization of electricity. The introduction of biokerosene is needed in air transport with the current technological knowledge. However, this will need to be imported at first due to the lack of national production infrastructure. In 2050, 30% of the aviation fuel consumption should be biokerosene if we want to keep up with the demand of air travel and reduce national transport emissions. In addition, the electrification of transport is only an efficient lever if the electricity production is decarbonized. This requires removing fossil fuels (coal, oil and natural gas) as much as possible and to develop new renewables energies like wind and solar power. By 2050, renewable production could increase from 56% to more than 94% of the national electricity production and move the carbon content of electricity from 209 gCO_2/kWh to 30 gCO_2/kWh. This cleaner production could be achieved with higher quantity and frequency of national concessions auctions. We estimate accumulated investment of $0.4 million (a net present value of $0.3 million with a discount rate of 10%) for the planification and development of a low carbon transport concessions auctions strategy by 2050.

Teleworking as a game changer. Reducing the number of kilometres travelled for work purpose could be achieved with teleworking. For example, two days of telework affecting 50% of metropolitan population and 25% of non-metropolitan areas could reduce the demand of total kilometres travelled by 20% in metropolitan areas and by 10% in non-metropolitan areas. However, communications of the benefits of this action should be applied to increase the quantity of days and business that apply teleworking. An option could be the introduction of policies which allows the digitalization business activities, it would make easier the change of working behaviour. We estimate accumulated investment of $0.3 million (a net present value of $0.2 million with a discount rate of 10%) for policy development and socializing activities by 2050. [F37]

The deep decarbonization pathway allows the reduction of accumulated emissions from the AFOLU and passenger transport sectors by 2,125 $MtCO_2$ eq. This represents a reduction of 40% compared to the BAU scenario. By 2050, the reduction will be reduced by -73%%, from 195.189 Mt C02 eq. to 51.920 $MtCO_2$ eq. Despite the additional effort that this new pathway to decarbonization represents, net-zero emissions won't be achieved by 2050; it shows that a real transformational change is necessary for the different sectors with a more aggressive proposal of policies that will allow reaching this objective by 2050. It highlights the need for the support of international cooperation for the design, evaluation and implementation of these policies to achieve net-zero emissions by 2050.

The models

The POLYSYS - Peru model was used for the AFOLU analyses to consider feedbacks across sectors and measure the impacts in GDP between forestry and agriculture. In the passenger transport sector the ASIF model was used to measure the impacts of the change in transport demand, fuel consumption and technology use. Please contact the authors for questions.

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The 2050 Pathways Platform is a multi-stakeholder initiative launched at COP 22 by High-Level Climate Champions Laurence Tubiana and Hakima El Haite to support countries seeking to develop long-term, net zero-GHG, climate-resilient and sustainable-development pathways. Designed as a space for collective problem-solving, the platform will also build a broader constellation of cities, states, and companies engaged in long-term low-emissions planning of their own, and in support of the national strategies.

2050pathways.org