Determinants of sectoral effective carbon rates on energy use *

Hildegart Ahumada (Di Tella University)

Santos Espina Mairal (FIEL)

Fernando Navajas (FIEL and University of Buenos Aires)#

Alejandro Rasteletti (Inter American Development Bank)

August 29, 2022

Abstract

We extend the measurement of effective carbon rates, adapting the OECD methodology (OECD-ECR, 2019, 2021), to 18 countries in Latin America and the Caribbean (LAC) for 2018, starting from energy balances and revising comprehensively the level and structure of excises and carbon taxes across countries and accounting for specificities in the emission structure (eg biofuels) and the existence of energy subsidies, all that quite differ from OECD patterns. This allows us to build up a sample of 66 countries (which includes some Asian and African countries also captured by OECD estimates) across 6 sectors and document stylized facts about the sectoral and aggregate level and structure of carbon pricing. Such facts show a biased structure of taxation towards road transport (which has a genesis, decades ago, different from the sole objectives of carbon taxation). This motivates an econometric modelling strategy where we first account for the determinants of economy-wide effective carbon rates (ECR) and then explain differences in road transport and the rest of sectors across countries with an automatic, machine learning model selection and using large set of potential explanatory variables that cover different structural, economic and institutional dimensions. Fiscal variables such as proxies for the marginal cost of public funds are important determinants of ECR in the road transport sector, as expected from the genesis of fuel excises. Emission trading systems tend to increase the value of ECR, while the same does not happen for carbon taxes suggesting that the later are introduced in a reform that substitute for excises. We document that LAC has a lower ECR and that energy subsidies are relevant in changing results only for some countries. However, we find that LAC does not depart from the model estimated for the whole sample insofar the main determinants of ECR. The exception are ETS since these are not observed in LAC, suggesting there might be an avenue for improving ECR by the introduction of ETS in some LAC countries.

Keywords: Carbon pricing, effective carbon rates, energy taxation

JEL class. numbers H23, Q54

---

* Paper to be presented at the GCET23, University of Parma, Italy; the LVII annual meeting of the AAEP, University of Cordoba, Argentina and the 8 ELAEE/IAEE Latin American energy economics meeting, University TADEO, Bogota, Colombia.

Corresponding author navajas@fiel.org.ar

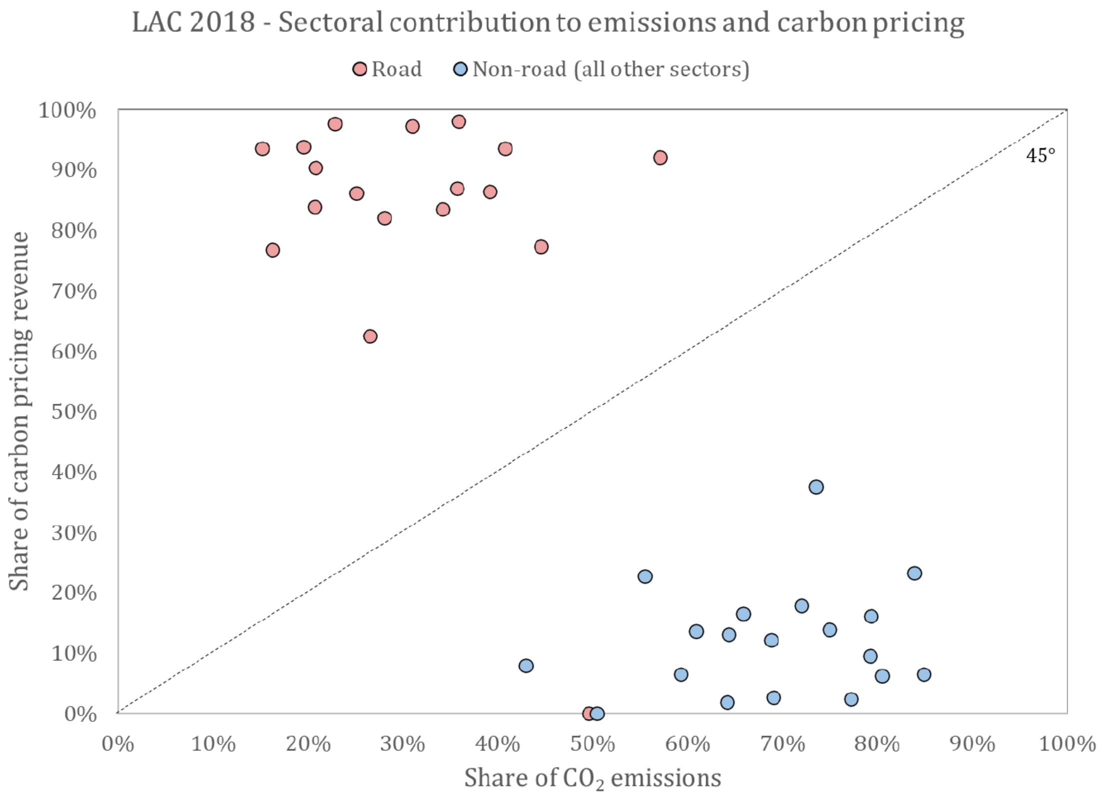
Determinants of sectoral effective carbon rates on energy use

1. Introduction

This paper starts with an effort to extend the measurement of carbon pricing in Latin America and the Caribbean (LAC), supported by an already standardized methodology applied to a group of countries monitored by the OECD (see OECD, 2019, 2021). The methodology is based on detailed studies of a broad and at the same time sectoral measurement of taxation on energy use (OECD, 2019a) where the bulk of carbon emissions come from, understanding taxation in a broad sense as the sum of three mechanisms or instruments. In the first place, due to their relative importance, we have indirect taxes (excises or so-called specific taxes) which already have a long history and recognition as elements that act "as if" they were "environmentally related" taxes, despite the fact that their initial or later objectives may have been different (see Barde and Bratheen, 2005 for the OECD and Navajas *et al* 2011, 2012; and Conte Grand, Rasteletti and Muñoz, 2022 for LAC). Excises on fuels for road transport have historically been, and still are, the main driver of these environmentally related taxes. Secondly, there are explicit carbon taxes that the countries have decided to incorporate particularly on energy use and that have a differential impact on the sectors, either through differential rates or exemptions. Thirdly, the OECD methodology incorporates into the definition of "effective carbon taxes" the prices resulting from market mechanisms such as emission trading systems (ETS), thus completing the "tripod" on which the estimation methodology is based. These three mechanisms that add up to define effective rates to carbon are applied according to this methodology to a sectorial classification (road transport, other transport, industry, agriculture and fishing, residential and commercial energy use, and the electricity sector). This allows weighting (based on the use of energy from the energy balance data that the IEA of the OECD has managed to standardize for these sectors, see IEA, 2021) the different effective carbon rates of the sectors to measure differences among sectors and instruments and arrive at an aggregate measure of the effective rate on carbon in a given country. This measure, in turn, allows computing the existing gap between the countries' effective carbon rates and a reference benchmark, which results in how far countries are from that benchmark and which sectors explain these differences.

The extension of this methodology to the case of LAC seems important for several reasons, ranging from the level and structure of energy use and emissions to different taxation structures and more pervasive use of energy subsidies in many countries. There is a group of the largest countries in the region (LAC 5 or Argentina, Brazil, Chile, Colombia and Mexico) that are already surveyed by the OECD and among them there are 4 countries of this LAC5 mentioned above (Argentina, Chile, Colombia and Mexico) that have carbon tax mechanisms. None of them have adopted general or sectoral emissions trading mechanisms, although Chile and Colombia are studying this mechanism for the future electricity sector and Mexico has a pilot experience for other sectors. In short, LAC is biased in terms of carbon prices and specific taxes on energy towards fuels in the transport sector, something that also occurs globally, but to a lesser extent. Figure 1, based on our estimates, shows how biased is the sectoral structure of carbon pricing in LAC, a fact that is common to OECD economies and also motivates the econometric modelling and reform direction debate insights obtained in this paper. Road transport faces the brunt of current carbon pricing while having a smaller part of the share in emissions compared to the aggregate of other sectors with very low effective rates on carbon emissions.

Figure 1



Much of the pattern shown in Figure 1 is explained by the fact that most of what we term effective carbon rates are excises that had a genesis quite different from environmental (not to mention climate change) objectives, where taxation of fuels used in transport played a major role in providing fiscal revenues and financing sources of transport infrastructure. Models that explain observed tax structures in more positive than normative terms provide a rationale for these observations (see for example, in general terms, Becker, 1983 and Kanbur and Myles, 1992; applied to environmentally related taxes, Navajas *et al*, 2012; applied to fossil fuels taxes and subsides, Mahdavi *et al*, 2022). Looking at observed sectoral effective carbon rates as coming from a previous status quo has a great advantage in terms of both explaining their current determinants and understanding the direction of reforms, being extending a carbon tax to all sectors or using emission trading systems in certain critical sectors. This paper is related to this literature as it estimates and recognizes a status quo of effective carbon rates that respond to a previous interest group equilibrium and needs to progress towards a new rationale based on cost effective climate policy.

The structure of this paper follows from our work to extend ECR measurement to LAC, to explaining the determinants of observed sectoral ECR, and to discuss desired or reasonable direction of reforms. In Section 2 we briefly describe the methodology we use to extend the OECD framework to LAC data. , with Appendix A providing some details and references to our database, which is available upon request along with a large annex, including country specific notes. All our estimates will refer to 2018 as this is a year where a whole OECD dataset was available at the time of writing this paper and best correspond to our own estimates of energy subsidies in LAC. Section 3 deals with observed differences among LAC countries and in relation to OECD countries both in terms of levels and the sectoral structure of ECRs. In Section 4 we report our estimates that depart from the more general OECD methodology and incorporate energy subsidies, observing the effects they have on the economy-wide level of effective carbon pricing in LAC. Section 5 presents our econometric approach to modelling the determinants of observed sectoral ECR in our sample of 66 countries which include OECD, LAC and Asia countries. We separate our econometric analysis in three models. The first is a study of determinants of economy-wide ECR. The second looks at the determinants of ECR in road transport. The third studies a panel of 5 sectors for the 66 countries estimating the determinants of ERC in sectors other than road transport. In all cases we search for differences in LAC vs OECD both in levels and in the interaction with determinants. We also study the effects of energy subsidies in an economy-wide cross section of ECR looking for their relevance both in redefining the dependent variable (ECR adjusted for subsidies) and in their likely effect on non-adjusted ECR. Section 6 briefly reports the variable definitions used in our regressions while Section 7 reports all results. Section 8 explore the relationship between emissions and ECR in our data. Section 9 concludes and suggests further research avenues.

2. Extending sectoral ECR to LAC: Methodology and Measurement

Pricing greenhouse gas emissions is part of a broader climate change mitigation policy. Emissions prices, through taxes or tradable emission permits, encourage emitters to look for profitable reduction options. Prices also signal strong political commitment, creating certainty for investors that carbon-neutral technologies are worth investing in. Carbon prices are effective in reducing emissions because they increase the price of carbon-based energy, thereby lowering demand (Arlinghaus 2015; Martin et al. 2016). Carbon pricing encourages substitution to less carbon-intensive forms of energy and reduces overall energy demand. Taking electricity generation as an example, producers can switch from coal or natural gas to non-carbon energy sources such as solar and wind power. In addition, where the market structure and regulation allow, electricity producers pass on the increased production costs resulting from electricity carbon prices to consumers, in the form of higher electricity prices, and this encourages consumers to reduce consumption. For example, businesses and households may be more vigilant in turning off appliances when they are not in use or may use them less, and may choose more efficient appliances at the time of replacement. Carbon prices are a profitable policy tool and this makes them attractive compared to other policy options (Metcalf, 2019, 2020). The appeal is due to three reasons. First, emitters have an incentive to reduce emissions as long as it is cheaper than paying the price, and this equalizes the marginal abatement costs on emitters, ensuring profitability across the economy. Second, carbon prices decentralize abatement decisions, thereby overcoming the information asymmetry between government and polluters: regulators do not need to stipulate which emissions must be reduced using which technologies. Third, they provide a continuing incentive to reduce emissions, thus stimulating innovation.

ECR/OECD Methodology

The OECD methodology is based on a tripod of three elements that define what constitutes the effective tax on carbon emissions. Effective carbon charges are the full price that is applied to CO_2 emissions from energy use as a result of market-based policy instruments. They are the sum of taxes and tradable emission permit prices, and have three components: first, specific taxes on energy use (mainly consumption taxes), which are normally set per physical unit or unit of energy, but which can be translated into effective tax rates based on the carbon content of each form of energy; second, carbon taxes, which typically establish a tax rate on energy based on its content, and third, the price of tradable emission permits, regardless of the permit allocation method, which represents the opportunity cost of issuing an extra unit of CO_2. The effective carbon rate measures how policies change the relative price of CO_2. As we will see later, the evidence of the application of this methodology (OECD, 2021) shows that for the whole of the sample of 44 OECD countries (where 5 countries of the region are located), the “excises” or taxes specifically explain 89% of the carbon price structure while carbon taxes and ETS explain 4% and 7% respectively. In the case of the LAC5 sample contained in this sample, the role of energy taxes is even greater, due to the lower incidence of carbon taxes (in force in 4 of the 5 countries, excluding Brazil) and due to the non-existence of emissions market prices at the time (beyond the fact that there are initiatives to study and explore ETS in at least 4 countries). The importance of ETS in the participation of carbon prices has increased in recent years due to the operational reforms of the main ETS market, which is the EU ETS and of which a significant group of the sample of countries of the EU is part. The significant rise in the market prices of the EU ETS after the 2018/19 reform and the introduction of ETS mechanisms in China explain why the ETS have increased their participation, especially if we look at their contribution to the increase in effective rates to carbon in recent years.

The three pillars or components of the effective carbon rates are translated into monetary units (Euros) that are applied on a homogenized tax base of energy uses at the level of sectors defined in advance for the purposes of international comparison and that are 1) road transport, 2) other forms of transport (off road transport), 3) industry, 4) agriculture and fishing, 5) residential and commercial sector, 6) electrical sector. This base comes from the extensive compilation of energy balances carried out by the IEA (2021) and known as Extended World Energy Balances (EWEB) that homogenizes the use of energy in common units (TJ, Tera Joules) and is accompanied by conversion matrices of units for each country, which relate commercial units on which taxes are defined with those common units. Conversion factors are then applied to link these homogeneous units with the corresponding carbon emissions associated with energy use and establish the effective carbon rate based on the three components mentioned. There is then a well-established link between the report on effective carbon taxes (OECD-ECR 2019, 2021) and the report on taxes on energy use (Taxing Energy Use (TEU), OECD-TEU, 2019). In turn, the TEU report provides files by country that explain the basis on which taxes on energy use are measured. This combines the information from the EWEBs and their conversion matrices with the taxes that are legally charged on the use of energy in the countries.

As we can see, the OECD methodology has two salient features. The first is that it focuses on emissions from energy use due to the most rigorous possible homogenization between countries provided by the EWEB base. This is what is called a combustion approach to energy. This leaves out emissions associated with activities other than energy use that we know are important in various sectors, such as agriculture and industry. Nor does the OECD methodology follow a life cycle approach or "footprints" of emissions, which in the case of biomass (or rather the production of biomass for the production of fuels or biofuels) is relevant. These differences (whether it is about emissions associated with the use or combustion of energy or that the impact of that combustion is looked at and not the previous life cycle) means that the data from the methodology of emissions of effective rates to carbon of the OECD is not comparable with UNFCCC accounting (which also includes greenhouse gases other than carbon). This is particularly so in the case of biomass, which is why the OECD also reports data excluding biomass to maintain a more homogeneous comparability between countries.

The second salient feature of the OECD methodology is that it has an explicit link with the current legal structure of energy taxes in each country. This implies a careful analysis of the tax code in practice, given the exemptions or special treatments that can change the results, and also including adjustments for differences that occur when different levels of government intervene. As the specific taxes on the use of energy are the object of analysis, other indirect taxes such as VAT are obviously excluded, which, although they fall on energy, are of a general nature for all goods. It is different if the VAT has a differentiated structure that gives rise to lower rates (which is the most common case) or higher rates for the use of energy. Value-added taxes affect end-user prices of energy products in many jurisdictions, in addition to the three components of effective carbon taxes. VAT is not usually specific to energy products: as long as the same rate is applied, the relative prices of energy products remain unchanged. In this case, VAT should not be taken into account, since the effective carbon rates measure the policies that modify the relative prices. However, differential VAT rates change the relative prices of energy products and VAT becomes a de facto specific tax measure. The OECD-TEU (2015) provides a general description of the differential VAT rates applied in the countries analyzed. Seventeen countries apply reduced or zero VAT rates to certain energy products. This counteracts the intention to increase the relative prices of energy products to the final consumer and can mitigate or even offset the effective carbon tax, depending on the relative magnitude of the price differentiation introduced by the differential VAT rate and the effective carbon tax. This effect of the differentiated VAT, which acts as a de facto specific tax, is not captured by the calculation methodology of the OECD.

Data and estimates for LAC

To complete our sample, we extended ECR/OECD methodology to 18 countries in LAC. The overlap with the LAC countries where OECD reports ECR (mainly LAC 5 as Argentina, Brazil, Chile, Colombia and Mexico) is useful to evaluate differences with our estimates. For our purposes we started with energy balances. Data from IEA's World Energy Balances[1] was used to assemble country-level detailed energy balances for 2018.[2] Following OECD-TEU (2019) methodology,[3] the Electricity sector was defined as that where primary energy use for electricity generation occurs (including transformation and distribution losses). Non-energy use of fuels was not taken into account in this document. Energy use not assigned to a particular sector (*Non-specified use*) was not included, with the exception of the Electricity sector, where energy is assigned on a primary-use criteria. Industry sector includes electricity generated in autoproducer plants.

Emission factors by fuel type were taken from EPA's 2018 update,[4] where missing data was completed based on EIA[5] and IPCC Emission Factor Database.[6] These were used to convert energy use from country balances (expressed in TJ) into CO_2 emissions. Regarding taxation, the main direct information sources were country-specific tax codes and national legislation (see Country Notes for details and sources). To convert taxed amounts into a common currency (euros), 2018 exchange rates from OECD[7] and World Bank[8] were used.

[1] https://www.iea.org/data-and-statistics/data-product/world-energy-balances

[2] OECD TEU 2019 uses energy balances corresponding to 2016. Despite changes in energy balances being gradual across time, some differences regarding results may be explained by this, as well as on data updates (see, for example, Colombia's country notes).

[3] https://www.oecd.org/tax/taxing-energy-use-efde7a25-en.htm

[4] https://www.epa.gov/sites/default/files/2018-03/documents/emission-factors_mar_2018_0.pdf

[5] https://www.eia.gov/environment/emissions/co2_vol_mass.php

[6] https://www.ipcc.ch/data/

[7] https://data.oecd.org/conversion/exchange-rates.htm

[8] https://data.worldbank.org/

In 2018 Latin America and the Caribbean, only Argentina, Chile, Colombia and Mexico had an operative carbon tax; Mexico included an additional subnational instrument in Zacatecas State.[9] In 2020, Chile and Colombia were studying ETS implementations, initiative also considered in Brazil from 2021 (see World Bank, 2021; ICAP, 2021; Amigo *et al* , 2020). Mexico developed a pilot version of this system since 2020, and also included since 2021 subnational carbon taxes in different States (Baja California, Zacatecas and Tamaulipas, with Jalisco under development). None of these regional inceptive ETS count with reference prices which can be included in the computing of Effective Carbon Rates (ECR).

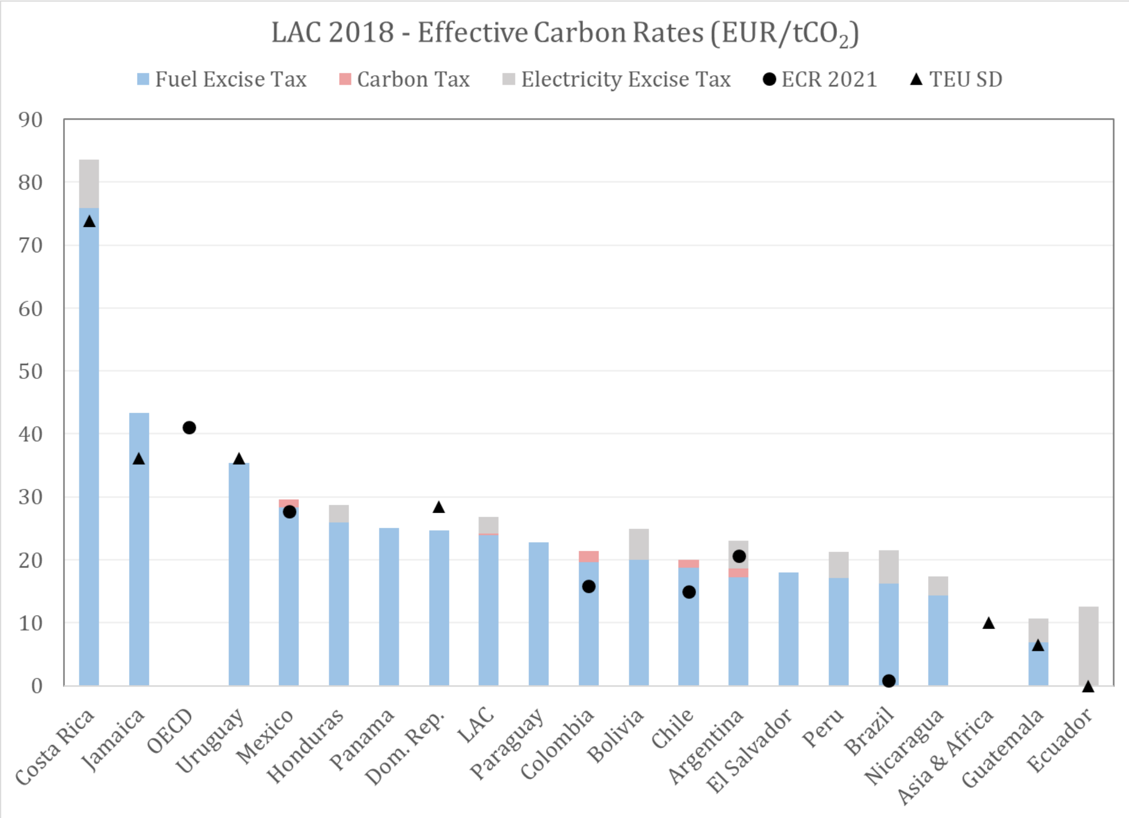
3. ECR in LAC vs. OECD: levels, structures, stylized facts

Our measurement of 2018 Effective Carbon Rates in LAC countries is broadly consistent with existing OECD estimates, and it places most of LAC members below the OECD regional average, as illustrated in Figure 2. Noteworthy exceptions are Costa Rica, that prices CO_2 emissions above the EUR 60 benchmark (OECD, 2021) and ranks above the average OECD member, and Jamaica plus Uruguay, both performing above the EUR 30 benchmark, near the OECD reference mark. Aside from these particular cases, the fifteen remaining countries included in our sample have operative ECRs below the EUR 30 benchmark, where Guatemala and Ecuador stand out pricing carbon below the Asia & Africa regional average at about 10 EUR/tCO_2 (Ecuador in fact lacks a pricing carbon estimate because it places no excises nor carbon taxes on fossil fuels). Thus, the average LAC member would need to approximately double its carbon pricing efforts to catch-up with OECD standards, and apart from counted exceptions most countries fall far behind the low-end benchmark, EUR 30 per ton of CO_2.

On inspection, carbon taxes in LAC countries explain a minimal proportion of ECRs. Operative uniquely in Argentina, Chile, Colombia and Mexico, in none of these countries do carbon taxes contribute more than 2 EUR/tCO_2 to total carbon pricing. For the whole of LAC countries considered, only 1% of carbon prices are explained by carbon taxes, whereas 4% was estimated for the worldwide sample considered in OECD-ECR (2021). Fuel excise taxes thus remain the primary instrument constituting ECRs in LAC, keeping in mind no country had an operative ETS in 2018. This latter observation does indeed distinguish the region from OECD countries, where ETS mechanisms are widespread as a feature of carbon pricing. According to OECD-ECR (2021), permit prices in 2018 accounted for 7% of carbon prices considering the worldwide sample of countries, including those with no ETS on place.

[9] https://carbonpricingdashboard.worldbank.org/map_data

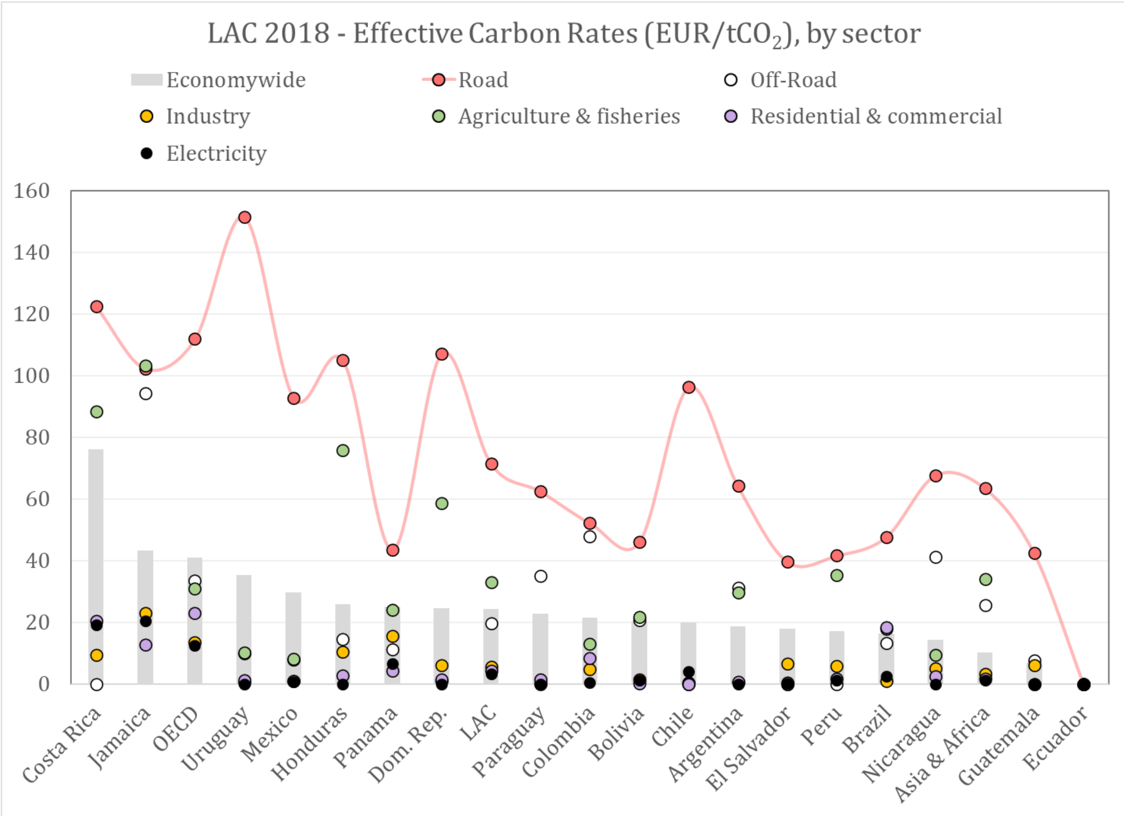
Figure 2



Note: regional averages are unweighted. Asia & Africa includes countries from both OECD (2021) and OECD TEU-SD (2021). Electricity Excise Taxes are shown for reference purposes but are not included in the Effective Carbon Rate definition.

This analysis can be extended from an Economywide, aggregate level to a sectoral representation, acknowledging CO_2 emission contributions from each sector may be priced in a heterogeneous way. Table A1 in Appendix A lists our measurement of ECRs for LAC countries in our sample with sectorial detail. Figure 3 depicts the intersectoral structure of ECRs, where asymmetry is apparent. Emissions stemming from Road transport tend to be priced much higher than those originated in the other sectors, with a sectoral ECR usually above the EUR 60 benchmark or at least well above the EUR 30 benchmark in virtually all LAC countries (apart from Ecuador). On average, the Agriculture & fisheries and the Off-road transport sectors are next in line, although this differs substantially across countries. Lastly, with counted exceptions, Industry, Residential & commercial, and Electricity sectors tend to have the lowest burden in terms of carbon pricing. The average OECD member, in comparison, tends to have a lower carbon pricing intersectoral dispersion than the average LAC member, considering sectors other than road transport.

Figure 3

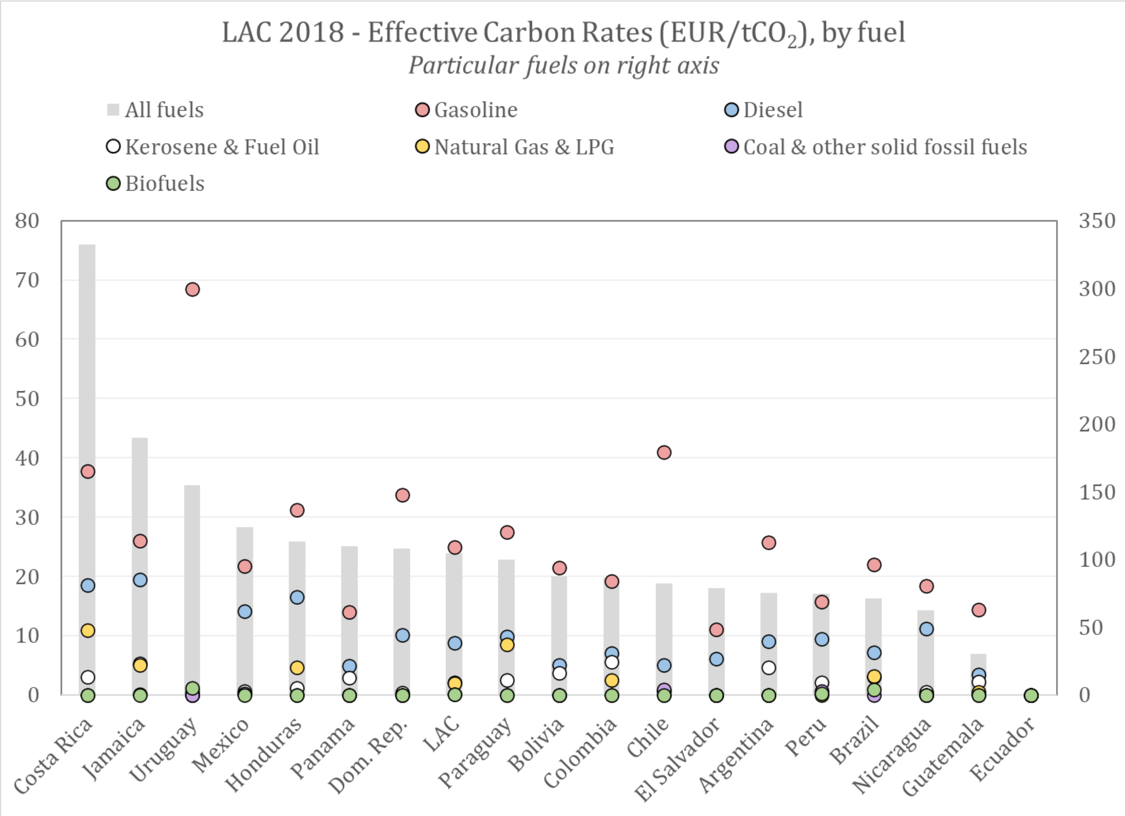


Note: regional averages are unweighted. Asia & Africa includes countries from both OECD ECR (2021) and OECD TEU-SD (2021). Missing sectors correspond to incomplete energy balances.

Altogether, this is consistent with the observation that the road transport sector drives overall ECRs, representing a disproportionate share of related revenues in terms of its contribution to economy-wide emissions. This pattern is consistent across countries and does not appear to be a regional feature of LAC members.

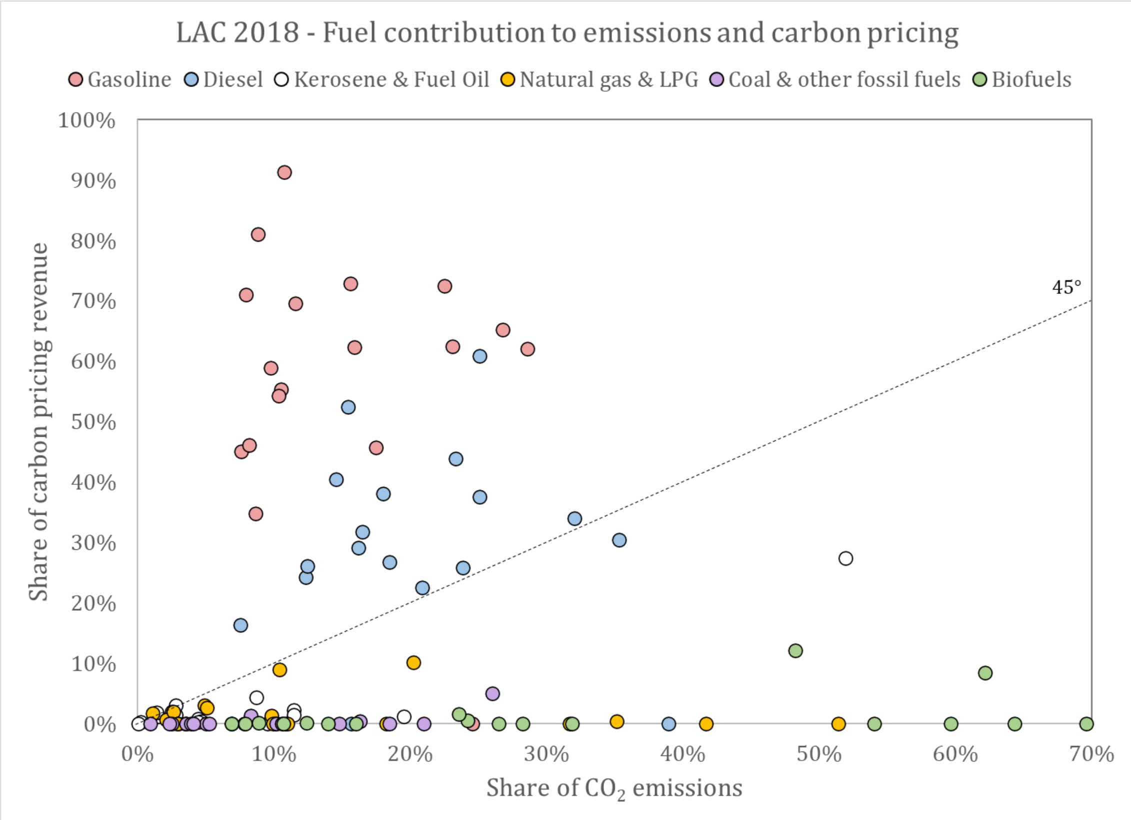
Interestingly, most of intersectoral heterogeneity regarding carbon pricing does not seem to be a consequence of sector-specific special tax treatment (exemptions, rebates, refunds and similar mechanisms). Figure A1 in Appendix A shows that if sector-level tax exonerations are not considered when computing ECRs, the resulting hypothetical increase is far behind from what a catch-up to road transport level would yield. Instead, ECR dispersion across sectors is best explained by examining ECR dispersion across fuels. Carbon pricing heterogeneously distributed across fuels translates into intersectoral dispersion because these enter differentially as inputs in each sector's energy use. Thus, as illustrated in Figure 4, the correlate of Road transport carrying most of the carbon pricing burden is the observation that gasoline and diesel have comparatively high ECRs with respect to other fossil fuels.

Figure 4



ECRs on kerosene, fuel oil, natural gas and LPG vary substantially by country but tend to follow gasoline and diesel in rank, although with no comparable levels. On the other hand, coal and solid fossil fuels in general, as well as biofuels, tend to be almost untaxed. Like in the case of sectors, this arrangement does not follow an ordering derived from fuel contributions to emissions, as depicted in Figure 5. Instead, fossil fuels other than gasoline and diesel can explain significant shares of carbon emissions remaining virtually untaxed. This posits the need for reform regarding carbon pricing across fuels (and thus, across sectors as well). ECRs should converge to homogeneous rates per emission unit or per energy content unit across fuels to align costs of CO_2 emissions and avoid placing incentives on distinct fossil fuels via relative price distortions. Regarding this goal, a critical obstacle for regions like LAC is the structural bias towards untaxed biofuels.

Figure 5



4. Energy subsidies and adjusted ECR

Energy subsidies directed to fossil fuels have remained significant at a global scale and have been pointed out in recent years as a problem for decarbonization (Coady *et al*, 2019; Parry *et al*, 2021). The structure of energy subsidies across regions such as EU and LAC have shown significant differences in both levels and structure with LAC more biased towards subsidies to households and to electricity.[10] Energy subsidies to fossil fuel use operate, in principle and as they alter effective prices, in opposition to ECRs and work as negative taxes on carbon emissions. Carbon pricing may be overestimated if one does not consider the effect of subsidies on energy use, as these can offset the incentives instrumented by excises, carbon taxes and ETS. Adjustment to ECR should ideally proceed in the same bottom-up way as tax rates are measured, i.e. at the sector level of energy used and therefore incorporated in the same way as excises, carbon taxes or ETS prices. This task is rather burdensome and it explains why OECD-ECR (2019, 2021) do not account for subsidies, despite

[10] European Commission (2021) accounts for the level and structure of fiscal energy subsidies (i.e. those registered in budgetary operations and including tax expenditures, that are captured by the ECR methodology) in the EU-27 showing an average of about 1.2% of GDP with large cross-country differences, mostly directed to renewable energy schemes and with fossil fuels accounting on average for about 0.3% of GDP and located in transport, manufacturing and agriculture. Electricity subsidies are a minor part of energy subsidies and subsidies to households explain less than 10% of aggregate subsidies, with this figure changing dramatically in 2022. On the contrary, electricity explains about two thirds of energy subsidies in LAC (on average 0.6% of GDP in a similar budgetary definition), according to FIEL (2020) and households have also a share of 66%.

that some recent effort in OECD TEU-SD (2021) have moved to account for subsidies in a few emerging countries where energy subsidies are important. Another delicate issue is the treatment of electricity subsidies, because electricity consumption does not directly imply emissions. Effects of electricity subsidies on emissions depend on the structure of electricity generation, as they may give rise to an increase in factor demand for fossil fuels that competes with other substitution effects in energy consumption that work in opposite direction by reducing emissions. These difficulties have probably led OECD TEU-SD (2021) assessment to be cautious on adjusting for electricity subsidies.

As we could not work bottom up from subsidy wedges contained in the pricing of sectoral energy use[11], we instead tried to make an approximation at an economy-wide level to the likely effect of energy subsidies on the picture that emerged from our estimation of ECR. We collected data on energy subsidies for countries in our sample and expressed them in comparable units to ECRs (EUR/tCO_2)[12], considering budgetary data for LAC countries from FIEL (2020), and using OECD-TEU SD (2021) and the OECD Inventory of Support Measures for Fossil Fuels as sources for the rest. Regarding OECD Inventory data, which reports budgetary transfers as well as tax expenditures as subsidy mechanisms, we excluded the latter from our analysis because these are already accounted for under the taxing energy use OECD methodology.

In Appendix B we explain in detail our estimation for an adjustment of ECR after fuel and electricity subsidies, that we take separately because of their differences. In the case of fossil fuels use (excluding use for electricity generation) we use estimates from FIEL (2020) for 2018 that are expressed as a percentage of GDP, use nominal GDP values to express them in US dollars, then in Euros and finally expressed then as a ratio of aggregate CO_2 emissions to obtain a proxy subsidy rate for the whole economy. For electricity we took energy subsidies and adjusted by a percentage factor expressing the share of thermal fossil fuel electricity generation (thus for economies with large renewable sectors electricity subsidies do not affect ECR as in those based on thermal generation) and assumed that variable costs of electricity generation associated with fossil fuels were 50%.

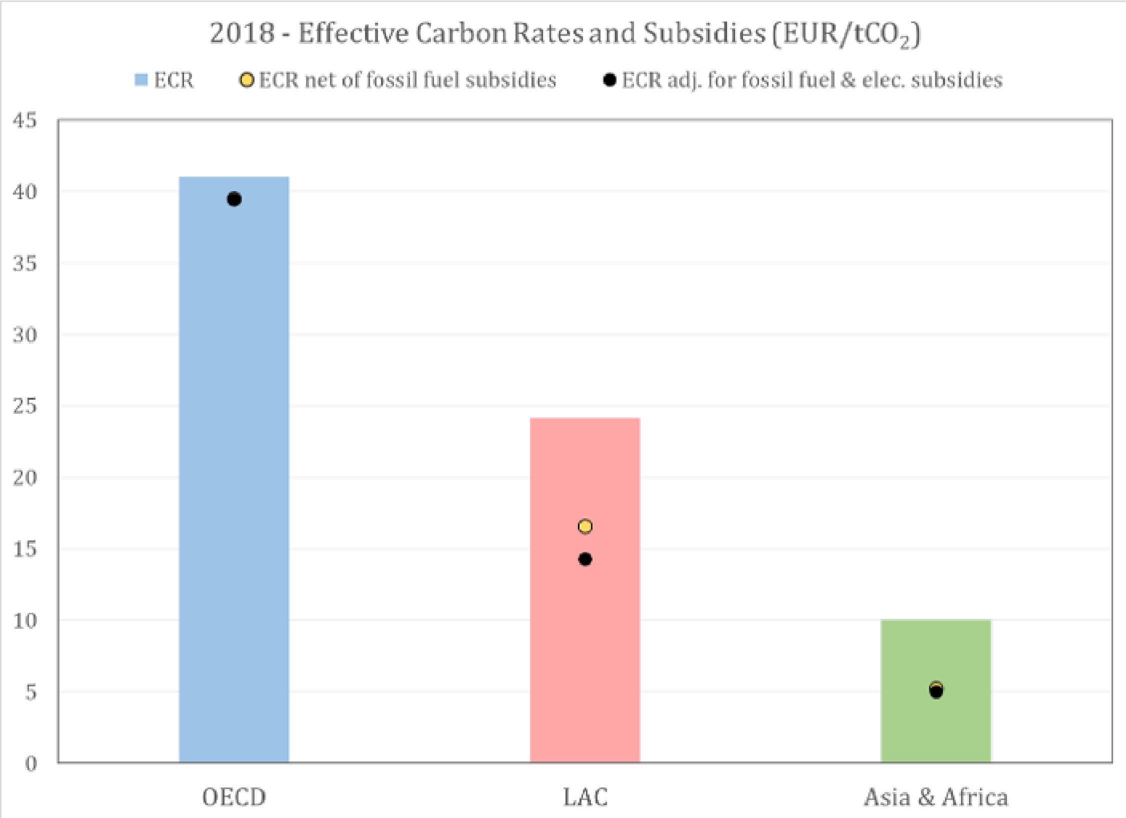
Figure 6 shows the regional averages for ECRs and their adjustments net of fossil fuel subsidies and net of both fossil fuel and electricity subsidies after following our estimation procedure. Because LAC countries place substantial energy subsidies, once their effect is subtracted from ECRs the gap relative to OECD is considerably higher. On average, LAC is the region with the highest subsidies on energy use.

---

[11] We considered using the data template built up by the IMF to assess global energy subsidies, see Parry, Black and Vernon (2021) and links to www.imf.org/en/Topics/climate-change/energy-subsidies. We had however problems with data compatibility with our OECD/ECR methodology. Also, we found some data errors in prices and subsidies reported in IMF data in some cases where we have first source information and experience, such as the case of Argentina, that made us reluctant. Nevertheless, we believe more effort to make these data sets compatible is well deserved.

[12] Emission data and currency conversion factors were taken from the World Bank, except for LAC countries where emissions were computed from IEA World Energy Balances.

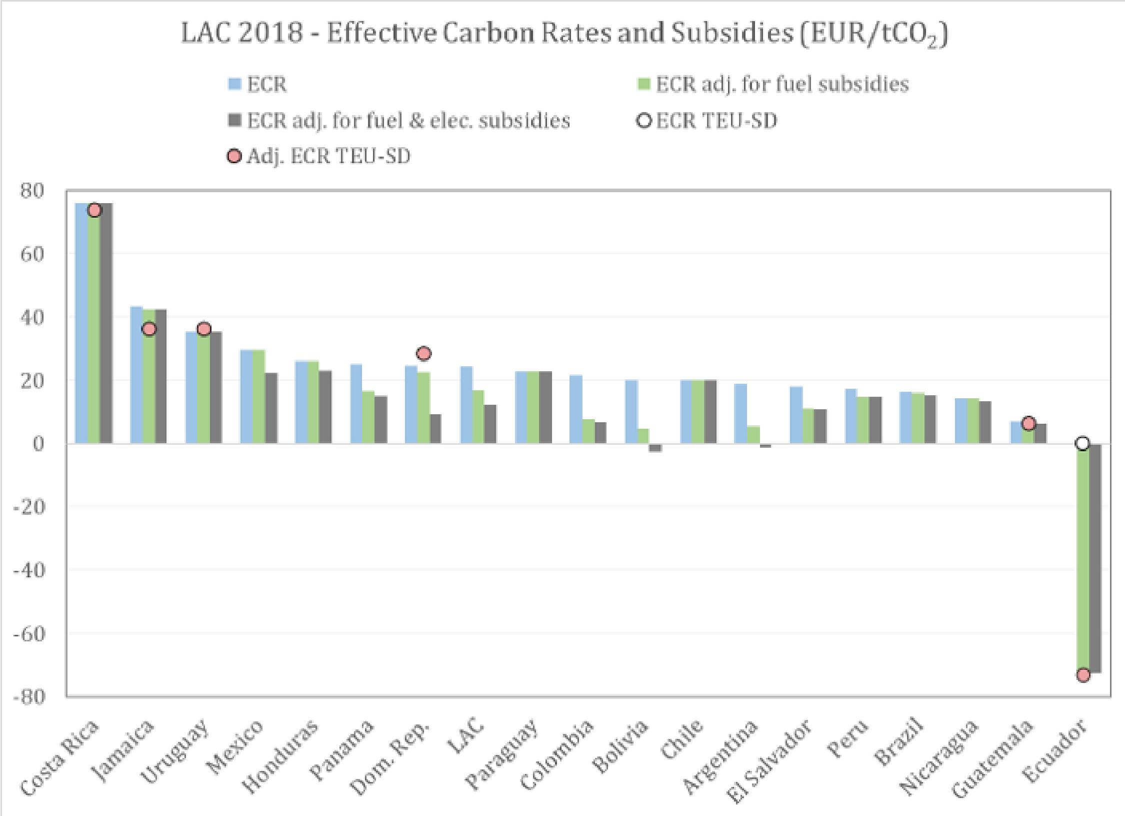
Figure 6



We can take a closer look at country-level subsidies for LAC, as depicted in Figure 7 (Figure A2 in Appendix A shows this detail including OECD and Asia & Africa countries). Costa Rica, Jamaica and Uruguay, ranked with the highest ECRs, do not place significant subsidies on energy use. Paraguay and Chile, with average ECRs compared to the region, do not have significant subsidies.

Dominican Republic, Colombia, Bolivia, and Argentina are noteworthy cases where an average-level ECR is substantially reduced once adjusted for energy subsidies. In Bolivia and Argentina and Dominican Republic, adjusted ECRs turn negative accounting for electricity subsidies, meaning energy use has an overall negative carbon pricing (a net subsidy). Ecuador is an extreme example in this case: not only does it have a null ECR, but it effectively and heavily subsidizes carbon emissions from energy use.

Figure 7



Note: group averages are unweighted. Bolivia provides negative excise (subsidy) rates on imported diesel. These account for transfers of about 1.2% of GDP, consistent with the 1.1% budgetary estimates from FIEL (2020).

Although adjusting ECRs for energy subsidies reveals some countries are further off from the relevant benchmarks, and that emissions may be actually subsidized rather than taxed in particular cases, this opens a direct avenue for reform. Reducing energy subsidies would not only increase effective carbon pricing but would also imply considerable fiscal savings.

5. Econometric modelling approach to ECR determinants

In this section we focus on the determinants of observed ECR, both sectoral and economy-wide in our sample of 66 countries which include OECD, LAC and Asia and Africa countries. In order to find the main determinants, we started by considering as potential explanatory variables a wide set of variables as detailed in the next section.

We separate our econometric analysis in three models. The first is a study of determinants of economy-wide ECR. Then, based on the different nature of taxation at disaggregated sectoral level we studied the determinants of road transport on the one hand and the rest of sectors on the other. With this aim, our second model looks at the determinants of ECR in road transport. The third model moves to the estimation of a panel of 5 sectors, other than road transport, for the 66 countries. In all cases we search for differences in LAC vs OECD both in levels and in the interaction with determinants. We also study the effects of energy subsidies in an economy-wide cross section of ECR looking for their relevance both in redefining the dependent variable (ECR adjusted for subsidies) and in their likely effect on non-adjusted ECR.

To handle many potential variables, an automatic algorithm (Autometrics, see Doornik, 2009 and Hendry and Doornik, 2014) helped us select the relevant determinants. This algorithm uses a tree search to discard paths rejected as reductions of the initial unrestricted model based on ordered squared t-statistics, given a p-value provided by the researcher and providing misspecifications tests. One advantage of using this algorithm is that it allows to obtain more robust estimations by selecting the observations that are outliers among all the observations in the sample (given a p-value). That is, by using impulse dummy saturation we can find countries that can be treated as outliers in the cross-country regressions, apart from testing the regional (OECD and LAC) effects.[13]

In the case of the panel we have the explained (ECR) and the (k.1) vector of explanatory variables $y_{s,i}$, $x_{s,i}$, respectively, where “s” indicates one of the 5 sectors (off-road, industry, agricultural and fisheries, residential and commercial, and electricity) and “i”, each of the 66 countries. For this model we can test for the effects of sectoral (α_s) and country (α_i) dummy variables (as fixed effects) but also for “s, i” outliers by using the algorithm. That is, the unrestricted model may have the following form,

$$y_{s,i} = \alpha_s + \alpha_i + \alpha_{si} + x_{si}{}' \beta + x^*_{si}{}' \beta_s + \varepsilon_{s,i} \qquad (1)$$

Since several variables are available only at aggregated (economy wide) level we also allow for heterogeneity by sectors using multiplicative dummies (x^*_{si})[14] for main variables being their marginal effect β_s .

6. Data and variables definition

Effective Carbon Rates for LAC countries were computed as described in section 2. Regarding OECD members and countries from Asia and Africa, ECR data was taken from OECD-ECR (2021), OECD-TEU (2019) and OECD-TEU SD (2021). All ECR data is expressed in 2018 Euros per ton of CO_2 emissions from energy use (EUR/tCO_2), and open in 6 sectors following OECD Taxing Energy Use methodology: Road transport, Off-Road Transport, Industry, Agriculture & fisheries, Residential & commercial, and Electricity.

Fossil fuel and electricity subsidies were calculated as described in Section 4 and Appendix B. Both expressed in EUR/tCO_2, this allowed us to generate subsidy-adjusted Effective Carbon Rates subtracting fossil fuel subsidies from ECR as explained in detail in Appendix B. To further adjust for electricity subsidies (also explained in Appendix B) we considered the fact that they increase the demand for

[13] We used 5% target (probability) values for variables and 1% for impulse dummy selection. *Autometrics* evaluates diagnostic tests for heteroscedasticity and normality in the data studied. In some cases, consistent standard errors are reported.

[14] The original variables are multiplied by indicators functions equal to 1 for each sector “s”.

fossil fuels to the extent that electricity generation is fossil fuel based. Thus, we corrected the magnitude of electricity subsidies with the share of electricity generated from fossil fuels and assumed an *ad hoc* variable cost structure explaining 50% of total electricity costs for such generation. Dummies coding for the operative presence of nationwide Emission Trading Systems (*ets*) and Carbon Taxes (*carbon*) in 2018.

A broad assortment of candidate explanatory variables was compiled from various sources. These include standard income-level measures as GDP per capita (*gdp*), and indicators that intend to proxy fiscal revenue needs, like gross government debt (*debt*) or the average primary fiscal deficit incurred in the five years prior to 2018 (*deficit_prim_5*). This last set of variables includes a proxy of the marginal cost of public funds (*mcf*) defined in a simple way from optimal indirect taxation formulae (Navajas et al, 2012) and based on the economy wide value added tax (VAT)[15]:

$$mcf = \frac{1 + VAT}{1 + 0.1\,VAT} \qquad (2)$$

It should be noted that ECR estimates in the present document exclude VAT by definition, and thus this measure is included not to control for varying VAT rates across countries, but rather to identify possible revenue-related factors underlying ECRs.[16]

A block of explanatory variables related to governance and institutions includes measures of regulatory quality (*regqual*) and perceived law enforcement (*rulelaw*), as well as the Polity Index that classifies political systems in a spectrum ranging from full autocracy to full democracy (*polity*). Some of these variables, became non significant when GDP was automatically selected. We also included infrastructure quality indicators regarding roads (*road_quality*) and logistic transport in general (*transport_infr*), with alternative objective measures of road quality based of the fraction of roads that are paved (*road_paved*) or the density of road networks

[15] The optimal uniform percentual tax wedge or margin between consumer (q) and producer (p) prices is defined as m=(q-p)/q=(λ/1)/λη where η is the aggregate good or consumption price elasticity of demand, assumed at 0.9 and λ is the marginal cost of public funds (or revenue constrain multiplier). As by definition q=p(1+t) where t is the uniform tax rate (assumed as the VAT rate) we have m=t/(1+t) and obtain λ=(1+t)/(1+(1-η)t).

[16] We also compiled several indicators related to energy use, as well as related CO_2 emissions. These include the fraction of energy consumption and electricity output derived from renewable sources (*renew_energy* and *renew_elec*, respectively), electric power transmission and distribution losses (*dist_loss*), the intensity of energy use per unit of GDP (*energy_use*), the intensity of derived CO_2 emissions per unit of GDP (*emission*) and the share of these stemming from the Transport sector (*emission_transport*). It should be noted that the included CO_2 emission variables, taken from the World Bank, are based on standard UNFCCC inventories and thus consider biofuels to have a carbon-neutral cycle, unlike the approach taken in ECR methodology where emissions are computed following a combustion approach. This means CO_2 emissions in these explanatory variables are not directly comparable to those implicit in the endogenous variable (ECR), and thus their inclusion in the model is based on control purposes. This set of variables is completed with indicators related to the "energetic trade balance": a dummy captures if the country is a net energy exporter (*net_exporter*), and oil rents are included as a possible measure of fiscal dependence (*oil*).

(*road_density*). These variables are broadly intended to capture services derived from transport infrastructure.

Finally, geographical indicators as latitude (*latitude*) were taken into account, as well as proxies for topographical irregularity like the elevation span, measuring the distance between the highest and lowest points in each country (*elevation_span*).

Table 1 lists a subsample of variables included in our analysis. For full set of variables and their corresponding sources, refer to Table A2 in Appendix A. These include, amongst others, a block of control variables related to public ownership of oil and gas resources, and another one corresponding to specific VAT exemptions on gasoline and diesel as well as their pricing across countries.

Table 1

Variable group	Variable name	Description
Country & group variables	**country**	Country name.
	oecd	Dummy coded =1 if country is OECD member. This definition excludes LAC member countries.
	lac	Dummy coded =1 if country is from LAC
	asia_africa	Dummy coded =1 if country is from Asia or Africa
Sector variables	**economywide**	Dummy coded =1 if sector=Economyide
	road	Dummy coded =1 if sector=Road
	off_road	Dummy coded =1 if sector=Off-road
	industry	Dummy coded =1 if sector=Industry
	agr_fish	Dummy coded =1 if sector=Agriculture & fisheries
	res_com	Dummy coded =1 if sector=Residential & commercial
	electricity	Dummy coded =1 if sector=Electricity
Carbon pricing variables	**ecr**	Effective Carbon Rate (EUR/tCO2) in 2018. ECR includes fuel excises, carbon tax, and marginal permit price for ETS systems, in case these instruments are operative. Data drawn from ECR 2021 was replaced from TEU 2019 uniquely for the Road sector in the particular cases where the sectoral ECR saturated the 120 benchmark.
	ets	Dummy variable coded =1 if Emission Trading System was operative in 2018, excluding subnational systems (as for the case of USA, Canada, Japan, China).
	carbon	Dummy variable coded =1 if Carbon Tax was operative in 2018, excluding subnational systems (USA).
	subsidy_fuel	Fossil fuel subsidies (EUR/tCO2) in 2018. LAC country data is from FIEL (2020). TEU SD countries have fuel subsidy data from OECD TEU SD, but do not have electricity subsidy data, so the latter are filled with zero-values. The remainder of the countries in the document have fuel subsidy data from OECD Inventory of Support Measures for Fossil Fuels, taking into acount uniquely Budgetary Transfers, because Tax Expenditures should already be accounted for under TEU methodology. Electricity-based support measures are taken as Electricity subsidies (see below).
	subsidy_elec	Electricity subsidies (EUR/tCO2) in 2018. Same sources as above.
	adj_ecr	Effective Carbon Rate net of Fuel Subsidies (EUR/tCO2)
	adj_ecr_elec	Effective Carbon Rate net of Fuel Subsidies and adjusted for Electricity subsidies (EUR/tCO2). This estimate is done assuming a cost structure where 90% are explained by variable costs, and considering that subsidies on electricity increase the demand for fossil fuels to the extent that electricity generation is fossil-fuel based. Thus, ECR net of fossil fuel subsidies is hereby adjusted by substracting **subsidy_elec** multiplied by 0.9 and by the share of electricity generated using fossil fuels (**1-renew_elec**).
Control variables	**gdp**	GDP per capita, 2018, PPP (constant 2017 international $)
	emission	CO2 emissions, 2018 (kg per PPP $ of GDP)
	emission_transport	Transport sector share in CO2 emissions from enery use. Keep in mind this sectoral definition encompasses Road and Off-Road transport, and takes into account emissions excluding biofuel combustion, and thus is not directly comparable with our approach.
	oil	Oil rents, 2018 (% of GDP)
	net_exporter	Dummy coded =1 if country is a net energy exporter
	renew_energy	Renewable energy consumption, 2018 (% of total final energy consumption)
	renew_elec	Renewable electricity output, 2015 (% of total electricity output)
	energy_use	Energy use (kg of oil equivalent) per $1000 GDP, 2014 (constant 2017 PPP).
	dist_loss	Electric power transmission and distribution losses (% of output), 2014
	polity	Polity Index, 2018 (10 is full democracy, -10 full autocracy)
	regqual	Normalized estimate based on a standard distribution (ranges from aprox -2.5 to 2.5). Reflects perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development. 2018.
	mcf	Marginal Cost of public Funds, proxied as (1+VAT)/(1+0.1*VAT). VAT data was sourced from PWC. For USA, State-level Sales & Use tax rates were weighted by total energy consumption shares for 2018 from EIA.
	debt	Gross Government Debt (% of GDP), 2018
	deficit_prim_5	General government primary net lending/borrowing (% of GDP), 2014-2018 avg
	pop_density	Population density, 2018 (people per sq. km of land area)
	latitude	Latitude value of capital city
	elevation_span	Elevation span (distance in m from lowest to highest point)
	road_quality	Road quality index, 2017-2018 edition (1 = extremely underdeveloped—among the worst in the world; 7 = extensive and efficient—among the best in the world])
	road_density	km of road per sq. km
	road_paved	Percentage of roads paved (%)
	transport_infr	Logistics performance index: Quality of trade and transport-related infrastructure (1=low to 5=high). Nicaragua was completed due to missing data using the OLS best fit prediction based on its road_quality value, given that the correlation coefficient between both variables is 0.77.
	vehicles	Motor vehicles per 1000 people (2014)

7. Results

Tables 2, 3 and 4 report the results of our econometric estimation of ECR determinants for economy-wide, road transport and rest of sectors respectively. Table 2 shows the selected equations obtained from our automatic selection procedure. Column 1 shows our selected equation for economy-wide ECR while columns 2 and 3 show sensitivity results using estimates of ECR adjusted for fossil fuels and fossil fuels cum electricity subsidies.

Economy-wide ECR rates can be modeled with GDP (in logs), a dummy representing if the country has an ETS mechanism (ets) and our proxy for the marginal cost of public funds (mcf) all with expected signs. Richer countries in our sample tend to have higher ECRs. Marginal cost of funds captures a fiscal, revenue raising motive for ECR, which is consistent with tax theory and with positive economics or politics explanations of energy taxes (Mahdavi et al, 2022). Finally, countries with ETS add up (see in column 1) an effect of about 7%, calibrated against the constant. Other automatically selected dummies stand for specific countries, where ECR is higher, such as Costa Rica (CR) and Switzerland and Luxembourg (SWT+LUX) which are added because both countries enter with similar coefficients. All other variables of our large, extensive dataset are not selected as significant. For instance, dummies related to the adding effect of carbon taxes on ECR are not significant. Our estimated effect of ETS is similar to the 7% share of ETS in ECR mentioned in section 3 and reported in OECD/ECR (2021). Our estimate tells that controlling for other factors (GDP, mcf) countries with ETS end up having a higher ECR in relation to the average of the sample. The same does not happen with carbon taxes. This suggests that ETS introduction is not compensated by a corresponding reduction in other ECR components, particularly excises. Since excises are mainly directed to road transport while ETS cover other sectors and have not yet been extended to transport in spite of current proposals (see Pollitt and Dolphin, 2022) there is no evidence of compensatory adjustment. The same does not happen with carbon taxes, as they are more akin to excises and in fact can be naturally be thought in terms of tax reform that replaces excises with carbon taxes (Navajas et al, 2012). Our evidence is compatible with some compensatory effects that make the introduction of carbon taxes more neutral (than ETS) for the effective level of carbon rates.

Sensitivity analysis to account for ECR definitions that adjust for subsidies show similar results, with same central variables being selected, some minor changes in coefficients and selecting new dummies for some countries with large energy subsidies (Egypt, Ecuador) or relatively large ECR (Jamaica).

Table 2. Economywide

OLS modeling of Effective Carbon Rates (ecr) and their adjustments net of fossil fuel subsidies (ecr_adj) and fossil fuel and electricity subsidies (ecr_adj_elec)

Model	**1**	**2**	**3**
Endogenous variable	**ecr**	**ecr_adj**	**ecr_adj_elec**
Lgdp	6.08**	6.80**	6.28**
	2.08	*2.01*	*2.14*
ets	11.0**	12.5**	16.1***
	4.09	*3.94*	*4.21*
mcf	104**	87.3*	73.8*
	35.08	*33.81*	*36.14*
CR	57.2***	59.9***	62.4***
	10.04	*9.65*	*10.31*
SWT + LUX	37.8***	37.7***	37.2***
	7.81	*7.50*	*8.02*
JAM		29.8**	32.1**
		9.61	*10.27*
EGYP		-35.9***	-33.7**
		9.60	*10.26*
ECU		-84.0***	-82.0***
		9.63	*10.29*
Constant	-157***	-149**	-131**
	45.02	*43.46*	*46.45*
Adjusted R^2	0.726	0.839	0.827
Observations	66	66	66

Standard errors shown in italics below coefficients. *p<0.05; **p<0.01; ***p<0.001

The fact that ETS are a determinant for economy-wide ECR but have not been directed towards the road transport sector, should imply its absence in the estimated equation of ECR for road transport. This is what is reported in Table 3, along with other determinants of ECR. It shows that both GDP and marginal costs of funds enter as controls. In the road sector, the public finance motive captured by our proxy for marginal cost of funds is an important determinant. Other three structural variables are selected by the model. Population density and the elevation span of the country have a positive impact on road transport ECR. On the other hand, being an oil producer has a negative effect. Our model reported in Table 2 does not select any other additional variables.

Table 3. Road Transport
OLS modeling of Effective Carbon Rates (ecr)

Endogenous variable	**ecr**
Lgdp	19.0**
	6.33
oil	-6.24*
	2.51
elevation_span	-0.005*
	0.003
mcf	559***
	125.90
pop_density	0.147***
	0.04
Constant	-725***
	147.40
Adjusted R^2	0.571
Observations	66

*p<0.05; **p<0.01; ***p<0.001

Standard errors shown in italics below coefficients.

With a very different pattern of ECR, captured in Figure 1 in the introduction, the rest of the sectors covered in OECD/ECR methodology (off-road transport, agriculture and fishery, manufacturing, residential/commercial and the electricity sector) must have a different structure of determinants, i.e. the modelling procedure should select another set of variables. These are reported in Table 4 were we estimate a panel regression for 5 sectors across the 66 countries of the sample. Variables such as GDP and the marginal cost of funds are not selected in this model, but ETS is selected with a greater quantitative effect with respect to the constant. Fixed effects are captured through many selected variables. Agriculture is a sector were ECR are substantially lower, an effect that is diminished where the country has an ETS, which increases the (rather low) ECR in the Agriculture and sector by 6.8% (-23.7/-346). Marginal cost of funds only shows up interacting with sectoral dummies, with positive effects in agriculture and off-road transport. Other effects are related to sectoral country dummies. Higher ECR are detected in Baltic countries and Switzerland off-road sectors, Netherlands residential/commercial and Costa Rica agriculture.

To sum up, ECR determinants selected at the economy-wide level are basically three, two of which (GDP and marginal cost of funds) come from ECR determinants in the road transport sector while the third (ETS) come from effects in the rest of sectors. Other structural and institutional elements play an auxiliary or secondary role, while most variables in our large dataset are not selected. The effect of ETS is significant and suggests an avenue for improving ECR. Carbon taxes are probably associated with compensatory effects in road transport excises, given their relatively minor role in other sectors. LAC as a region is not captured as having a different model nor does it interact with individual variable effects. The only test for differences in LAC versus OECD is shown in the role of ETS, since these are not operative in LAC.

Table 4. Sectoral panel, excluding Road
OLS modeling of Effective Carbon Rates (ecr)

Model	**1**
Endogenous variable	**ecr**
agr_fish	-346***
	66.78
ets	7.27**
	2.83
ets*agr_fish	-23.7**
	5.72
mcf*agr_fish	327***
	59.00
mcf*off_road	11.5***
	2.23
Baltic_offroad	80.1***
	10.53
latitude	0.101**
	0.045
NDL_res_comm	88.3***
	17.72
SWIT_off_road	81.9***
	17.80
CR_agr_fish	64.9***
	17.90
Constant	3.81***
	1.62
Adjusted R^2	0.462
Observations	330

Robust standard errors shown in italics below coefficients.

*p<0.05; **p<0.01; ***p<0.001

8. ECR and emissions

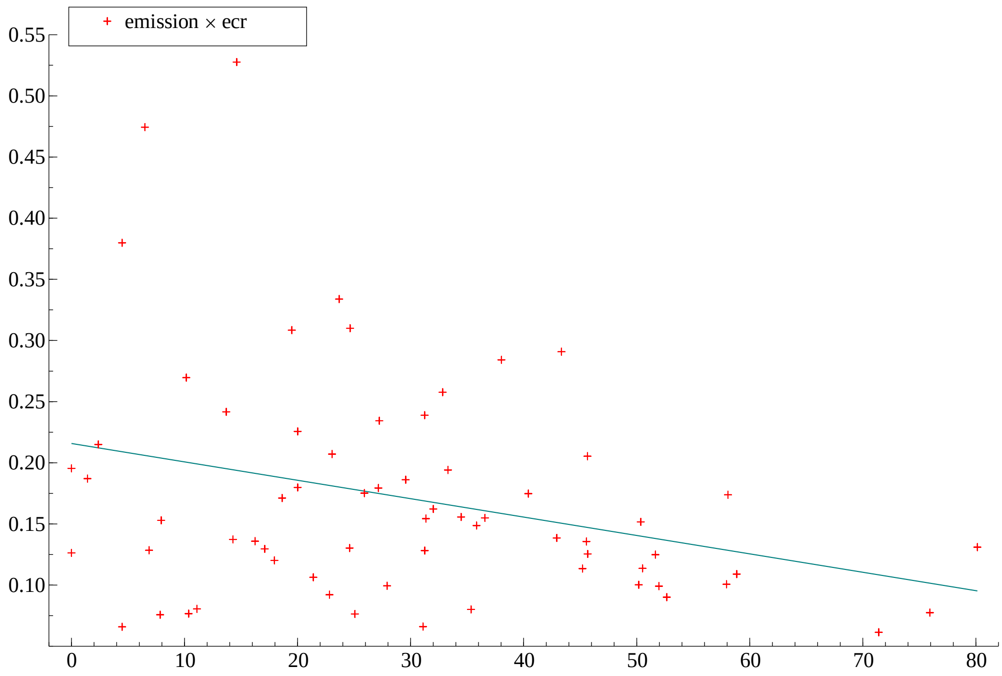
Some reports by OECD (OECD-ECR, 2021, chapter 2) and background papers (e.g. Sen and Vollebergh, 2018; Martin, Muûls and Wagner, 2016) have reported evidence that ECRs reduce energy consumption and emissions. More recently there has been some discussion on the effect of carbon pricing on aggregate emissions. Evidence referred to in Metcalf (2019), an excellent and useful review of carbon pricing in the US, has been challenged by Pretis (2022) on a thorough policy evaluation assessment of the carbon tax reform in British Columbia, where he claims that carbon taxes do show an effect on transport sector emissions, but evidence does not show an effect on aggregate emissions. While our paper is focused on other objectives and cannot contribute to such a discussion due to data limitations, in this section we refer our data on the relationship between ECR and available estimates on aggregate emissions. One must notice that ECR are a combination of three different instruments (excises, carbon taxes and ETS) that works through prices to signal the cost of carbon emissions. In this paper we have found that ECR in road transport (which are mainly formed from excises and, to a lesser extent, carbon taxes) is much more important than ECR in other sectors, where taxation is rather low (beyond exemptions, we found) and ETS mechanisms are incipient and operating in some advanced economies. It is not strange from the perspective of our results that impacts through transport tax signals (including carbon taxes) should emerge as more significant than effects in other sectors were taxation is rather low (See Figure 1 in the introduction).

In this section we use our data base to analyze the cross-country relationship between aggregate emissions (kg of tCO_2 per PPP$ of GDP; see Table 1) and ECR (EUR/tCO_2). Figure 8 shows the cross plot between total emissions and ECR using our data base of 66 countries for 2018.

Figure 8

ECR and aggregate emissions

units: ECR (EUR/tCO2); emissions (kg/PPP$ GDP)



We can observe the negative relationship and from this descriptive picture we can move to estimate a relationship using the log of GDP and population as controls for emissions. Results of the OLS estimation from a conditional model of the log of emissions on ECR are reported in Column 1 and 3 in Table 5.

Table 5. Emissions and ECR
OLS (columns 1 and 3) and IVE (columns 2 and 4) modeling of aggregate Emissions (in Logs) on Effective Carbon Rates (ecr) and their adjustments net of fossil fuel subsidies (ecr_adj)

Model	**OLS**	**IVE**	**OLS**	**IVE**
Endogenous variable	**Lemission**	**Lemission**	**Lemission**	**Lemission**
Lgdp	0.228**	0.302**	0.200*	0.311**
	0.081	*0.11*	*0.08*	*0.11*
ecr	-0.012**	-0.018**		
	0.004	*0.01*		
adj_ecr			-0.0086**	-0.016**
			0.003	*0.006*
pop	0.0006*	0.0005*	0.0007**	0.0006*
	0.0002	*0.0002*	*0.0002*	*0.0002*
Constant	-3.86***	-4.43***	-3.72***	-4.65***
	0.74	*0.92*	*0.73*	*1.02*
Adjusted R^2	0.230		0.220	
SER	0.422	0.429	0.425	0.444
Observations	66	66	66	66

Standard errors shown in italics below coefficients. *p<0.05; **p<0.01; ***p<0.001

Population in millions of habitants.

In columns 2 and 4 additional instruments are **mcf** and dummies for CR and SWIT .

We note that this analysis is different from the policy evaluation approach for a given country of tax impacts on carbon tax over emissions as recently discussed in Pretis (2022) and Metcalf (2019), which find mixed evidence. In our case we report the effect of ECR on emissions from the comparisons of 66 worldwide countries at a point in time. The results from OLS estimates indicate a significant negative effect of ECR on the log of emissions. Given the log linear functional form, the elasticity of emission with respect to ECR is evaluated at mean and maximum values of ECR. In the case of column 1, the elasticity values are 0.36 and 0.96, respectively. These values are consistent with estimates reported in OECD-ECR (2021, chapter 2) based on Sen and Vollebergh (2018). At mean values, a country which has ECR 10% higher than other has 3.6% less of emissions. The model using ECR adjusted for subsidies show lower elasticity values, of 0.22 and 0.69, respectively. To take into account the possibility of biases in the estimates due to the effect of emissions on ECR we re-estimated the models by using IV and making ECR endogenous. We used the marginal cost of public funds (mcf) and two country dummies as instruments. According to the results in section 7, mcf is a determinant of ECR and is not related to the level of country emissions. As shown in Column 2 and 4, the negative effect of ECR on emissions is higher using IV; e.g. the elasticity value is 0.53 in the case of mean values of unadjusted ECR.

9. Conclusions and further research

Effective carbon rate methodology is a useful way to normalize cross country measures of carbon pricing on energy use that encompasses different forms of price signals with the main ones being excises, carbon taxes and ETS prices. The methodology is a bottom-up sectoral measurement in 6 sectors, using IEA energy balances in a format that allows comparison. We have extended this methodology to 18 Latin American and Caribbean countries in 2018, which is a reasonable pre pandemic year where data is available. Our measurement allowed to differentiate the level and structure of ECR in LAC and the OECD and enabled us to construct a sample of 66 countries, to our knowledge the largest assembled data across countries. We included a simple adjustment to account for energy subsidies, which are particularly relevant in LAC and elsewhere. We found a ranking of ECR across counties in 2018, with 40 EUR/tCO_2 on average for OECD, 25 for LAC and 10 for the Asian and African countries of our sample. These values are slightly reduced for OECD when energy subsidies are considered, but the adjustment is much more significant for LAC and Asian/African countries. At the sectoral level we found a stylized fact where ECR are biased towards road transport, while the rest of the sectors have much lower tax pressure and face lower carbon price signals. Beyond the fact that this provides an argument for a direction of reform, we acknowledge that this motivates a search of the determinants of ECR across countries and sectors that calls for a separate search in road transport and the rest of sectors, as road transport excises (a main determinant of ECR both in the sector and in aggregate terms) have a genesis related to fiscal revenue collection for different purposes, notably road infrastructure finance, that quite differs from both local and global environmental control.

We complement our data set with a large number variables potentially useful for the study of ECR determinants, which we made available for research and analysis. From this we implement an econometric approach to select determinants of ECR across countries and sectors based on an automatic, machine-learning methodology. We are able to select three regression equations, one for the economy-wide ECR across our sample, another for the road transport sector and another panel regression for the remaining 5 sectors of OECD/ECR methodology. Explanatory variables are selected from a large sample, but the three models end up selecting a few variables that allow us to elaborate a representation of ECR determinants. Economy-wide ECR across countries are explained by GDP, the marginal cost of public funds and the existence or not of an ETS mechanism. The first two variables drive the equation for road transport ECR while ETS significance comes from the panel estimate for the (poorly taxed) rest of sectors. The quantitative contribution of ETS to economy-wide ECR (but not to transport ECR as it relies on excises and carbon taxes) is significant in magnitude (countries with ETS have on average 7% higher ECR) and shows that the introduction of ETS does not carry a compensatory adjustment of other components of ECR, mainly excises. This is reasonable as excises operate on road transport ECR. But the fact that there is no "carbon pricing crowding out" (if we are allowed to use the term) after the introduction of ETS is we believe a significant feature in practice. The same cannot be said in the case of carbon taxes, according to our results, probably do to the fact that carbon pricing results may come with compensatory adjustments in excises in road transport fuels.

Finally, our data, being basically a cross section of ECR across sectors for 2018, is not fit for an evaluation of the effects of ECR or its components on the aggregate or sectoral level of emissions. Our cross-correlation analysis of ECR and emissions show a negative relationship, controlling for factors such as GDP and population. We do not take side on the recent discussion on the sectoral (transport) versus aggregate impact of carbon taxes and are open to coming evidence, subjected to due scrutiny. However, we think price signals in the energy sector are a central ingredient of carbon policy. This applies, symmetrically, to carbon taxes and to the reform of fossil fuel subsidies: in both cases efficiency, cost effectiveness (including fiscal outcomes) and equity considerations must intervene in the analysis. This view underlies our motivation and effort to collect data, extend estimates of ECR to LAC and perform an analysis of its determinants. Further work, we believe, along the line of this work has several avenues. One is to move to a panel ECR across countries and sectors by adding post pandemic 2021. A second is to move towards a more detailed bottom-up, observed price related, estimate of sectoral energy subsidies that can be integrated to ECR methodology. Third, a bottom-up sectoral measurement of emissions from energy sources across time can also be essential to obtain precise estimates of the effects of the different components of ECR on sectoral and aggregate emissions. Fourth, and from a policy reform perspective, the extent of carbon pricing crowding out (i.e. the introduction of an instrument that reduces the use of another) deserves attention. Finally, the introduction of ETS in regions such as LAC, its sectoral orientation or specialization and the extent of its contribution to make progress in ECR on energy use at sectorial level needs to be assessed against the institutional limits to introducing market-based mechanisms in countries where such mechanisms are absent in central energy price formation, and which are the countries were such a reform may look more promising.

References

Amigo P., S. Cea-Echenique y F. Feijoo et al (2020), "An Emissions Trading System to reach NDC targets in the Chilean electric sector", *arXiv*:2005.03843v1 [econ.GN], May 8.

Arlinghaus, J. (2015), "Impacts of Carbon Prices on Indicators of Competitiveness: A Review of Empirical Findings"*, OECD Environment Working Papers*, No. 87, Paris: OECD

Arlinghaus, J. and K. Van Dender (2017), "The environmental tax and subsidy reform in Mexico, OECD Taxation Working Papers, No.31 Paris: OECD.

Barde J.P. and N. Braathen (2005), "Environmentally Related Levies", Chapter 5 in Cnossen S. (ed), *Theory and Practice of Excise Taxation: Smoking, Drinking, Gambling, Polluting and Driving*. Oxford: Oxford University Press.

Becker, G. 1983. "A Theory of Competition among Pressure Groups for Political Influence." *Quarterly Journal of Economics* 96: 371-400.

Coady D., I. Parry, N.P. Le, and B. Shang (2019) "Global Fossil Fuel Subsidies Remain Large: An Update Based on Country-Level Estimates" IMF Working Paper No. 19/89, International Monetary Fund.

Conte Grand M., A. Rasteletti and J. Muñoz (2022), "Impuestos a los combustibles en la teoría y en la práctica", Nota Técnica #2323, Inter-American Development Bank.

Doornik, J.A. 2009. "Autometrics." In: J. L. Castle and N. Shephard, editors. *The Methodology and Practice of Econometrics: A Festschrift in Honour of David F. Hendry*. Oxford, United Kingdom: Oxford University Press.

European Commission (2021), *Study on energy subsidies and other government interventions in the European Union*, Final Report, https://op.europa.eu/en/publication-detail/-/publication/be5268ba-3609-11ec-bd8e-01aa75ed71a1/language-en

FIEL (2017), "Calidad y eficiencia del gasto público en América Latina y el Caribe: actualización de estimaciones de niveles de gasto y filtraciones en asistencia social, energía y gasto tributario." Background paper for Izquierdo *et al* (2018) op.cit.

FIEL (2020), "Análisis de la eficiencia e incidencia del gasto público en países seleccionados de la región", Report paper to the IADB.

Hendry, D., and J. Doornik. 2014. *Empirical Model Discovery and Theory Evaluation: Automatic Selection Methods in Econometrics*. Cambridge, United States: MIT Press.

ICAP (2021), *Emissions Trading Worldwide: Status Report 2021*. Berlin: International Carbon Action Partnership

IEA (2021), *World Energy Balances: Energy balances for 190 countries and regional aggregates.* Paris: International Energy Agency, https://www.iea.org/data-and-statistics/data-product/world-energy-balances

Izquierdo A., C. Pessino y G. Vuletin (2018), *Better spending for better lives*, Washington: Inter-American Development Bank.

Kanbur, S., and G. Myles. 1992. "Policy Choice and Political Constraints." *European Journal of Political Economy* 8: 1-29

Marten, M. and K. van Dender (2019), "The use of revenues from carbon pricing", *OECD Taxation Working Papers*, No. 43, OECD Publishing, Paris.

Mahdavi P., C. Martinez-Alvarez and M. Ross (2022), "Why do governments tax or subsidize fossil fuels", *The Journal of Politics*, https://www.journals.uchicago.edu/doi/suppl/10.1086/719272

Martin, R., M. Muûls and U. Wagner (2016), "The Impact of the European Union Emissions Trading Scheme on Regulated Firms: What Is the Evidence after Ten Years?", *Review of Environmental Economics and Policy*, Vol. 10/1, pp. 129-148.

Metcalf, Gilbert E. (2019), "On the Economics of a Carbon Tax for the United States." *Brookings Papers on Economic Activity*, (Spring), 405-458

Navajas, F., M. Panadeiros and O. Natale (2011), "Environmentally Related Energy Taxes in Argentina, Bolivia and Uruguay", *MPRA working paper 37829,* https://mpra.ub.uni-muenchen.de/37829/

Navajas F., M. Panadeiros y O. Natale (2012), "Workable Environmentally Related Energy Taxes.", IDB Research Department Working Paper, IDB-WP-3 51, November.

OECD-TEU (2015), *Taxing Energy Use 2015: OECD and Selected Partner Economies*, , Paris: OECD.

OECD-ECR (2019), *Effective Carbon Rates 2018: Pricing carbon emissions through taxes and emission trading,* Paris: OECD

OECD TEU (2019), *Taxing Energy Use 2019: Using taxes for climate action*, Paris: OECD

OECD ECR (2021), *Effective Carbon Rates 2021: Pricing carbon emissions through taxes and emission trading,* Paris: OECD

OECD TEU-SD (2021), *Taxing Energy Use for Sustainable Development: Opportunities for energy tax and subsidy reform in selected developing and emerging economies*, Paris: OECD

OLADE (2021), *Estadística energética e información legal*, https://sier.olade.og Quito: Organización Latinoamericana de Energía.

Parry I., S. Black and N. Vernon (2021), "Still Not Getting Energy Prices Right: A Global and Country Update of Fossil Fuel Subsidies", IMF Working Paper No, 2021/236.

Pollitt M. and G. Dolphin (2022), "Should the EU ETS be Extended to Road Transport and Heating Fuels?", *Economics of Energy and Environmental Policy*, 11, 2, pp.125-44

Pretis F. (2022), "Does a Carbon Tax Reduce CO2 Emissions? Evidence from British Columbia", *Environmental and Resource Economics*, published online https://doi.org/10.1007/s10640-022-00679-w

Sen, S. and H. Vollebergh (2018), "The effectiveness of taxing the carbon content of energy consumption", *Journal of Environmental Economics and Management*, Vol. 92, pp. 74-99.

World Bank (2021), *Emission trading in practice: A handbook on design and implementation*, 2nd edition. Washington DC: World Bank

Appendix A

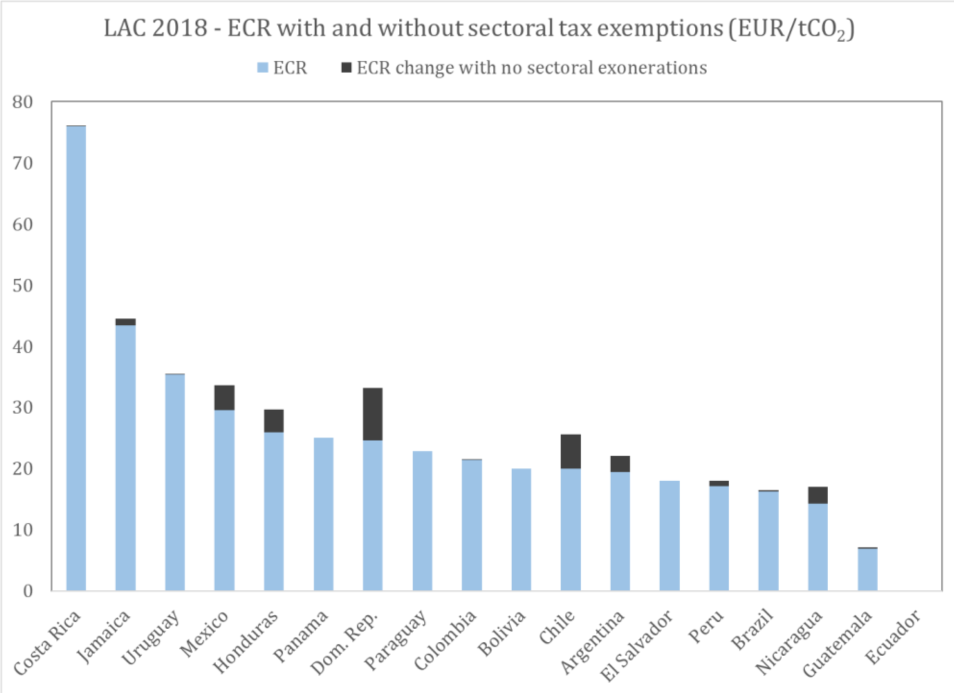
ECR-LAC, exemptions, subsidies and variables database

Table A1

country	Fuel Excise Tax	Carbon Tax	**Effective Carbon Rate**	*Electricity Excise Tax*
	2018, in EUR/tCO₂			
Argentina	17.18	1.46	**18.64**	*4.39*
Bolivia	20.02	0.00	**20.02**	*4.95*
Brazil	16.24	0.00	**16.24**	*5.26*
Chile	18.77	1.24	**20.01**	*0.00*
Colombia	19.68	1.72	**21.39**	*0.00*
Costa Rica	75.93	0.00	**75.93**	*7.66*
Dom. Rep.	24.61	0.00	**24.61**	*0.00*
Ecuador	0.00	0.00	**0.00**	*12.59*
El Salvador	17.95	0.00	**17.95**	*0.00*
Guatemala	6.86	0.00	**6.86**	*3.75*
Honduras	25.91	0.00	**25.91**	*2.83*
Jamaica	43.34	0.00	**43.34**	*0.00*
Mexico	28.28	1.28	**29.57**	*0.00*
Nicaragua	14.28	0.00	**14.28**	*3.06*
Panama	25.07	0.00	**25.07**	*0.00*
Paraguay	22.83	0.00	**22.83**	*0.00*
Peru	17.09	0.00	**17.09**	*4.14*
Uruguay	35.35	0.00	**35.35**	*0.00*
LAC simple average	*23.85*	*0.32*	***24.17***	*2.70*

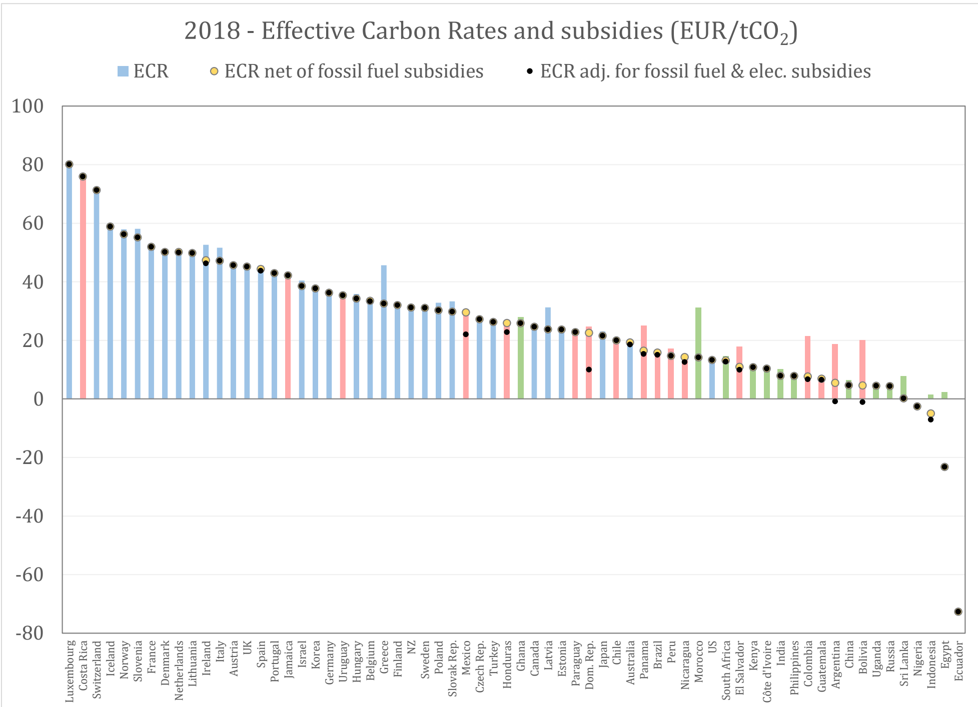
Source: own estimation based on country-level legislation and tax codes, and EIA World Energy Balances.

Figure A1



Note: this hypothetical simulation assumes a static scenario with no fuel substitution effects following relative price changes. Its goal is to depict the magnitude of underlying sectoral exemptions.

Figure A2



Sources: Own estimation and FIEL (2020) for LAC countries. OECD TEU SD. OECD Inventory of Support Measures for Fossil Fuels, considering only budgetary transfers. CO_2 Emissions and local currency exchange rates taken from World Bank, except for emissions for LAC countries, from IEA World Energy Balances.

Table A2

Variable group	Variable name	Description	Source
Country & group variables	**country**	Country name.	
	group	Group where country is assigned. OECD excludes LAC member countries.	
	group_code	Code for group where country is assigned. 0=OECD, 1=LAC, 2=Asia&Africa, 999="LAC B"	
	oecd	Dummy coded =1 if country is OECD member	
	lac	Dummy coded =1 if country is from LAC (does not include "LAC B" countries)	
	asia_africa	Dummy coded =1 if country is from Asia or Africa	
Sector variables	**sector**	Sectoral classification according to primary energy use: Road transport, Off-road transport, Agriculture and fisheries, Industry, Residential and Commercial, Electricity.	
	sector_code	Code for sectoral classification. Economywide=0, Road=1, Off-road=2, Agr. & fish.=3, Industry=4, Res. & com.=5, Electricity=6.	
	economywide	Dummy coded =1 if sector=Economyide	
	road	Dummy coded =1 if sector=Road	
	off_road	Dummy coded =1 if sector=Off-road	
	industry	Dummy coded =1 if sector=Industry	
	agr_fish	Dummy coded =1 if sector=Agr. & fish.	
	res_com	Dummy coded =1 if sector=Res. & com.	
	electricity	Dummy coded =1 if sector=Electricity	
Carbon pricing variables	**ecr**	Effective Carbon Rate (EUR/tCO2) in 2018. ECR includes fuel excises, carbon tax, and marginal permit price for ETS systems, in case these instruments are operative. Data drawn from ECR 2021 was replaced from TEU 2019 uniquely for the Road sector in the particular cases where the sectoral ECR saturated the 120 benchmark.	OECD ECR 2021, OECD TEU 2019, OECD TEU SD
	ets	Dummy variable coded =1 if Emission Trading System was operative in 2018, excluding subnational systems (as for the case of USA, Canada, Japan, China).	https://carbonpricingdashboard.worldbank.org/
	carbon	Dummy variable coded =1 if Carbon Tax was operative in 2018, excluding subnational systems (USA).	https://carbonpricingdashboard.worldbank.org/
	subsidy_fuel	Fossil fuel subsidies (EUR/tCO2) in 2018. LAC country data is from FIEL (2020). TEU SD countries have fuel subsidy data from OECD TEU SD, but do not have electricity subsidy data, so the latter are filled with zero-values. The remainder of the countries in the document have fuel subsidy data from OECD Inventory of Support Measures for Fossil Fuels, taking into acount uniquely Budgetary Transfers, because Tax Expenditures should already be accounted for under TEU methodology. Electricity-based support measures are taken as Electricity subsidies (see below).	
	subsidy_elec	Electricity subsidies (EUR/tCO2) in 2018. Same sources as above.	
	adj_ecr	Effective Carbon Rate net of Fuel Subsidies (EUR/tCO2)	
	adj_ecr_elec	Effective Carbon Rate net of Fuel Subsidies and adjusted for Electricity subsidies (EUR/tCO2). This estimate is done assuming a cost structure where 90% are explained by variable costs, and considering that subsidies on electricity increase the demand for fossil fuels to the extent that electricity generation is fossil-fuel based. Thus, ECR net of fossil fuel subsidies is hereby adjusted by substracting **subsidy_elec** multiplied by 0.9 and by the share of electricity generated using fossil fuels (**1-renew_elec**).	
	ecr_gap_road	Sectoral ECR relative to Road sector ECR. Ecuador and Nigeria, with null ECR values, were completed with zeros.	
	database	Dataset from where ECR value is retrieved.	
Control variables	**gdp**	GDP per capita, 2018, PPP (constant 2017 international $)	World Bank
	gini	Gini index, 2018	World Bank
	sav	Gross savings (% of GDP)	World Bank
	emission	CO2 emissions, 2018 (kg per PPP $ of GDP)	World Bank
	emission_share	Sectoral CO2 emission share. Only available for LAC countries.	IEA World Energy Balances
	emission_transport	Transport sector share in CO2 emissions from enery use. Keep in mind this sectoral definition encompasses Road and Off-Road transport, and takes into account emissions excluding biofuel combustion.	Our World in Data
	oil	Oil rents, 2018 (% of GDP)	World Bank
	energy_imports	Energy imports, net, 2014 (% of energy use).	World Bank
	net_exporter	Dummy coded =1 if country is a net energy exporter (energy_imports<0)	
	fuel_exports	Fuel exports (% of merchandise exports), 2018	World Bank
	fuel_imports	Fuel imports (% of merchandise imports), 2018	World Bank
	renew_energy	Renewable energy consumption, 2018 (% of total final energy consumption)	World Bank
	renew_elec	Renewable electricity output, 2015 (% of total electricity output)	World Bank
	energy_use	Energy use (kg of oil equivalent) per $1000 GDP, 2014 (constant 2017 PPP).	World Bank
	dist_loss	Electric power transmission and distribution losses (% of output), 2014	World Bank
	agr_gdp	GDP share in Agriculture, 2018. Argentina replaced with official National Accounts data because of outlier.	World Bank
	ind_gdp	GDP share in Industry, 2018	World Bank
	agr_e	Employment share in Agriculture, 2018. Argentina replaced with official National Accounts data because of outlier.	ILO
	ind_e	Employment share in Industry, 2018	ILO
	agr_lp	Agriculture labor productivity, 2018 (constant 2015 $ per worker)	World Bank
	ind_lp	Industry labor productivity, 2018 (constant 2015 $ per worker)	World Bank
	agr_lp_gap	Agriculture labor productivity gap, 2018 (relative to Economywide)	
	ind_lp_gap	Industry labor productivity gap, 2018 (relative to Economywide)	
	lp_growth	Economywide labor productivity annual growth rate, 1960 (or first year of available data)-2019, %	PWT 10.0
	ex	Inverse real exchange rate proxy (PPP/XR), price level of USA GDPo in 2017=1	PWT 10.0
	polity	Polity Index, 2018 (10 is full democracy, -10 full autocracy)	Systemic Peace, Polity IV
	regqual	Normalized estimate based on a standard distribution (ranges from aprox -2.5 to 2.5). Reflects perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development. 2018.	Worldwide Governance Indicators
	rulelaw	Normalized estimate based on a standard distribution (ranges from aprox -2.5 to 2.5). Reflects perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence. 2018.	Worldwide Governance Indicators
	green_tax_rev	Environmentally related tax revenue (% of tax revenue, 2018). Russia, Sri Lanka and Indonesia (missing) replaced extracting revenue from ECR and expressing as a share of total tax revenue.	OECD
	vat	Value Added Tax (%) or most similar tax rate. For USA, State-level Sales & Use tax rates were weighted by total energy consumption shares for 2018 from EIA.	PWC
	mcf	Marginal Cost of public Funds, proxied as (1+VAT)/(1+0.1*VAT)	
	tax	Tax revenues (% of GDP, 2018)	World Bank
	inflation	Inflation rate (GDP deflator), 2010-2019 simple average	World Bank
	debt	Gross Government Debt (% of GDP), 2018	IMF
	deficit_prim	General government primary net lending/borrowing (% of GDP), 2018	IMF
	deficit_fisc	General government net lending/borrowing (% of GDP), 2018	IMF
	deficit_prim_5	General government primary net lending/borrowing (% of GDP), 2014-2018 avg	IMF
	deficit_fisc_5	General government net lending/borrowing (% of GDP), 2014-2018 avg	IMF
	area	Surface area (sq. km)	World Bank
	pop	Population, 2018	World Bank
	pop_density	Population density, 2018 (people per sq. km of land area)	World Bank
	latitude	Latitude value of capital city	https://en.wikipedia.org/wiki/List_of_national_capitals_by_latitude
	latitude_abs	Asbolute latitude value of capital city	
	island	Dummy =1 if country is an island. Australia was listed as island, although it technically is a continent.	https://en.wikipedia.org/wiki/List_of_island_countries
	elevation_avg	Average elevation above sea level (m)	https://en.wikipedia.org/wiki/List_of_countries_by_average_elevation
	elevation_span	Elevation span (distance in m from lowest to highest point)	https://en.wikipedia.org/wiki/List_of_elevation_extremes_by_country
	road_quality	Road quality index, 2017-2018 edition (1 = extremely underdeveloped—among the worst in the world; 7 = extensive and efficient—among the best in the world])	World Economic Forum
	road_km	Total length of the road network in km., last observation	CIA
	paved_road_km	Total length of the paved roads in km., last observation	CIA and World Bank if missing
	road_density	km of road per sq. km	World Bank
	road_paved	Percentage of roads paved (%)	
	transport_infr	Logistics performance index: Quality of trade and transport-related infrastructure (1=low to 5=high). Nicaragua was completed due to missing data using the OLS best fit prediction based on its road_quality value, given that the correlation coefficient between both variables is 0.77.	World Bank
	vehicles	Motor vehicles per 1000 people (2014)	World Bank
	noc_reserves	% of national oil and gas reserves owned by National Oil Companies (NOCs), 2011-2018 average	https://www.nationaloilcompanydata.org/indicator
	noc_production	% of oil and gas production done by NOCs, 2011-2018 average	
	noc_revenue	NOC total revenues as a % of government revenues, 2011-2018 average	
	noc_revenue_gdp	NOC total revenues as a % of GDP, 2011-2018 average	
	noc_debt	NOC debt as a % of government gross debt, 2011-2018 average	
	noc_income_rev	NOC net income as a % of government revenue, 2011-2018 average	
	noc_transfer_inc	NOC transfers to government as a % of NOC net income, 2011-2018 average	
	noc_transfers_exp	NOC transfers to government as a % of total public expenditure, 2011-2018 average	
	noc_transfer_rev	NOC transfers to government as % of NOC revenues, 2011-2018 average	
	noc_transfers_barrel	NOC transfers to government per barrel (USD/barrels of oils equivalent), 2011-2018 average	
	vat_imf	VAT provided by the IMF Fuel Subsidies Template. Although variations respect to vat are minimal, it is taken into account for vat exemption purposes.	IMF Fuel Subsidies Template
	vat_gasoline_ex	VAT exemption magnitude for gasoline.	IMF Fuel Subsidies Template
	vat_diesel_ex	VAT exemption magnitude for diesel.	IMF Fuel Subsidies Template
	vat_gasoline_fraction	% of standard VAT rate applicable to gasoline	
	vat_diesel_fraction	% of standard VAT rate applicable to diesel	
	gasoline_sc	Supply cost for gasoline, 2021 USD/liter (2018)	IMF Fuel Subsidies Template
	gasoline_rp	Retail price for gasoline, 2021 USD/liter (2018).	IMF Fuel Subsidies Template & GIZ IFP for Morocco (missing)
	diesel_sc	Supply cost for diesel, 2021 USD/liter (2018)	IMF Fuel Subsidies Template
	diesel_rp	Retail price for diesel, 2021 USD/liter (2018)	IMF Fuel Subsidies Template
	gasoline_wedge	Difference between retail price and supply cost as a % of retail price, for gasoline	
	diesel_wedge	Difference between retail price and supply cost as a % of retail price, for diesel	
	gasoline_neg_wedge	Dummy =1 if supply cost for gasoline is greater than its retail price	
	diesel_neg_wedge	Dummy =1 if supply cost for diesel is greater than its retail price	
	gasoline_transport	Share of gasoline consumed in transportation	IMF Fuel Subsidies Template
	diesel_transport	Share of diesel consumed in transportation	IMF Fuel Subsidies Template

Appendix B

Adjusting ECR for energy subsidies

This section describes the methodological aspects of quantifying subsidies in a comparable way to how ECRs are computed in OECD TEU. This enables a posterior correction of ECRs based on energy subsidy amounts, considering the economy as a whole (with no sectoral detail). Energy subsidies considered in this document can fall either on fossil fuels or on electricity.

For LAC countries, energy subsidies were taken from FIEL (2020), which details their magnitude in 2018 as a percent of GDP for a set of countries, based on country-level budgetary analysis. These are disaggregated into fossil fuel or electricity subsidies, keeping in mind fossil fuel subsidies do not include fuels used for electricity generation to avoid double accounting issues (this is accounted for in subsidies on electricity). Subsidies were converted into monetary units (2018 Euros) using current price GDP data from the World Bank[17] and reference exchange rates published by OECD[18]. Meanwhile, 2018 carbon emissions were calculated based on IEA World Energy Balances as described in Appendix A. Subsidies were posteriorly applied over this emission base, which by definition is identical to that upon which Effective Carbon Rates fall. In other words, we expressed energy subsidies in comparable units to ECRs (EUR/tCO_2), enabling direct adjustments to carbon pricing through simple subtraction of subsidies from taxes.

OECD TEU-SD (2021) provides fossil fuel subsidy data in comparable units to ECRs, and effectively subtracts the former from taxes to calculate the latter. Thus, for TEU-SD countries in our sample (excluding LAC overlapping ones), fossil fuel subsidy data could be compiled, but not electricity subsidy data. For the remainder of countries, we consulted the OECD Inventory of Support Measures for Fossil Fuels[19], that provides detailed information on policies that encourage consumption or production of fossil fuels. These support measures are divided into Budgetary Transfers and Tax Expenditures, and the latter were not considered in this document because they should be accounted for under Taxing Energy Use (TEU) methodology (i.e.: they are already discounted from ECRs by construction). Additionally, each support measure is targeted to a particular fuel type, and those aimed at fuels used for electricity generation fall under the category of "Electricity-based support", which we took as reference for electricity subsidies. OECD and World Bank exchange rates used for currency conversion were used. For countries other than LAC, carbon emissions were taken from World Bank data. These do not include emissions from biofuels, and thus may be underestimated under our present methodology, meaning estimated subsidies measured in EUR/tCO_2 may be overestimated for countries with intensive biofuel use. Nonetheless, the fact that LAC countries stand out as those with the higher energy subsidies only emphasizes the relevance of the issue in the region.

[17] https://data.worldbank.org/

[18] https://data.oecd.org/conversion/exchange-rates.htm

[19] https://www.oecd.org/fossil-fuels/countrydata/

We adjusted ECRs by energy subsidies on two levels. A first stage involved correcting carbon pricing for fossil fuel subsidies. In this case, subsidies on fossil fuels were directly subtracted from ECRs, in a way compatible with TEU-SD methodology. This can be done solely because taxes and subsidies fall on the same base regarding fossil fuels, and it results in an adjusted ECR:

$$adj\_ecr = ecr - subsidy\_fuel$$

A second step involves correcting this further by contemplating subsidies on electricity. This matter is not straightforward: electricity itself does not directly generate carbon emissions, but it does create a derived demand for fossil fuels as inputs in its generation process. To the extent that subsidies on electricity indirectly increase the use of fossil fuels, we can consider them as rival to ECR incentives. Thus, the impact of electricity subsidies on carbon emissions will be dependent on the configuration of electricity production: a hypothetical country where electricity generation is completely renewable means electricity subsidies will not induce an increase in the use of fossil fuels (and therefore, carbon emissions). Additionally, the impact of subsidies on electricity depends on the structure of costs of the Electricity sector: because subsidies can cover fixed as well as variable costs, the share of variable costs (i.e.: fossil fuel inputs) will be determinant on the extent of subsidies that are translated into a higher demand for fossil fuels. Combining these observations, to further correct ECRs by the amount of subsidies on electricity, we subtracted them adjusted by the share of electricity produced based on renewable sources[20], and by an *ad hoc*, conservative estimate of 50% share of variable costs for all countries in our sample:

$$adj\_ecr\_elec = adj\_ecr - 0.5\ subsidy\_elec\ (1 - renew\_elec)$$

We therefore calculated two adjusted versions of ECRs. One of them accounted for subsidies placed on fossil fuels directly, while the other additionally corrected for electricity subsidies considering these only increase carbon emissions to the extent that electricity generation is based on fossil fuel inputs, and that subsidies can also cover fixed costs that are irrelevant in terms of emissions.

[20] Data on renewable electricity production was taken from IEA, sourced by the World Bank.