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Committed emissions and the risk of stranded assets from power plants in Latin America and the Caribbean

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Abstract

Latin America and the Caribbean (LAC) has the least carbon-intensive electricity sector of any region in the world, as hydropower remains the largest source of electricity. But are current plans consistent with the international climate change goals laid out in the Paris Agreement? In this paper, we assess committed CO_2 emissions from existing and planned power plants in LAC. Those are the carbon emissions that would result from the operation of fossil-fueled power plants during their typical lifetime. Committed emissions from existing power plants are close to 6.9 Gt of CO_2. Building and operating all power plants that are announced, authorized, being procured, or under construction would result in 6.7 Gt of CO_2 of additional commitments (for a total of 13.6 Gt of CO_2). Committed emissions are above average IPCC assessments of cumulative emissions from power generation in LAC consistent with international temperature targets. 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. Our results suggest that building more fossil-fueled power plants in the region could jeopardize the achievement of the Paris Agreement temperature targets.

1. Introduction

Latin America and the Caribbean (LAC) has the least carbon-intensive electricity sector of all regions in the world, thanks to the highest share of hydroelectricity in the world (IEA 2018a). But this is changing. Hydropower generation has scaled down its percentage in the power mix from 58% in 2009 to 50% in 2016 (IEA 2018a). Utilization rates have been reduced by droughts, and capacity additions have slowed down due to social and environmental concerns, and increasing capital cost (Pereira de Lucena *et al* 2011, Soito and Freitas 2011, IRENA 2016, Van Vliet *et al* 2016, de Queiroz *et al* 2019).

Natural-gas-based power generation has generally filled the gap, sustained by abundant and competitive supply, turning it into the second source in the power mix (IRENA 2016, Yépez-García *et al* 2018). While installation of wind, solar, geothermal, and bioenergy and waste power plants is growing rapidly, representing 57% of renewable capacity addition in 2017, it still represents only 6.5% of total capacity (ENERDATA 2019a). In the absence of changes in public policies and/or market design, natural gas and coal could play an increasingly important role in the electricity mix (Calderón *et al* 2016, Clarke *et al* 2016, Lucena *et al* 2016, van der Zwaan *et al* 2016).

All countries in the region have presented nationally determined contributions (NDC) that include emission reductions in the power sector as part of their contribution to the Paris Agreement (World Bank 2019). But current energy planning is only partially consistent with commitments, and would result in the addition of new fossil fuel power plants in the region (OLADE 2018, Cadena 2019). Worse, current NDCs are not aligned with the temperature targets of the Paris Agreement (Iyer *et al* 2015, Rogelj *et al* 2016, UNEP 2017, Binsted *et al* 2019), so that even if countries did implement their NDCs, they would continue to add more fossil fuel power plants than what would be consistent with the achievement of the international temperature targets.

To keep climate change impacts on development in check (Hallegatte *et al* 2015), global leaders have agreed to pursue efforts to limit global warming well below 2 °C, and as close to 1.5 °C as possible (United Nations 2015). Either target requires reaching net zero emissions of CO_2 globally (Fay *et al* 2015, Rogelj *et al* 2015, Sachs *et al* 2016) and in LAC (Vergara *et al* 2016, Paredes 2017). In particular, stabilizing climate change requires that all regions switch to carbon-free electricity before 2050 (Williams *et al* 2012, Audoly *et al* 2018, Davis *et al* 2018). The IPCC's special report on global warming of 1.5 °C finds that by 2050, the net carbon content of the power sector should fall to close to 0 and renewable supply should represent 70% of the electricity mix (Huppmann *et al* 2018a).

Long-term decarbonization goals matter for energy infrastructure planning because power plants lifetime may range from 30 to 50 years (Fay *et al* 2015, Millar *et al* 2016, Sachs *et al* 2016, Grubb *et al* 2018). To assess the impact of long-lived infrastructure on climate change, Davis and Socolow (2014) introduced the concept of *committed* carbon emissions in existing infrastructure. Those are the carbon emissions that would result from the operation of existing fossil-fueled power plants and other carbon-intensive equipment during their typical lifetime and with typical utilization rates. The same concept has been applied to *planned* power plants, that is plants that are announced, authorized, being procured, or under construction (Shearer *et al* 2017, Edenhofer *et al* 2018, Pfeiffer *et al* 2018).

Here, we assess committed emissions from operational and planned power plants in LAC. We use the power plan tracker (PPT) database from ENERDATA (ENERDATA 2019a), which provides information on power plants classified by fuel type, age, capacity, historical output, and operational status as of January 2019.

We compare committed emissions with a wide range of *carbon budgets for the LAC power sector*. We define those as the sum of gross CO_2 emissions from the LAC power sector in the scenarios of the world economy that keep global warming in the 1.5 °C–2 °C range reported in the IPCC Special Report on 1.5 °C (2018)[5]. The IPCC considers pathways generated using a variety of modeling paradigms; different technology assumptions—in particular, exploring the impact of whether carbon dioxide removal can offset emissions from power generation and different costs and potentials for non-CO_2 emission reductions–, discount rates, interpretations of temperature targets—peak or long-term warming (Huppmann *et al* 2018a, 2018b). We consider all those pathways.

We find that committed emissions from the existing power sector in LAC amount to 6.9 $GtCO_2$. This commitment is within the range of LAC power carbon budgets consistent with 1.5 °C, which we find to be 1.9 to 13.5 $GtCO_2$. However, committed emissions are greater than the median of 1.5 °C-compliant carbon budgets reported in the IPCC database, and greater than the 60th percentile of 2 °C carbon budgets in the same database. If all planned power plants are built, we find that committed emissions would rise to 13.6 $GtCO_2$, which is more than 90% of LAC power carbon budgets reported in any scenario consistent with 1.5 °C or 2 °C published by the IPCC.

These findings suggest that to meet the average allowable carbon budget for 2 °C (6.2 $GtCO_2$) or 1.5 °C (5.8 $GtCO_2$), utilities in the region would need to close prematurely 10%–16% of the existing fossil-fueled capacity, respectively, or reduce the utilization rate of existing plants to the same effect. Doing so could be politically difficult, as policies that result in the closure or reduced utilization of power plant would diminish the financial value of those assets, i.e. they would create *stranded assets*[7]. Closing down power plants would also result in sudden losses of jobs for the workers and communities who depend on those assets. Both impacts are politically difficult to manage because they create concentrated losses on homogenous groups that can easily organize to protest the reforms (Olson 1977, Trebilcock 2014), and because they can go against policy objectives of social inclusion (Hallegatte *et al* 2013, Jenkins 2014, Bertram *et al* 2015, Nemet *et al* 2017, Vogt-Schilb and Hallegatte 2017, Gambhir *et al* 2018, ILO 2018, Rozenberg *et al* 2018).

This paper is part of a growing literature that quantifies committed emissions in energy infrastructure (Davis *et al* 2010, Pfeiffer *et al* 2018, 2016, Tong *et al* 2019). This literature has focused on global

[5] In IPCC scenarios where carbon capture and storage is used to produce negative emissions in the power sector, we add net emissions from power generation and captured emissions to compute our gross carbon budgets (see Methods and data). Carbon budgets are computed over the lifetime of all the existing and planned power plants, that is 2019–2054.

[6] See footnote 5.

[7] The words *stranded assets* are used in the literature on climate change to describe various things (Caldecott 2017): assets that are lost because of the impact of climate change itself, fossil fuel resources that cannot be burnt into the atmosphere if a given climate target is to be reached, also called unburnable carbon (Solano-Rodriguez *et al* 2019); and man-made capital that has to be retired early because of climate policies, such as coal power plants that become unprofitable after a carbon price is implemented. In this paper we focus on power plants. With this definition, closing a power plant or reducing its utilization rate for environmental reasons creates stranded assets for its owners irrespective of whether the power plant had already reached its financial payback period. A power plant is stranded if and when it could technically be used longer and produce more revenues, but is closed due to environmental (or other) policy.

Table 1. Classification of the generators.

Category	Subcategory	Count	Percentage of capacity (%)	Average date of commissioning
Existing	Operational	4146	62.2	2001
	Synchronized	3	0.1	2019
Planned	Announced	61	4.5	2023
	Authorized	196	8.6	2019
	Bidding process	90	16.3	2021
	Under construction	109	8.3	2019

emissions, or on showing that coal power plants under construction globally (Edenhofer *et al* 2018), or even just in India (Shearer *et al* 2017), would make a significative contribution to global emissions. In this paper, we focus in LAC, a region that was home to only 5% of global CO_2 emissions in 2016 (IEA 2018b). Unlike global commitments from coal, the committed emissions we find in LAC are not a game changer for the global climate change agenda. But our results show that international temperatures targets do matter to LAC energy planners: existing plans would surpass most of LAC's power carbon budgets, and adding fossil fuel power plants may increase the risk of stranded assets in LAC.

Section 2 presents the methods and data. Section 3 provides results. Section 4 discusses those results and concludes.

2. Methods and data

We define committed emissions as the emissions that will occur over the remaining lifespan of a fossil-fuel-burning electric generator[8]. We focus on generators, defined as devices that generate electrical power for use in an external circuit. A plant consists in one or more generators.

2.1. Carbon emissions per generator from ENERDATA and IEA

We compute committed emissions in two basic steps. In the first step, we assess current emissions by generator. We decompose CO_2 emissions F ($tCO_2\,yr^{-1}$), as the product of capacity C (GW), utilization rate E/C where E is electricity output ($GWh\,yr^{-1}$), and carbon intensity of electricity generated F/E ($tCO_2\,GWh^{-1}$). We assume utilization rates and carbon intensities to be constant over time. To make the most of the data available, each quantity is computed per country i,fuel f, and status s:

$$F_{i,f,s} = C_{i,f,s} \times \left(\frac{E_{i,f}}{C_{i,f}}\right)_s \times \frac{F_{i,f}}{E_{i,f}}. \quad (1)$$

We take existing and planned capacities $C_{i,f,s}$ from the Power Plant Tracker (see appendix 4, appencies are available in the online supplementary materialis available online at stacks.iop.org/ERL/14/124096/mmedia) (ENERDATA 2019b). The PPT reports unit status, date of commissioning, fuel type, net capacity, electricity output and localization in January 2019. The database reports 14 816 generators in LAC, 34% of which (5048) are fossil-fuel-based (oil; coal, peat and oil shale; and natural gas). We focus on fossil fuel plants, as the others do not commit CO_2 emissions.

The PPT classifies generators in operational, announced, authorized, bidding process and under construction, stopped, canceled, mothballed, and synchronized statuses. We qualify as *planned* the generators under the announced[9], authorized[10], bidding process and under construction statuses. Those do not currently emit carbon dioxide but will do so starting at their commission date. Operational and synchronized units are included in the *existing* status. Those are already emitting carbon dioxide. Table 1 summarizes the amount of generator per category.

We take electricity output $E_{i,f}$ per country and energy type from ENERDATA (2019a) and ENERDATA (2019b). These two sources are slightly inconsistent. The total (bottom-up) sum of power generation listed in Power Plant Tracker (ENERDATA 2019b) does not match national statistics of power generation per country and fuel (ENERDATA 2019a). In total, fossil-fuel-based generation reported in PPT for 2016 (450 TWh) represents 67% of total electricity production from national statistics (665 TWh)[11]. We solve this issue at the country and fuel level. In most cases, the sum from PTT is lower than the reported national statistic. One reason is that PPT does not report any electricity output for some generators. Another is that for some flex-fuel plants, PPT reports only generation from the main fuel. We fill missing generation data using averages per country and fuel, then scale up production from all

[8] Davis and Socolow (2014) define committed emissions as the emissions that occur over the lifetime of a fossil-fuel-burning (realized emissions plus remaining emissions). Our approach focuses on what they call remaining committed emissions.

[9] Project either announced by a company or planned in a national development plan released by Governments, TSOs, regulators, agencies.

[10] The power project has received public/statutory consents by the national authorities in charge of delivering authorizations for new power infrastructures.

[11] Appendix 1 presents the fossil-fuel-based generation at the country level from these two sources.

Table 2. Lifespan and average carbon intensity of electricity.

Fuel	Lifespan (years)	Carbon intensity (g kWh^{-1})
Coal, peat and oil shale	37	930
Natural gas	35	427
Oil	32	640

plants to match production from national statistics. (We implicitly assume no bias for not reporting any type of power plants.) In very rare cases, production from PPT is slightly larger than production reported in ENERDATA (2019a). For those cases, we scale down linearly the electricity output in the PPT database to match the statistics.

We take CO_2 emissions by country and fuel *F* from ENERDATA (2019a). Since the last year fully reported for CO_2 emissions is 2016, we compute the carbon intensity of electricity per country and fuel based on electricity output for 2016 reported in ENERDATA (ENERDATA 2019a, 2019b). We latter test the sensitivity of our results to the data sources chosen.

2.2. Remaining lifetime of generators

The second step to compute committed emissions is to project the remaining lifetime of each generator. The PPT provides a date of commissioning for most generators. We fill data gaps with the averages at country, technology and unit status level. In addition, there are 23 fossil-fuel-based generators (for a total of 6.2 GW or 3.7% of 2019 capacity) that classify as planned, but for which the reported date of commissioning is in the past. For those, we give priority to the status reported and set the commissioning date to 2019. (Note that the commissioning date does not impact our estimates of committed emissions as long as it is not in the past.)

We assume the lifetime of power generators to be 37, 35 and 32 years for coal, natural gas and oil technologies, respectively, following Davis and Socolow (2014). (We later perform a sensitivity analysis on these assumptions.) The PPT reports 251 operating fossil-fuel based generators older than that (for a total of 19.7 GW or 11.6% of 2019 capacity). For those, we assumed their lifespan is extended by 5 years more, following Pfeiffer *et al* (2018)[12].

Table 2 summarizes the assumed lifespan and average carbon intensity of electricity in LAC by technology. Appendix 2 reports carbon intensity by country and technology.

2.3. Correcting for missing countries

The PPT covers only 18 Latin American countries: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Jamaica, Mexico, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, and Venezuela. According to ENERDATA (2019a) these countries are responsible for 94% of carbon emissions from electricity generation in LAC. We create a 'rest of LAC[13]' aggregate to which we assign the missing emissions per fuel type, with average age taken from the other countries reported in PPT.

2.4. Carbon budgets from IPCC

To assess carbon budgets available for power generation in LAC, we rely on the IAMC 1.5 °C public database hosted by IIASA (Huppmann *et al* 2018a). This database contains an ensemble of quantitative, model-based climate change mitigation pathways consistent with 1.5 °C and 2 °C warming supporting the IPCC's special report on 1.5 °C (IPCC 2018, Huppmann *et al* 2018b). The IPCC uses seven categories of scenarios, grouped by their likelihood to satisfy different temperature targets. Table 3 provides a classification of the pathways reported.

Many climate-stabilization trajectories reported by the IPCC feature negative emissions in the power sector in the second half of the century. One key technology to produce electricity with negative net GHG emissions is bio-energy with carbon capture and storage (BECCS); it relies on the burning of biomass in power plants in connection with the long-term storage of resulting CO_2 (Smith *et al* 2016, Williamson 2016). When BECCS is available, the least-cost strategy to achieve global carbon neutrality is to eventually generate negative-emission electricity thereby offsetting previous overshoot emissions or emissions from other sectors of the economy that are more difficult to decarbonize (Audoly *et al* 2018).

We thus need to use two variables from the IPCC database to compute carbon budgets: *CO_2 emissions of electricity supply*, which reports emissions net from any carbon dioxide removal, and the separate *carbon sequestration in the electricity supply*. We compute gross CO_2 emissions from the power sector as the sum of net CO_2 emissions from electricity supply[14] and carbon sequestration in the electricity supply sector[15] (see also appendix 6). To compute total budgets, we simply sum these two variables, between 2019 and 2064—which is the year when the last planned unit would operate under normal conditions according to

[12] Assuming these power plants are immediately retired would reduce our estimate of committed emissions by less than 2%.

[13] The IEA reports total emissions (IEA 2018b) for Cuba, Haiti, Honduras and Nicaragua. Those countries are not reported in ENERDATA (2019a, 2019b), so we aggregate them in a category 'rest of LAC'.

[14] *CO_2 emissions from electricity and CHP production and distribution* (IPCC category 1A1ai and 1A1aii) (Mt CO_2 yr^{-1}) (Huppmann *et al* 2018a).

[15] *Total carbon dioxide emissions captured from bioenergy use in electricity production* (part of IPCC category 1A1a) and stored in geological deposits (e.g. in depleted oil and gas fields, unmined coal seams, saline aquifers) and the deep ocean (Mt CO_2 yr^{-1}) (Huppmann *et al* 2018a).

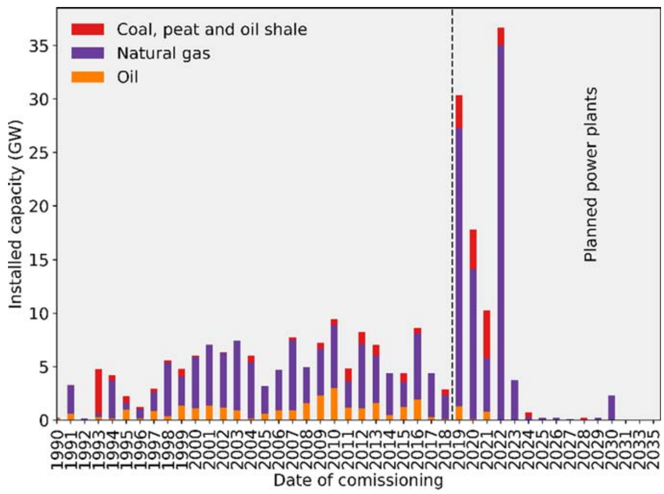


Figure 1. Capacity by date of commissioning. The bars in 2019 and after correspond to planned power plants. We plot data from 1990, however, the database includes units which started to operate before that.

Table 3. Categorization of scenarios supporting the special report on global warming of 1.5 °C.

Category	Subcategory	Probability to exceed warming threshold	Number of scenarios
1.5 °C consistent	Below-1.5 °C	$0.34 < P_{1.5\,°C} \leqslant 0.50$	9
	Lower 1.5 °C-low overshoot	$0.50 < P_{1.5\,°C} \leqslant 0.67$ and $< P_{1.5\,°C}(2100) \leqslant 0.34$	44
	Higher 1.5 °C-low overshoot	$0.50 < P_{1.5\,°C} \leqslant 0.67$ and $0.34 < P_{1.5\,°C}(2100) \leqslant 0.50$	
	Lower 1.5 °C-high overshoot	$0.67 < P_{1.5\,°C}$ and $< P_{1.5\,°C}(2100) \leqslant 0.34$	37
	Higher 1.5 °C-high overshoot	$0.67 < P_{1.5\,°C}$ and $0.34 < P_{1.5\,°C}(2100) \leqslant 0.50$	
2 °C consistent	Lower-2 °C	$P_{2.0\,°C} \leqslant 0.34$	74
	Higher-2 °C	$P_{2.0\,°C} \leqslant 0.34$	58

Note: The term $P_{1.5\,°C}$ refers to the probability of exceeding warming of x °C throughout the century in at least one year and $P_{1.5\,°C}(y)$ refers to the probability of exceedance in a specific year y. Assumptions of each scenario can be observed in the documentation of the IAMC 1.5 °C public database hosted by IIASA (Huppmann *et al* 2018a).

our assumptions. Since the 1.5 °C database provides regional model outputs, we select the ensemble of scenarios related to the region R5LAM.

3. Results

3.1. Committed emissions of operating and planned generators

We first consider power generation capacity reported in PPT. The database reports that 4146 existing generators in January 2019 use coal, peat and oil shale (*coal* for short); natural gas; or oil as their main fuel. This comprises 169 GW of fossil-based capacity. Their average age is 17 years (they have operated since 2001 on average), corresponding to an average remaining lifetime of 18 years (to 2037). Mexico and Argentina lead the natural gas capacity with 44 GW and 23 GW, respectively. For coal, Mexico and Chile have most of the capacity with 6 GW and 4.9 GW, respectively. Brazil and Mexico lead oil capacity with 11 GW and 6.7 GW, respectively. Figure 1 displays operational and planned capacity by technology in LAC (appendix 3 contains results per country).

Figure 1 displays large quantities of fossil fuel power plants, particularly based on natural gas to come online between 2019 and 2022. The peak in 2022 is a result of the entry into operation of the plants which are in bidding process, especially in Brazil (31 GW). If instead of filling up the missing date of commissioning based on averages at country, technology and unit status level, we would have used a distribution of entry dates, this peak would be smoothed over time. Also, most plants *under construction* or *authorized* in the ENERDATA database report a commissioning date of 2019, which may reflect a bias in the way the data is reported. The peak in 2019 is further influenced by our decisions to 'correct' to 2019 the commissioned date of units that appear as 'planned' but with a commissioning date in the past in the PPT. None of those peaks affect our estimates of total committed emissions.

The PPT reports 456 planned fossil-based generators, summing to 102 GW or 61% of current fossil-fueled capacity in the region. Most planned fossil fuel power plants are natural gas plants (87 GW), followed by coal, peat and oil shale (13.5 GW) and oil (2.1 GW). Brazil leads the fossil-based pipeline, with 38 GW of natural gas, 4.8 GW of coal, and 0.9 GW of oil. Mexico and Chile have in their planned pipelines 22 GW and

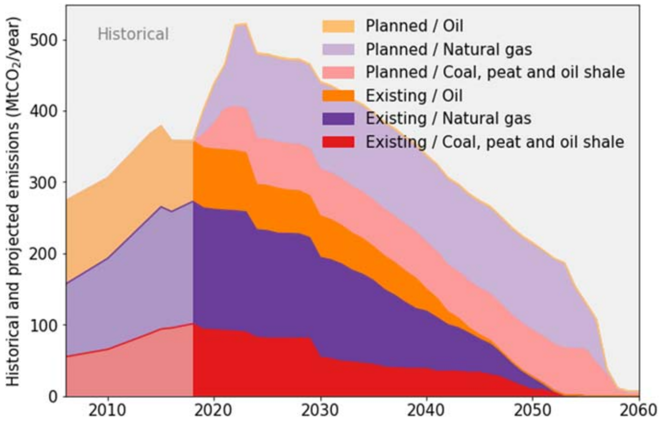


Figure 2. Historical and committed emissions (operational and planned plants). Under normal conditions, the last operational unit would operate until 2054. The last unit in the current planned pipeline would operate until 2064. Dark colors indicate operational status, while the planned pipeline is displayed in light colors.

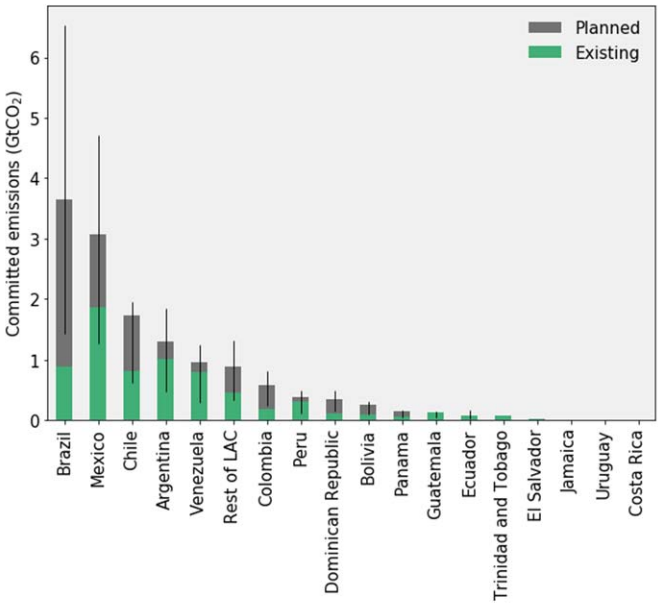


Figure 3. Committed emissions from existing and planned power plants by country (2019–2064). Error bars represent results of the sensitivity analysis described in the section 3.3. The minimum values correspond to estimates done from ENERDATA emission assessment and 15 years lifetimes, and the maximum values correspond to IEA data and 50 years lifetime assumptions.

6.7 GW of natural gas capacity, respectively. Committed emissions from the pipeline are dominated by natural gas (63%), followed by coal (26%).

In terms of committed emissions, we find that the continued operation of existing capacity over its remaining lifetime at current utilization rates would result in 6.9 $GtCO_2$ of emissions through the coming decades. Most committed emissions from operational generators in LAC come from natural gas (52%). This contrasts with the global situation, where coal generators are the main contributors of committed emissions (Pfeiffer *et al* 2018).

Figure 2 shows projected emissions through time by fuel and status (appendix 3 shows projections by country). Projected emissions increase at an average annual rate of 13% between 2018 and 2030 as planned power plants are built and start to operate. Meanwhile, projected emissions from the operational plants decrease at an average annual rate of 2.9% as existing plants reach the end of their lifetime and are decommissioned. Additions to the capital stock are higher than retirements over this period. Committed emissions from operational generators decrease to zero by 2054, as the last planned generator will start to operate in 2030. In total, building all planned power plants would add 6.7 $GtCO_2$ of committed emissions.

Figure 3 provides details of committed emissions from both existing and planned power plants by country. Mexico, Argentina, and Brazil lead committed emissions from operational generators, at 1.8, 1 and 0.9 $GtCO_2$, respectively. If planned plants are built, Brazil would become the top contributor to committed

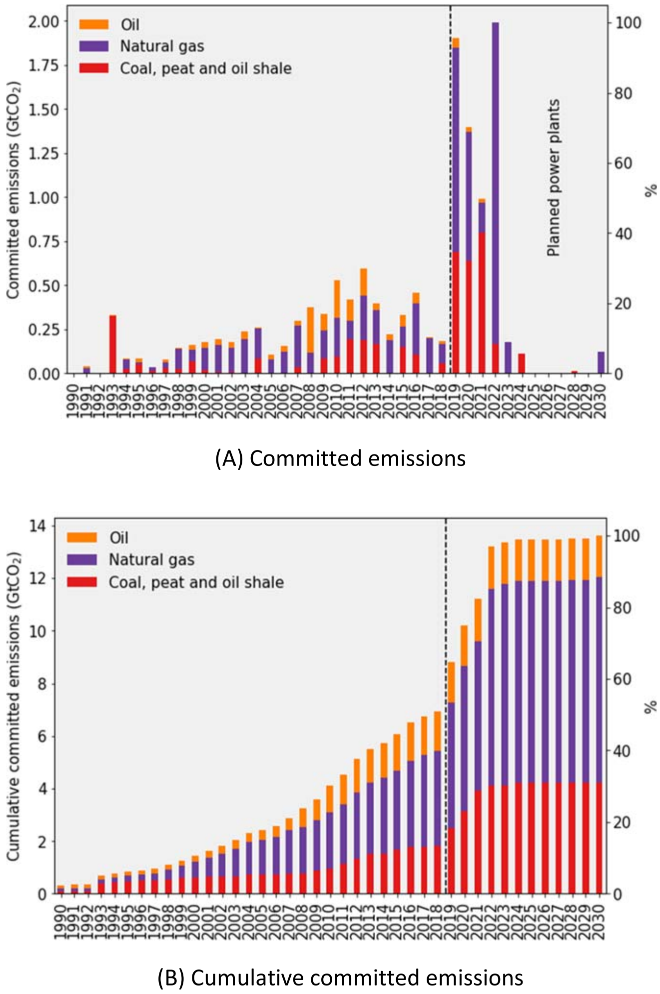


Figure 4. Committed emissions by fuel and year of commissioning. (A) Remaining committed emissions in 2019 grouped by the date when existing power generators where built. (B) The same information cumulatively.

emissions in the region, with 2.7 $GtCO_2$, almost tripling committed emissions from its operational generators. Mexico would add 1.2 $GtCO_2$; Chile would add 0.9 $GtCO_2$ and become the third largest committer in the region. Brazil, Colombia, and Dominican Republic are the countries where building the planned plants add most emissions relative to committed emissions from operational plants (at 3.1, 2.1 and 1.8 times the operational committed emissions, respectively, while the average among other countries is 0.6). If both Brazil and Colombia's committed emissions from planned power plants where only 60% of committed emissions from existing power plants, committed emissions from planned power plants in the region would sum to 4.3 $GtCO_2$ (and total committed emissions would sum to 11.2 $GtCO_2$).

Figure 4 shows the same information by year of commissioning and fuel (see appendix 5). Each bar in figure 4(A) corresponds to committed emissions from power plants added at a specific year in the past. Committed emissions added by the generators in operation in the 90s come primarily from coal. In LAC, natural gas started to gain importance in the late 90s and it turned into the main contributor of committed emissions from 2001 onward. Figure 4(B) plots the same information in a cumulative fashion. It shows that while committed emissions have roughly grown linearly over the last two decades, building all the power plants that appear as *planned* in the PPT would roughly double committed emissions in only four years. (Again, our assessment does not feature a prediction of how much of the units planned in the PPT will be actually built.)

Committed emissions from plants under construction and bidding status sum 4.3 $GtCO_2$, while authorized and announced would add 1.4 $GtCO_2$ and 0.9 $GtCO_2$, respectively. More than half (62%) of committed emissions from planned power plants come from natural gas generators, which would add 4.2 $GtCO_2$. The largest chunks would be added by Brazil (1.9 $GtCO_2$) and Mexico (1.1 $GtCO_2$). This finding is consistent with previous results putting into question the fitness of building new gas power plants in the region as part of a strategy to reduce emissions and comply with the Paris Agreement (Binsted *et al* 2019): while gas power plants do reduce emissions when compared to diesel or coal power plants, they still results in more emissions than what seems consistent

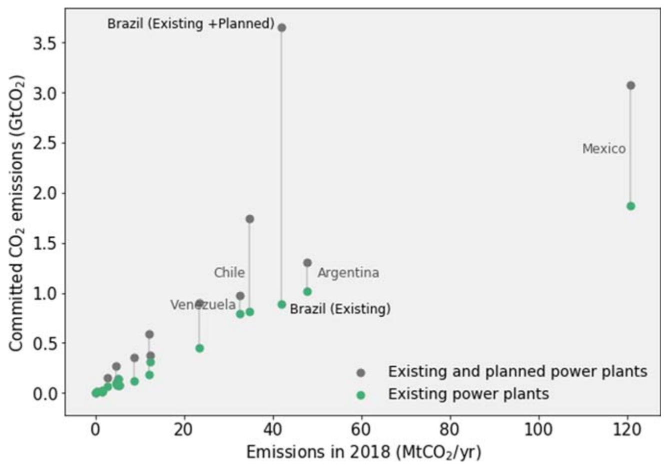


Figure 5. Emissions in 2018 versus total committed emissions. Dark dot indicates committed emissions from existing and planned power plants, while existing power plants are displayed in light colors.

with the achievement of the global temperature targets.

Building all planned power plants in LAC would add as much emissions as what all existing plants would emit over 28 years. Cancellations of planned natural gas power plants would result in a reduction of 31% of total committed emissions. Canceling all the planned coal generators (which add 2.4$GtCO_2$) would represent a reduction of 18% of total committed emissions. Replacing all the planned coal power plants by planned natural gas power plants would reduce committed emissions from planned power plants by 1.4 $GtCO_2$, or 10% total committed emissions.

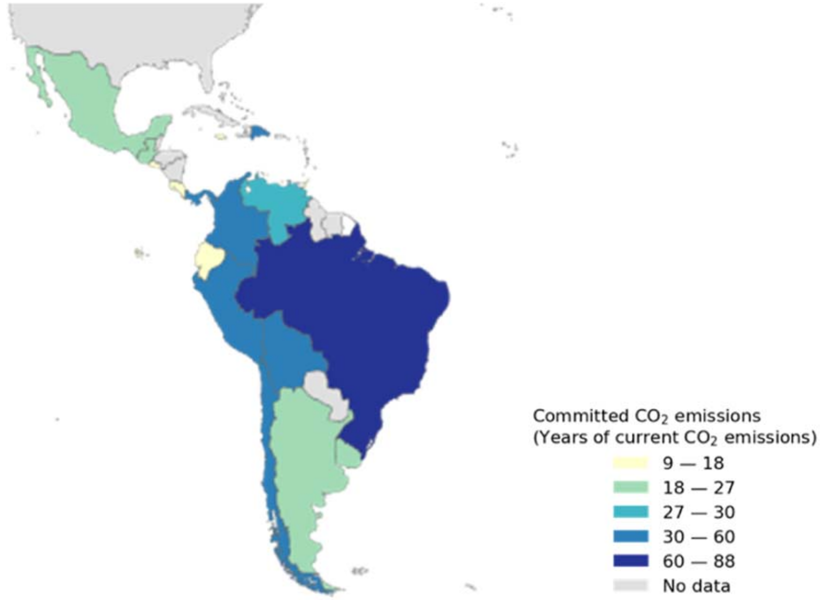
Our finding of 6.7 $GtCO_2$ is slightly higher than, but close to the 6.0 $GtCO_2$ reported by Pfeiffer *et al* (2018) for planned fossil fuel generators in LAC. We interpret this closeness as a sign of the robustness of the approach. This small difference could come from more projects being planned between the moment Pfeiffer at al collected their data and January 2019, and when we collected ours in January 2019. Unfortunately, the databases used in both studies are paywalled, and our data does not contain a date when projects where announced, so we cannot verify that. The difference is small enough that part of it could also come from different gaps in the data. Pfeiffer *et al* merge five databases for generators allocating in the planned pipeline the generators under construction or planned statuses in early 2017. They use emission factors from individual fuels and historic heat rated from the IEA. Conversely, we use the PPT database comprising the planned pipeline to announced, authorized, bidding process and under construction statuses in early 2019. We calculate emission factors from the country dashboard from ENERDATA (2019a).

Figure 5 plots committed emissions against current emissions. For instance, the green dots on the right indicates that Mexico today emits 120 $MtCO_2\,yr^{-1}$ from the power sector. But existing power plants will emit about 1.8 $GtCO_2$ over their lifetime and adding planned power plants would bring this number to 3 $GtCO_2$. The Brazilian case is the most contrasting. Today, Brazil emits 42 $MtCO_2\,yr^{-1}$. However, committed emissions from existing plants will be 0.9 $GtCO_2$ over their lifespan. This number will scale up to 3.6 $GtCO_2$ if the planned power plants are fully implemented. In other words, committed emissions from existing and planned generators in Brazil represents 87 years of CO_2 emissions. Map 1 shows that Brazil is the most extreme case according to that metric. On average in the region, committed emissions from existing and planned power plants sum to 34 years of current emissions.

As committed emissions would grow if planned power plants are built, so would the average carbon content of electricity. Table 4 shows the carbon intensity of electricity generation of the top four countries CO_2 emitters in LAC in 2012 (OECD 2015) 2018 (ENERDATA 2019b) and 2030. We calculated the electricity output from the full set of operational and planned technologies (both renewable and fossil fuel) based on PPT capacities and the ratio between current electricity and capacity (ENERDATA 2019b). If the planned plants are fully implemented in Brazil, the carbon intensity of the electricity would be 134$gCO_2\,kWh^{-1}$, which is 61% higher than the current intensity.

3.2. Compatibility of the capital stock with remaining carbon budgets

Figure 6 shows the range of carbon budgets for the LAC power sector computed from the pathways gathered in Huppmann *et al* (2018a), using the same grouping as in table 2. The central line in the boxplot shows the median budget in that group, the rectangle shows the interquartile range, and the whiskers extend to the full range. In the scenarios compatible with 1.5 °C, gross carbon budgets range from 1.1 $GtCO_2$ to 13.5 $GtCO_2$, with an average of 5.8 $GtCO_2$. In the scenarios compatible with 2 °C, gross carbon budgets



Map 1. Committed emissions from existing and planned power plants per country, expressed as years of current emissions from the power sector.

Table 4. Carbon intensity of electricity generation ($gCO_2\ kWh^{-1}$).

Country	OCDE (2015)	ENERDATA (2019a, 2019b), base year–2018	Own projection (2030)
Brazil	55	83	134
Mexico	549	384	265
Chile	444	771	740
Argentina[a]	NA	353	297

[a] The report includes 41 OECD countries, Argentina was not reviewed in this report (OECD 2015).

range between 1.7 $GtCO_2$ to 16 $GtCO_2$, with a mean of 6.2 $GtCO_2$.

Committed emissions from existing generators (6.9 $GtCO_2$) are thus within the range of LAC power carbon budgets consistent with 1.5 °C–2 °C. However, they are above 60% of 1.5 °C-compliant carbon budgets reported in the IPCC database, and above 50% of 2 °C carbon budgets. If all planned power plants are built, the committed emissions would surpass 85% of the carbon budget scenarios consistent with 2 °C and all the scenarios consistent with 1.5 C.

These results suggests that, if the temperature targets of the Paris Agreement are to be achieved, roughly[16] 52%–55% of existing and planned fossil-fueled power plants in Latin America will need to be underutilized, retired early, or retrofitted with expensive CCS or efficiency upgrades.

[16] We simply report the ratio of committed emissions to the average carbon budgets, minus 100%.

3.3. Sensitivity of findings

We conduct a sensitivity analysis to assess the extent to which our conclusions depend on our lifespan and emission factor assumptions.

The lifetimes we used are calibrated from typical historical averages. In the private sector, payback times can be shorter than technical lifetimes. For instance, contractual terms in LAC auctions vary from 15 to 30 years, with most of countries adopting a contract term of 20 years (Mejdalani *et al* 2019). If power plants are used only during the typical time required for financial profitability, committed emissions would be lower. To quantify that and provide a lower bound to our estimates of committed emissions, figure 7 compares the results of committed emissions using a lifespan range between 15 and 50 years in order to perform but only technical lifespan but also shorter payback times and contractual terms in auctions.

With lifetimes of 15 years, for instance, committed emissions from both existing and planned plants would be much smaller (5.3 $GtCO_2$, 40% of our best guess estimate). In fact, they would be below our estimate of committed emissions from just existing power plants used during the typical lifetimes (6.3 $GtCO_2$), and average carbon budgets from IPCC. However, committed emissions from existing generators (2.8 $GtCO_2$) would still be above 20% of 1.5 °C–2 °C-compliant carbon budgets, and adding planned power plants would surpass 50% of the carbon budgets consistent with 1.5 °C or 2 °C.

We also test different data sources. We run a simulation using emission factors calculated with the CO_2 emissions from *Electricity and heat production* from (IEA 2018b) and *Electricity output from electricity power plants* from the energy balances (IEA 2018a) instead of

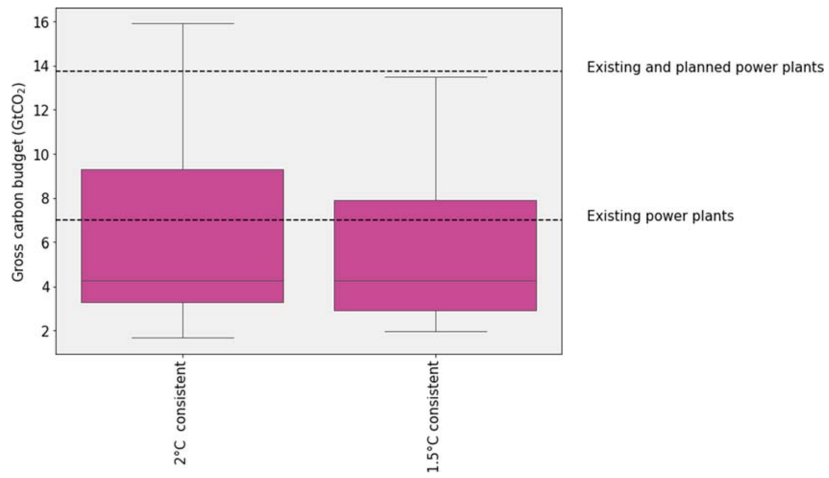


Figure 6. Comparison of our central estimate of committed CO_2 emissions in the LAC power sector (dashed lines) with the distribution of carbon generation budgets for the LAC power sector computed from the emission pathways reported in the IPCC 1.5 °C report.

ENERDATA. Using data from the IEA (and back to long our central estimates of lifetimes), committed emissions from both operational and planned pipeline jump to 13.6 $GtCO_2$ to 17.52 $GtCO_2$ (+29%), reflecting perhaps the inclusion of 'heat generation' in the scope of carbon emissions. Using the IEA as a data source would thus increase our estimate of the amount of asset stranding required to meet the average carbon budget from the IPCC.

In light of the results of our sensitivity analysis, we find recent results by Tong *et al* (2019) for the LAC power sector to be high. They find 14.3 $GtCO_2$ committed just from existing power plants. One reason is that they use 40 years lifespan for all power plants, while we use 32–37 years. When using 40 years lifespan and data from the IEA to calibrate carbon emissions (as they do), we find that existing power plants in LAC commit a total of 10.5 $GtCO_2$ (figure 7). In addition, they assume a flat utilization rate of 53%, while we compute implicit utilization rates at the country and fuel level based on historic data (equation (1)). Using a flat 53% rate across countries and fuels, we find 11.4 $GtCO_2$. We interpret the remaining difference as evidence that the database power plants that Tong *et al* use contains more power plants than Enerdata's (both papers use paywalled databases, making a bottom up comparison difficult). More importantly, our results concur with their conclusion that the existing stock of power plants is too large when compared to carbon budgets consistent with the Paris temperature targets. Our paper is the first to reach this conclusion at the region and sector level, comparing committed emissions with carbon budgets for a particular region and sector.

4. Discussion and conclusion

Our comparison of committed emissions from existing and planned power plant and total emissions in IPCC scenarios provide a crude quantification of the possible disruption to plant owners, workers, and communities that may happen during a transition to clean electricity consistent with the Paris Agreement targets. They do not quantify a fraction of power investments that would turn out to be net losses for their owners from a financial perspective (Vermeulen *et al* 2018)—this would require much finer data on the cost of building power plants (including terms of financing and tax structures), the cost of operating those power plants (including data on wages and fuel costs accounting for any energy subsidy or tax), and revenues from using them (including electricity wholesale prices), which we do not have access to. Lower utilization rates do not necessarily mean lower economic returns. Even at lower utilization rates, the price of power generated by fossil fuel power plants, and the value of the power reserve they may be able to provide are important parts of the equation.

Notwithstanding those limitations, our results illustrate how international climate change commitments matter to energy infrastructure planners even in developing countries with low baseline emissions. Today the power sector in LAC only emits 357 $MtCO_2$ per year, but implementing the totality of fossil-fueled power expansion projects reflected in ENERDATA's Power Plant Tracker would commit 6.7$GtCO_2$, or 46 years of emissions. We find that 10%–16% of existing fossil-fueled power plants in the region would need to be stranded to meet average carbon budgets from IPCC. More than half of those commitments come from new planned power plants. If the planned power plants are fully implemented, the need of stranded assets to meet average carbon budgets from IPCC would range between 52% and 55%.

Ultimately, assessing the compatibility of any fossil fuel power plant addition with the temperature goals of the Paris Agreement is necessarily more complex than the simple assessments presented in this paper.

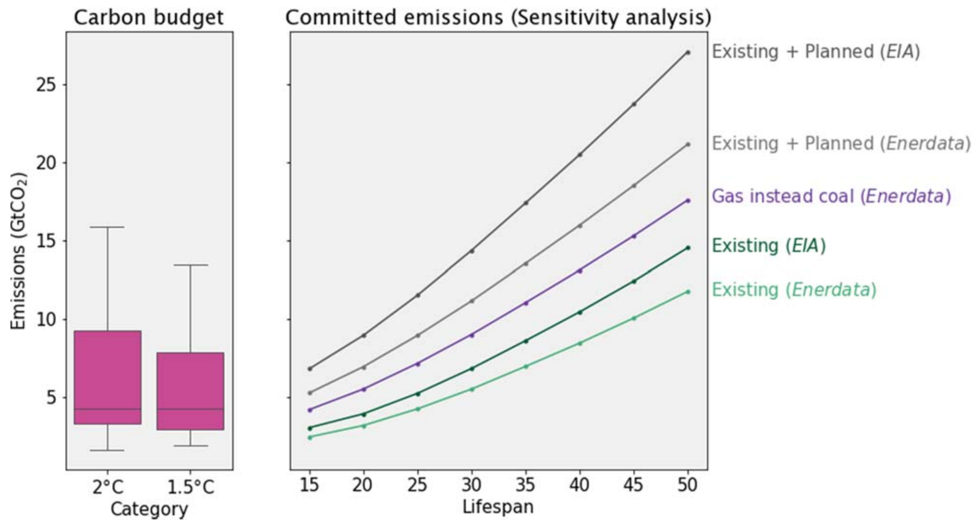


Figure 7. Sensivity analysis of committed CO_2 emissions from existing and planned power plants in LAC (life spans ranging between 15 and 50 years and emission factors from ENERDATA and EIA).

The key for governments to do so might be to develop domestic long-term power generation development strategies that start from the goal of achieving net zero carbon power generation by 2050, and work backward to establish sectoral roadmaps towards that goal (Fay *et al* 2015, Pathak 2017, Binsted *et al* 2019, Waisman *et al* 2019). Countries in the region and internationally have already started using such tools to decide on the expansion plans and the scheduled decommissioning of existing coal power plants, taking into account social, technical and economic impacts of doing so (O'Ryan 2019, Wacket 2019).

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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