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CO_2 emissions from service sectors in Ecuador: an analysis using input–output subsystems

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Abstract

Ecuador is one of the most megadiverse countries in the world and a pioneer in establishing some regulations to take care of its environment. Despite this, its levels of pollution and environmental deterioration are higher than those of neighboring countries. A better understanding of the pollution channels of a subsystem such as services, which increasingly occupies a more relevant place in the economy and many of its activities tend to go unnoticed as a source of pollution, allows the development of mitigation strategies that could be analyzed and adopted for similar contexts. We estimated direct and indirect emissions for the 71 economic activities of Ecuador and applied an input–output subsystem analysis, breaking down the generation of total CO_2 emissions (direct and indirect) of the 18 activities that make up the services subsystem into 6 sources. Total emissions of the services subsystem were a third of the emissions for the year 2018. Although it is known that transport is a well-known relevant actor in overall CO_2 emissions, our decomposition provides a clearer view of the direct and indirect pollution channels of other relevant service sectors. We detect several service sectors with an insignificant level of direct CO_2 emissions and a high level of total emissions. This is the case of trade services, real estate services, services provided by professionals, telecommunications or the government public administration. These sectors induce the generation of emissions from other sectors inside and outside the services subsystem. The results inform the design of policies to mitigate CO_2 emissions in Ecuador.

Keywords: Input–output subsystem, CO_2 emissions, Service sectors, Spillover, Energy policy

1 Introduction

70% of the world's biological megadiversity is concentrated in just 18 countries (Scarano et al. 2021). These countries bear the greatest burden of conserving the Earth's biodiversity and have the great responsibility to conserve it. This weight seems to be even more concentrated in Latin America and the Caribbean, where 9 of the 17 most megadiverse countries in the world are located (Bolivia, Brazil, Colombia, Costa Rica, Ecuador, Guatemala, Mexico, Peru, and Venezuela); but at the same time this region is home to 10 of

the 35 areas known as "hotspots"; that is, areas of great concern worldwide due to their dual condition of high biodiversity and threat (Zhang et al. 2023).

Despite the environmental importance of this area, the threat of worsening the situation is high since these are developing countries, with high political and economic problems, where decision-making in environmental matters can be complex. For example, the greenhouse gas emissions generated per million dollars of each country's GDP presented in Fig. 1 show the heterogeneity of this group of countries.

Although a significant reduction in greenhouse gas emissions is observed for this group of countries, this reduction is more notable in the case of Venezuela and Costa Rica (95.3% and 83.1%, respectively). Ecuador presents a smaller reduction (72.1%), being the third with the smallest reduction during the analysis period and ranking in 2018 as the third country with the highest greenhouse gas emissions of the 7 analyzed.

When analyzing CO_2 emissions per capita for 2018 from some sectoral activities such as buildings, electricity and transportation, differences are also observed in the structure of pollution for this group of countries. The highest CO_2 emissions per capita in transportation are found in Mexico, Costa Rica and Ecuador (with 1.19, 1.13 and 1.10 tons, respectively); while for electricity, Venezuela and Mexico have CO_2 emissions per capita well above the rest of the countries (1.92 and 1.52 tons, respectively); and, finally, in buildings, the highest CO_2 emissions per capita are in Ecuador with 0.22 tons, Mexico and Venezuela with 0.17 tons each (Fig. 2).

Of these 9 countries, Ecuador is an interesting case study to deepen the analysis of the existing relationships between productive structures and the effects that their interrelation generates on the environment, since it is considered the most megadiverse country in the world per square kilometer and its Amazon is considered one of the last wild areas of high biodiversity in the world (Bass et al. 2010; García, 2014).

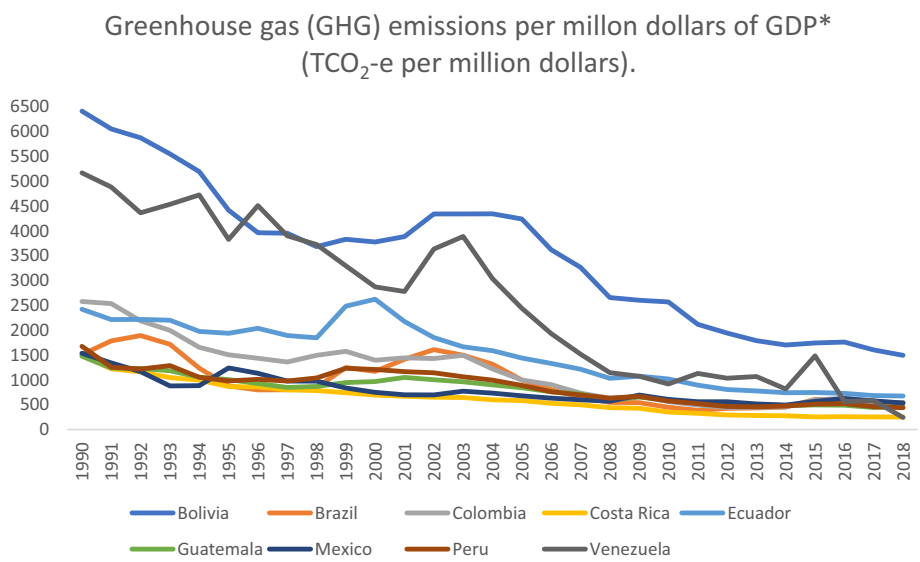

Fig. 1 Greenhouse gas emissions per millions dollars of GDP for most megadiverse countries in the world located in Latin America and the Caribbean. *Total excluding land use change and forestry. Source: prepared by the authors based on information of The Economic Commission for Latin America and the Caribbean (CEPALSTAT 2023)

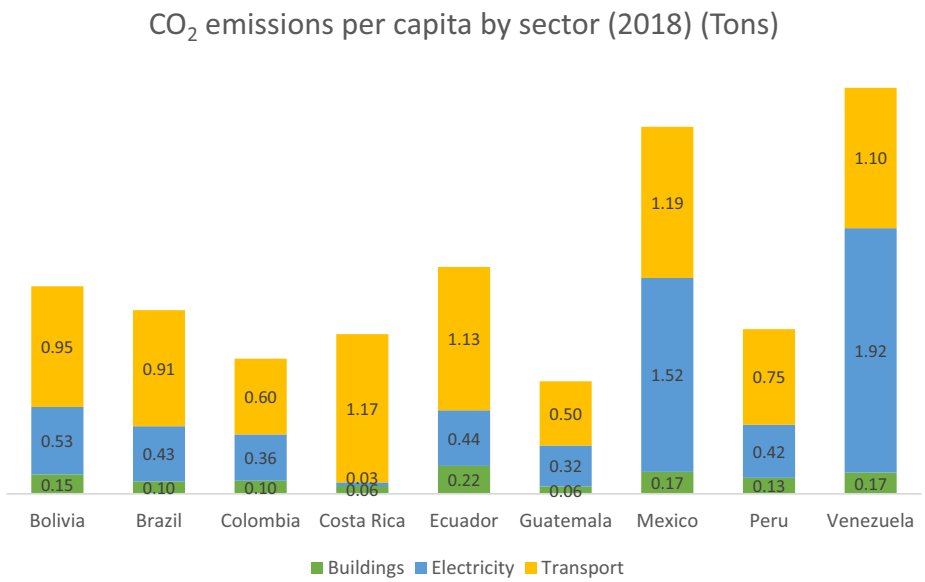

Fig. 2 CO_2 emissions per capita by sector for most megadiverse countries in the world, located in Latin America and the Caribbean (2018). Source: prepared by the authors based on information of Climate Analysis Indicators Tool (CAIT 2023) (2018) via Our World in Data

Mestanza-Ramón et al. (2020), citing various authors (Meza 2002; Donald et al. 2019; Mestanza et al. 2019, among others), points out that Ecuador has a diversity of geographical zones and climatic floors that allows it to have several ecosystems that are home to 16% of the world's bird species, 8% of amphibians, 5% of reptiles, and 8% of mammals, among other. Despite being a country that has signed various international agreements for environmental conservation, being a pioneer in establishing constitutional rights to nature and creating laws declaring biodiversity as a strategic resource of the State, environmental pollution continues to grow, due to the continuous increase in the use of petroleum derivatives, generating serious implications for the environment (Arroyo and Miguel 2019).

According to the Ministry of Energy and Non-Renewable Natural Resources (MERNNR 2018), Ecuador's per capita energy consumption grew by 15.3% between 2008 and 2018, from 4.77 to 5.50 Barrels of Oil Equivalent (BOE) per capita. The highest growth occurred between 2008 and 2013, with an average annual rate of 2.5%. Oil was the most important primary energy source. An average production of 189 million barrels of oil was registered between 2008 and 2018, reaching the historical maximum between 2013 and 2014, with an annual production of 203 million barrels. In 2018, primary energy production was 216 million BOE. Fossil sources represented 87.5% and only 7.8% were sources of renewable origin, despite the fact that the share of energy from renewable sources increased by 33% in that period.

The National Energy Agenda 2016–2040 establishes that "Greenhouse gas emissions from energy projects will be kept at their lowest possible levels" (MCSE 2016). The Ministry of Electricity and Renewable Energy (MEER 2017) set out, in the National Plan for Energy Efficiency 2016–2035 (PLANEE), the goal of a minimum threshold

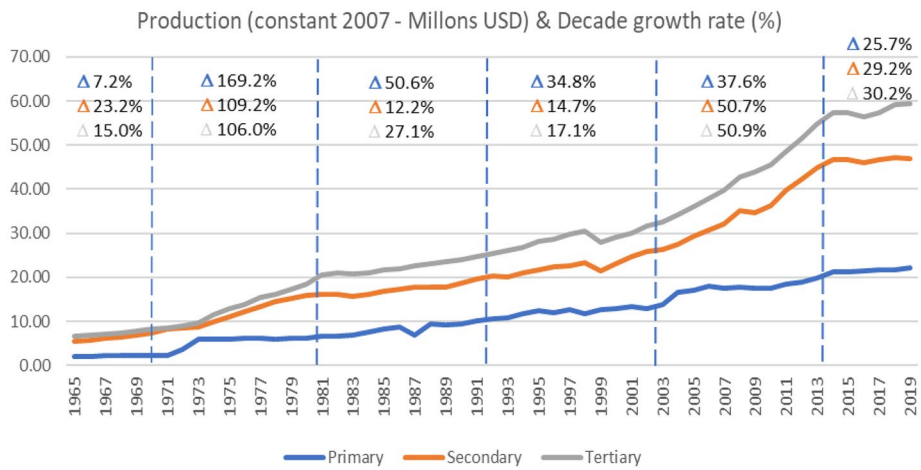

Fig. 3 Primary, secondary and tertiary production in Ecuador (1965–2019). Source: prepared by the authors based on information of Central Bank of Ecuador (BCE)

of energy saved of 543 million BOE. This saving would represent approximately USD 84,131 million and an estimated reduction of 65 $MtCO_2eq$.

However, achieving these objectives is complex. Ecuador has one of the largest projections of demand for fossil energy consumption at the regional level, due to the consumption of fuel oil in thermal power plants, the industrial sector and transportation, as well as the low participation of natural gas in the energy mix (Chavez-Rodriguez et al. 2018). Although there is potential in Ecuador to have alternative sources of renewable energy, such as wind or solar (Cevallos-Sierra and Ramos-Martin 2018), these changes require strong investments and long-term policies. A major transformation in the short and medium term, dismantling fossil fuel production, modifying highly energy-intensive industries and substituting renewable energy for fossil fuels, would be a difficult challenge.

An integrating vision between the economy and the environment can help to achieve the goals of reducing CO_2 emissions, delving into the interactions that exist between the productive sectors and demystifying the importance of certain activities in environmental pollution. This would help visualize additional environmental mitigation strategies. Services are a clear example of this complexity since they are the sectors with the highest growth in recent decades. Figure 3 shows the evolution of sectoral production from 1965 to 2019 for Ecuador. Since the 1970s, the country began its oil exploitation, generating significant growth throughout the economy. The tertiary sector has been a relevant actor throughout history. It has outperformed primary and secondary sectors and, in the last two decades, has shown the highest growth rates.

However, except for transportation, other service sectors, such as trade services, real estate, or telecommunications, among others, have gone unnoticed by mitigation policy policymakers in Ecuador, since efforts have been focused on the sectors historically considered as the main polluters (Buenaño et al. 2021). Ignoring the sectoral interrelationships that exist in an economy, where the service sectors are relevant in productive terms, limits the possibilities of analysis and the policies that could be generated to reduce pollution more efficiently.

Input–output models and their extensions are useful analysis tools for this purpose. Among these extensions are the "input–output subsystems", which, applied to the environment, aim to break down the different channels through which the emissions generated by the productive activities of a given subsystem are produced and transmitted. This technique was originally proposed by Sraffa (1960) and enables independent analysis of the productive structure of each subsystem that makes up the economic system without separating it from the rest of the economy. The technique enables underlying patterns that are behind the generation of environmental pollution to be determined, by isolating the relationships of a sector or group of sectors in relation to the entire system. In this way, valuable and specific information is obtained on the production relations of a sector (or group of sectors) and the impacts that can be generated (Alcántara and Padilla 2009).

Pasinetti (1973, 1988), Deprez (1990) and Scazzieri (1990), among others, worked on the original approach of subsystems. Alcántara (1995) developed this tool from an environmental point of view, which was extended by Sánchez-Chóliz and Duarte (2003) incorporating elements of additive decomposition to their analysis to give the model greater explanatory power. The analysis of subsystems applied to environmental issues has made it possible to better understand the channels through which environmental pollution is generated. Navarro and Alcántara (2010) and Navarro (2012) use it to understand methane emissions from the Catalan agri-food subsystem; Llop and Tol (2013) for the greenhouse gas emissions of the Irish economy. Alcántara and Padilla (2009), Ge and Lei (2014) or Piaggio et al. (2015) have used the input–output subsystems to show the relevance of the service sectors in the indirect pollution of CO_2 emissions in Spain, the city of Beijing and Uruguay, respectively. Zhou et al. (2019) show the importance of tertiary activities—specifically the role of information and communication technologies—in the generation of CO_2 emissions in China, demonstrating that these activities induce significant amounts of emissions through their need for carbon-intensive intermediate inputs. This is also evidenced by Zhen and Li (2021) in their analysis of the formation and transmission of carbon emission responsibilities between sectors in the Zhejiang province in China.

We decompose the subsystem into six components (own net, internal feedback, internal spillover, scale, external feedback and external spillover) (as done in Navarro 2012[1]; or Piaggio et al. 2015), in order to provide greater explanatory power and depth to the analysis, It is relevant to carry out this decomposition into 6 components since the indicated references have shown that it is possible to delve deeper into the interrelationships that occur within the subsystem and disaggregate what happens within it into more elements. This allows us to better understand the origin of the flows, disaggregating the internal effect, so that the conclusions and recommendations drawn from the analysis can be better refined.

Given the importance of the service sectors in economic development and their influence on environmental pollution, our objective is to identify those service sectors that, due to their direct or indirect influence on the generation of emissions, may be

[1] Particularly, the method we used is similar to that used by Navarro (2012), but although we reached the same decomposition, the path we used is different as it is simpler and more direct. However, it is worth noting that the main novelty of this research compared to said work is that we apply the decomposition for the analysis of CO_2 emissions of the services subsystem for the Ecuadorian case.

relevant for the design of mitigation policies. In addition, like Ecuador, other developing countries depend on primary-export activities, but their economies also have a growing weight of service activities. These economies are especially sensitive to the effects of global warming. Therefore, the analysis of CO_2 emissions from the services subsystem of a country like Ecuador can help to identify the main emission sources and develop mitigation strategies that can be applied in other countries or regions with similar characteristics. This analysis should make it possible to find a better balance between economic development and environmental sustainability.

The article is structured as follows. The second section presents the methodology used for the analysis of the services subsystem in CO_2 emissions. The third section provides a brief description of the data used. The fourth section presents and discusses the results. Finally, the fifth section presents the conclusions.

2 Methodology for the subsystem analysis

We start from the Leontief model $\mathbf{Ax} + \mathbf{y} = \mathbf{x}$, where $\mathbf{A}$ is the matrix of coefficients or technical requirements, $\mathbf{x}$ is the vector of total domestic production and $\mathbf{y}$ is the vector of final demand. $\mathbf{x}$ can be expressed as $(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$, being $(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{B}$, the Leontief inverse matrix.[2] If we denote by S those activities that belong to the subsystem of interest and by M those activities that are outside the subsystem, and, isolating the production that is required only for the subsystem, as presented in Alcántara and Padilla (2009) the model can be written as $\begin{pmatrix} \mathbf{B}_{\mathrm{MM}} & \mathbf{B}_{\mathrm{MS}} \\ \mathbf{B}_{\mathrm{SM}} & \mathbf{B}_{\mathrm{SS}} \end{pmatrix} \begin{pmatrix} 0 \\ \mathbf{y}^{\mathrm{S}} \end{pmatrix} = \begin{pmatrix} \mathbf{x}_{\mathrm{S}}^{\mathrm{M}} \\ \mathbf{x}_{\mathrm{S}}^{\mathrm{S}} \end{pmatrix}$, which shows the production necessary to obtain the final demand of the sectors belonging to subsystem S. Rewriting this expression as $\left[\begin{pmatrix} \mathbf{B}_{\mathrm{MM}} & \mathbf{B}_{\mathrm{MS}} \\ \mathbf{B}_{\mathrm{SM}} & \mathbf{B}_{\mathrm{SS}} \end{pmatrix} - \begin{pmatrix} \mathbf{I} & 0 \\ 0 & \mathbf{I} \end{pmatrix} \right] \begin{pmatrix} 0 \\ \mathbf{y}^{\mathrm{S}} \end{pmatrix} + \begin{pmatrix} 0 \\ \mathbf{y}^{\mathrm{S}} \end{pmatrix} = \begin{pmatrix} \mathbf{x}_{\mathrm{S}}^{\mathrm{M}} \\ \mathbf{x}_{\mathrm{S}}^{\mathrm{S}} \end{pmatrix}$, the total production necessary to provide the total final demand of subsystem S can be broken down into a system of two equations (Navarro and Alcántara 2010):

$$\mathbf{B}_{\mathrm{MS}}\mathbf{y}^{\mathrm{S}} = \mathbf{x}_{\mathrm{S}}^{\mathrm{M}}, \tag{1}$$

$$(\mathbf{B}_{\mathrm{SS}} - \mathbf{I})\mathbf{y}^{\mathrm{S}} + \mathbf{y}^{\mathrm{S}} = \mathbf{x}_{\mathrm{S}}^{\mathrm{S}}. \tag{2}$$

Moreover, expression $(\mathbf{B}_{\mathrm{SS}} - \mathbf{I})\mathbf{y}^{\mathrm{S}}$ contains useful information that can be disaggregated using the piecewise inverse computation for the matrix $\mathbf{B}_{\mathrm{SS}}$:

$$\mathbf{B}_{\mathrm{SS}} = (\mathbf{I} - \mathbf{A}_{\mathrm{SS}})^{-1}(\mathbf{I} + \mathbf{A}_{\mathrm{SM}}\mathbf{B}_{\mathrm{MS}}). \tag{3}$$

Replacing (3) in (2) and operating we have: $\left[(\mathbf{I} - \mathbf{A}_{\mathrm{SS}})^{-1} - \mathbf{I}\right]\mathbf{y}^{\mathrm{S}} + \left[(\mathbf{I} - \mathbf{A}_{\mathrm{SS}})^{-1}\mathbf{A}_{\mathrm{SM}}\mathbf{B}_{\mathrm{MS}})\right]\mathbf{y}^{\mathrm{S}} + \mathbf{y}^{\mathrm{S}} = \mathbf{x}_{\mathrm{S}}^{\mathrm{S}}$.

Therefore, the system of Eqs. (1) and (2) can be rewritten as:

$$\mathbf{B}_{\mathrm{MS}}y^{\mathrm{S}} = \mathbf{x}_{\mathrm{S}}^{\mathrm{M}}, \tag{4}$$

[2] The matrices are represented by uppercase letters, while the vectors are represented by lowercase letters. Both vectors and matrices are indicated with bold. The symbol "^" represents the diagonalization of a vector.

$$\left[(\mathbf{I}-\mathbf{A}_{\mathrm{SS}})^{-1}-\mathbf{I}\right]\mathbf{y}^{\mathrm{S}}+(\mathbf{I}-\mathbf{A}_{\mathrm{SS}})^{-1}\mathbf{A}_{\mathrm{SM}}\mathbf{B}_{\mathrm{MS}}\mathbf{y}^{\mathrm{S}}+\mathbf{y}^{\mathrm{S}}=\mathbf{x}_{\mathrm{S}}^{\mathrm{S}}. \tag{5}$$

Expression (5) shows the decomposition of the output of subsystem S into three elements: the production of the subsystem for itself in order to obtain its final demand (first term to the left of equality). The second summand to the left of the equality represents the production for other sectors as a consequence of the production of those for the subsystem. Clear feedback on the subsystem from outside the subsystem. And lastly, the net output of the subsystem is the third summand.

If in expression (5) we calculate the inverse $(\mathbf{I}-\mathbf{A}_{\mathrm{SS}})^{-1}$ in parts, we can arrive at a broader estimate of the production components. Thus, knowing that the main diagonal elements of the Leontief inverse are given by $\mathbf{b_{jj}}=\left(1-\mathbf{a_{jj}}\right)^{-1}+\left(1-\mathbf{a_{jj}}\right)^{-1}\sum_{\mathbf{i}\neq\mathbf{j}}\mathbf{a_{ji}}\mathbf{b_{ij}}$; and, again using the piecewise inverse computation for the matrix $(\mathbf{I}-\mathbf{A}_{\mathrm{SS}})$, from expression (5), we have:

$$(\mathbf{I}-\mathbf{A}_{\mathrm{SS}})^{-1}=(\mathbf{I}-\mathbf{A}_{\mathrm{SS}}^{\mathrm{D}})^{-1}+(\mathbf{I}-\mathbf{A}_{\mathrm{SS}}^{\mathrm{D}})^{-1}\otimes\left[\mathbf{A}_{\mathrm{SS}}^{0}(\mathbf{I}-\mathbf{A}_{\mathrm{SS}})^{-1}\right]+\left[(\mathbf{I}-\mathbf{A}_{\mathrm{SS}})^{-1}\right]^{0}, \tag{6}$$

where matrix $\mathbf{A}_{\mathrm{SS}}^{\mathrm{D}}$ contains the main diagonal of $\mathbf{A}_{\mathrm{SS}}$ while the rest of its elements are zero; the matrix $\mathbf{A}_{\mathrm{SS}}^{0}$ contains zeros on its main diagonal and off its diagonal are the rest of the elements of the matrix $\mathbf{A}_{\mathrm{SS}}$. Such that $\mathbf{A}_{\mathrm{SS}}=\mathbf{A}_{\mathrm{SS}}^{\mathrm{D}}+\mathbf{A}_{\mathrm{SS}}^{0}$, as shown in Alcántara and Padilla (2009). Also $\otimes$ represents the Hadamard product, that is, the element-by-element product of two matrices, the second term of expression. Note that taking into account that b_{ij} are the elements of the matrix $(\mathbf{I}-\mathbf{A}_{\mathrm{SS}})^{-1}$, it is evident that the second summand is nothing but a diagonal matrix that collects, for each of the sectors belonging to the subsystem, the computation of $\left(1-\mathbf{a_{jj}}\right)^{-1}\sum_{\mathbf{i}\neq\mathbf{j}}\mathbf{a_{ji}}\mathbf{b_{ij}}$ to which we referred earlier.

Replacing (6) in the system of Eqs. (4) and (5) and conveniently adding and subtracting the identity matrix, the system of equations can be written as:

$$\mathbf{B}_{\mathrm{MS}}\mathrm{y}^{\mathrm{S}}=\mathbf{x}_{\mathrm{S}}^{\mathrm{M}}, \tag{7}$$

$$\begin{aligned}&\left[\left(\mathbf{I}-\mathbf{A}_{\mathrm{SS}}^{\mathrm{D}}\right)^{-1}-\mathbf{I}\right]\mathbf{y}^{\mathrm{S}}+\left\{(\mathbf{I}-\mathbf{A}_{\mathrm{SS}}^{\mathrm{D}})^{-1}\otimes\left[\mathbf{A}_{\mathrm{SS}}^{0}(\mathbf{I}-\mathbf{A}_{\mathrm{SS}})^{-1}\right]\right\}\mathbf{y}^{\mathrm{S}}\\&+\left[(\mathbf{I}-\mathbf{A}_{\mathrm{SS}})^{-1}\right]^{0}\mathbf{y}^{\mathrm{S}}\quad+(\mathbf{I}-\mathbf{A}_{\mathrm{SS}})^{-1}\mathbf{A}_{\mathrm{SM}}\mathbf{B}_{\mathrm{MS}}\mathbf{y}^{\mathrm{S}}+\mathbf{y}^{\mathrm{S}}=\mathbf{x}_{\mathrm{S}}^{\mathrm{S}}.\end{aligned} \tag{8}$$

We arrive at the decomposition reached in Navarro (2012),[3] using some changes from an operational perspective.

Thus, the components of the left side of expressions (7) and (8) represent the following:

[3] It should be noted that Ge and Lei (2014) use a similar but simpler decomposition, with only 5 components. Furthermore, a similar decomposition is found in Piaggio et al. (2015), although the authors start from a multiplicative decomposition, which they then combine with an additive decomposition. However, for our interests we consider that the decomposition of Navarro (2012), which is also based on Alcántara and Padilla (2009) like this work, had room for improvement by simplifying the path used to obtain the results more directly.

$\mathbf{B}_{\mathrm{MS}}\mathbf{y}^{\mathrm{S}}$: represents the spillover component, also known as backward linkage or pure pull component, which is generated by the production of inputs that must be carried out by sectors that do not belong to subsystem S to satisfy the input demand of the sectors of the subsystem.

$\left[\left(\mathbf{I}-\mathbf{A}_{\mathrm{SS}}^{\mathrm{D}}\right)^{-1}-\mathbf{I}\right]\mathbf{y}^{\mathrm{S}}$: represents the own net component. That is, the production associated with the own inputs that each sector of the subsystem S needs to satisfy its own final demand.

$\left\{(\mathbf{I}-\mathbf{A}_{\mathrm{SS}}^{\mathrm{D}})^{-1}\otimes\left[\mathbf{A}_{\mathrm{SS}}^{0}(\mathbf{I}-\mathbf{A}_{\mathrm{SS}})^{-1}\right]\right\}\mathbf{y}^{\mathrm{S}}$: represents the internal feedback component, which expresses the production that each sector of the subsystem must generate to provide inputs to the rest of the sectors of the subsystem S, so that they generate the production that is then demanded by the sectors of the subsystem.

$\left[(\mathbf{I}-\mathbf{A}_{\mathrm{SS}})^{-1}\right]^{0}\mathbf{y}^{\mathrm{S}}$: represents the internal spillover component, which includes the pull effect generated by the sectors belonging to subsystem S, but on the subsystem itself.

$(\mathbf{I}-\mathbf{A}_{\mathrm{SS}})^{-1}\mathbf{A}_{\mathrm{SM}}\mathbf{B}_{\mathrm{MS}}\mathbf{y}^{\mathrm{S}}$: represents the external feedback component, which is generated by the production of inputs that each sector of the subsystem S must make to supply the rest of the sectors that do not belong to the subsystem, so that they generate the production that then the sectors of the subsystem S demand.

$\mathbf{y}^{\mathrm{S}}$: represents the scale component, which is generated exclusively by the final demand of the subsystem S.

If the vector $\mathbf{y}^{\mathrm{S}}$ is replaced by its diagonalization $\widehat{\mathbf{y}}^{\mathrm{S}}$, the expressions described will remain in the form of a matrix, so the sum by columns of this matrix enables knowing the impact of any sector of the subsystem on the rest of the sectors of the subsystem.

Finally, the described analysis can be extended to an environmental variable to measure the different effects generated by each productive sector or group of sectors belonging to a subsystem. In this sense, let $\mathbf{c}$ be a vector of CO_2 emissions generated per unit of production; the vector $\mathbf{c}$ can be broken down into $\mathbf{c}^{\mathrm{M}}$ corresponding to the CO_2 emissions of the activities belonging to the subsystem M, and $\mathbf{c}^{\mathrm{S}}$ corresponding to the CO_2 emissions of the activities belonging to the subsystem S. The different components analyzed above can now be expressed in terms of CO_2 emissions related to a given subsystem, according to the following set of vectors:

Net own component:

$$\mathbf{CPN}=\mathbf{c}^{\mathbf{S}'}\left[\left(\mathbf{I}-\mathbf{A}_{\mathrm{SS}}^{\mathrm{D}}\right)^{-1}-\mathbf{I}\right]\widehat{\mathbf{y}}^{\mathrm{S}}, \tag{9}$$

Internal feedback component:

$$\mathbf{CFI}=\mathbf{c}^{\mathbf{S}'}\left\{(\mathbf{I}-\mathbf{A}_{\mathrm{SS}}^{\mathrm{D}})^{-1}\otimes\left[\mathbf{A}_{\mathrm{SS}}^{0}(\mathbf{I}-\mathbf{A}_{\mathrm{SS}})^{-1}\right]\right\}\widehat{\mathbf{y}}^{\mathrm{S}}, \tag{10}$$

Internal spillover component:

$$\mathbf{CSI}=\mathbf{c}^{\mathbf{S}'}\left[(\mathbf{I}-\mathbf{A}_{\mathrm{SS}})^{-1}\right]^{0}\widehat{\mathbf{y}}^{\mathrm{S}}, \tag{11}$$

Scale component:

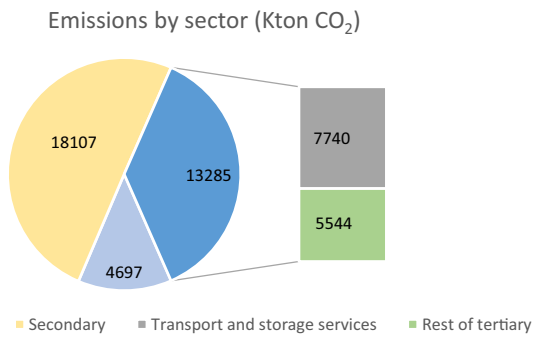

Fig. 4 Direct CO_2 emissions by sector. Source: prepared by the authors based on Annex 1

$$\mathbf{CE} = \mathbf{c}^{\mathbf{S}'}\widehat{\mathbf{y}}^{\mathrm{S}}, \tag{12}$$

External feedback component:

$$\mathbf{CFE} = \mathbf{c}^{\mathbf{S}'}(\mathbf{I} - \mathbf{A}_{\mathrm{SS}})^{-1}\mathbf{A}_{\mathrm{SM}}\mathbf{B}_{\mathrm{MS}}\widehat{\mathbf{y}}^{\mathrm{S}}, \tag{13}$$

External spillover component:

$$\mathbf{CSE} = \mathbf{c}^{\mathbf{M}'}\mathbf{B}_{\mathrm{MS}}\widehat{\mathbf{y}}^{\mathrm{S}}, \tag{14}$$

in such a way that the total, direct and indirect, pollution associated with the production of the subsystem is defined as the sum of Eqs. (15) to (20), as follows:

$$\mathbf{E} = \mathbf{CPN} + \mathbf{CSI} + \mathbf{CFI} + \mathbf{CE} + \mathbf{CFE} + \mathbf{CSE}. \tag{15}$$

3 Data description

Ecuador does not have official figures for CO_2 emissions disaggregated by economic sector. Therefore, we follow the proposal by Buenaño et al. (2021) based on the method by Alcántara and Roca (1995) to estimate the CO_2 emissions by economic activity for the year 2018 for the 71 sectors that make up the input–output matrix. We built a vector total of primary and secondary energy used by each sector with data on energy balances published by the International Energy Agency (IEA 2021), data on energy balances published by the Coordinating Ministry of Strategic Sectors of Ecuador (MCSE 2018) and final energy consumption data disaggregated in supply and use tables provided by Banco Central de Ecuador (BCE). We then estimated a vector of CO_2 emissions with conversion factors from IPCC (2008). The estimate made for the year 2018 is presented in the Annex. Based on that estimate, Fig. 4 shows the CO_2 emissions for the 71 activities, grouping them into primary, secondary and tertiary sectors.

The direct emissions of the service sectors were 13,284 kt of CO_2 (7740 kt of CO_2 corresponds only to transport service and 5544 kt of CO_2 corresponds to rest of tertiary sector), which represents 37% of the total emissions generated in Ecuador in 2018, compared to 18,107 kt of CO_2 from secondary sectors and the 4697 kt of CO_2 from primary sectors, which represent 50% and 13%, respectively. Although the secondary sectors have a greater responsibility for CO_2 emissions, the service sectors are directly responsible

Table 1 *Direct and total CO_2 emissions generated by service sectors*

Cod	Activity	Direct emission (KtCO2)	%	Total emission (KtCO2)	%
54	Trade services	1033	2.9%	1775	4.9%
55	Repair and maintenance services of motor vehicles and motorcyles	15	0.0%	19	0.1%
56	Accommodation services	194	0.5%	164	0.5%
57	Restaurant services	1119	3.1%	1338	3.7%
58	Transport and storage services	7740	21.4%	4922	13.6%
59	Postal and courier services	32	0.1%	44	0.1%
60	Telecommunications, transmission and information services	559	1.5%	922	2.6%
61	Financial intermediation services	89	0.2%	190	0.5%
62	Insurance services and pension funds	11	0.0%	50	0.1%
63	Real estate services	199	0.6%	757	2.1%
64	Services provided to companies and production	1142	3.2%	131	0.4%
65	Administrative services of the government and for the community in general	499	1.4%	968	2.7%
66	Private education services	15	0.0%	99	0.3%
67	Public education services	159	0.4%	394	1.1%
68	Social and health services	15	0.0%	78	0.2%
69	Non-market social and health services	168	0.5%	527	1.5%
70	Association services, leisure, cultural and sports	296	0.8%	446	1.2%
71	Domestic service	0	0.0%	0	0.0%
	Rest of economy	22,804		23,266	
	Total services	13,285	36.8%	12,823	35.5%
	Total	36,088		36,088	

Source: prepared by the authors

for more than a third of the emissions from the productive system. This is very relevant, since service sectors, with the exception of transport, are not usually considered important actors in CO_2 emissions, due to the false belief that their activity, unlike the manufacturing sector, is dematerialized (Alcántara 2007). However, several studies have shown the importance of these sectors regarding CO_2 emissions (Alcántara and Padilla 2009; Gadrey 2010; Nansai et al. 2009; Piaggio et al. 2015; Suh 2006), particularly when considering the indirect emissions, they induce in other sectors.

Table 1 presents the emissions generated by the service sectors (direct and total). It should be remembered that if only direct emissions were considered, the fact that a large part of the emissions emitted by certain productive sectors serves to facilitate the productive process of other sectors would be ignored. In other words, looking only at direct emissions would ignore that the production of an activity requires the production of goods or services from other activities. Thus, of the 36,088 kt of CO_2 emitted by the entire production system in 2018, 13,285 kt of CO_2 were generated directly by service sectors (36.8% of total emissions generated by the productive system), but if total emissions (direct and indirect) are considered, the emission was 12,823 kt of CO_2 (35.5% of emissions), with a significantly different distribution among the different service sectors.

Although the total emissions of the subsystem are 1.3% lower than the direct ones, it can be seen in Table 1 that, except for the sectors "Transport and storage services", "Services provided to companies and production", and "Accommodation services", the other service sectors have a percentage of total emissions greater than their direct emissions. This is because most service sectors are characterized by a significant demand for the production of other sectors to generate their production, which implies that they are also indirectly responsible for the emissions generated by other production processes. In terms of environmental policy, this is not easy to detect since the interest is generally focused on monitoring direct emissions.

The sector "Transportation and storage services" presents the greatest decrease, in absolute terms, in direct emissions compared to total emissions (2818 kt of CO_2). This means that, although transport is a highly polluting activity, about half of its pollution is generated to meet the demand for transportation services that other activities require. Similarly, in terms of environmental policy, knowing these interrelationships makes it possible to improve its design.

Among the service sectors that have more total than direct emissions, the sector "Trade services" stands out, with an increase of 742 kt of CO_2 (a 72% increase). This is due to its high degree of integration with the entire production system as an intermediary link, which makes this sector more relevant than it appears in terms of its direct CO_2 emissions. Other sectors that also have greater total than direct emissions are the sectors "Real estate services", with an increase of 558 kt of CO_2 (281% increase), "Administrative services of the government and for the community in general", with an increase of 470 kt of CO_2 (a 94% increase), "Telecommunications, transmission and information services", which changes from 559 kt of CO_2 to 922 kt of CO_2 (an increase of 65%), "Non-market social and health services" with an increase of 359 kt of CO_2 (a 214% increase), and "Restaurant services", with an increase of 219 kt of CO_2 (a 20% increase).

4 Results and discussion

Applying the methodology described in the previous section, Table 2 presents the breakdown of the total CO_2 emissions of the services subsystem broken down into the six components calculated from Eqs. (9) to (15).

Breaking down the internal components of the subsystem, of the 12,823 kt of CO_2 of total emissions of the subsystem, 6950 kt of CO_2 correspond to the scale component (54.2%), which is attributable to the final demand of the service sectors. The internal spillover component is one of the most important, with a total of 2112 kt of CO_2 (16.5% of the total emissions of the subsystem). This pull component, unlike the previous one, is caused within the subsystem itself since it occurs when a sector of the services subsystem demands inputs from other service sectors. The own component, which arises as a consequence of satisfying the own demand of the subsystem's activities, has a small weight of 2.6% of the total emissions of the subsystem. Finally, of the internal components of the subsystem, the pollution generated by the production that one activity sells to another so that the latter can use it in its production process, generating outputs that will be sold to the first activity, called the internal feedback component, is the smallest component with barely 0.3% of the total emissions generated by the subsystem.

Table 2 Breakdown of total emissions of the services subsystem by economic sector

Cod	Sector	Own net	%	Internal spillover	%	Internal feedback	%	Scale	%	External feedback	%	External spillover	%	Total	%
54	Trade services	5.9	2	817.9	39	2.7	8	538.1	8	17.4	7	393.2	13	1775	14
55	Repair and maintenance services of motor vehicles and motorcycles	0.0	0	5.6	0	0.0	0	6.0	0	0.7	0	6.5	0	19	0
56	Accommodation services	0.0	0	13.8	1	0.0	0	110.4	2	4.2	2	35.6	1	164	1
57	Restaurant services	0.3	0	73.1	3	0.4	1	980.0	14	46.8	19	237.1	8	1338	10
58	Transport and storage services	282.8	84	102.3	5	29.4	84	3,510.2	51	21.9	9	975.3	31	4922	38
59	Postal and courier services	–	0	13.7	1	0.0	0	19.5	0	0.5	0	9.9	0	44	0
60	Telecommunications, transmission and information services	23.4	7	180.9	9	1.2	3	442.6	6	15.5	6	257.9	8	922	7
61	Financial intermediation services	2.1	1	84.8	4	0.2	1	37.7	1	5.9	2	59.2	2	190	1
62	Insurance services and pension funds	2.3	1	25.6	1	0.0	0	4.5	0	1.8	1	15.7	1	50	0
63	Real estate services	6.9	2	316.0	15	0.3	1	157.6	2	33.1	13	243.3	8	757	6
64	Services provided to companies and production	7.5	2	19.4	1	0.7	2	75.4	1	1.3	1	27.1	1	131	1
65	Administrative services of the government and for the community in general	0.2	0	159.0	8	0.0	0	494.0	7	28.1	11	287.0	9	968	8
66	Private education services	0.0	0	34.2	2	0.0	0	15.0	0	7.3	3	42.2	1	99	1
67	Public education services	–	0	85.9	4	–	0	159.3	2	14.3	6	134.3	4	394	3
68	Social and health services	0.0	0	20.3	1	0.0	0	14.8	0	5.8	2	37.3	1	78	1
69	Non-market social and health services	–	0	91.1	4	–	0	167.8	2	28.9	12	238.7	8	527	4
70	Association services, leisure, cultural and sports	6.5	2	68.4	3	0.2	1	216.9	3	16.2	6	137.5	4	446	3
71	Domestic service	–	0	–	0	–	0	–	0	–	0	–	0	0	0
	Total emissions service sectors	338	100	2112	100	35	100	6950	100	250	100	3138	100	12,823	100
	% of total CO_2 emissions	0.8%		5		0.1		16.5		0.6		7.5		35	

Source: prepared by the authors

In terms of external components, the external spillover or pure pull component is the second component in importance is, with 3183 kt of CO_2, (24.5% of the total emissions of the subsystem), which shows the high linkage of the services subsystem with the rest of the economy. This is one of the most relevant in terms of policy analysis, since it captures the indirect emissions induced by the services subsystem, but which are usually attributed (directly) to other activities that are outside the subsystem. Finally, the external feedback component, similar to that described in the previous paragraph, but generated between the activities of the subsystem and those that are outside of it, also has a marginal weight since it represents only 1.9% of total emissions of the subsystem.

These results, although with different nuances, coincide with what was found in similar studies for other contexts, such as Alcántara and Padilla (2009), Ge and Lei (2014) and Piaggio et al. (2015). The first two find that the external spillover component represents the largest component in the breakdown of total emissions (21.7% and 25.3% of total CO_2 emissions for Spain and the city of Beijing, respectively), giving great importance to this component and to service sectors in mitigation policies proposals. This is due to the high share that services have in their GDP. The case of Uruguay (Piaggio et al. 2015) is more similar to the case of Ecuador, where the external spillover component is relevant, but with less weight than in the other cases (9.3% of total CO_2 emissions for Uruguay). This is due to the size of the economies and the share of the service sectors in GDP, since both the Ecuadorian and Uruguayan economies are primary exporting developing economies.

The proposed decomposition enables demonstrating more clearly the relevance of service sectors in the direct and indirect emissions of CO_2 by sector and to understand the different pollution channels that affect service sectors.

Thus, in the case of the net own component, that is, the one caused by satisfying the own demand, this is concentrated in the sector "Transport and storage services" with 84% of that component, which is equivalent to 282.8 kt of CO_2. For the rest of sectors, this component is minimal or zero.

The internal spillover component, which represents the emissions pulled within the subsystem itself, is concentrated in the sector "Trade services", with 39%; and in the sector "Real estate services", with 15%. It is also worth highlighting sectors such as "Telecommunications, transmission and information services" and "Administrative services of the government and for the community in general", with 9% and 8%, respectively. In general, this component is explained by the strong relationship of the different sectors of the services subsystem with transportation, but the methodology shows that the sector "Services provided to companies and production" is also very important since the demand of this sector on the rest of the subsystem is high: it generates a third (467.29 kt of CO_2) of what is generated by transport in this component (see Table 3).

Similarly, it is interesting to observe that the sector "Administrative services of the government and for the community in general" which, in addition to generating an internal spillover effect with transportation and professional services, also does so with sectors such as "Accommodation services" and "Restaurant services", due to the mobilization generated by the bureaucratic apparatus concentrated mainly in the capital.

In the case of the internal feedback component, almost the entire component is concentrated in the "Transport and storage services" sector with 84% of the total

Table 3 Distribution of the internal spillover component within services subsystem sectors

Activities	Transport and storage services (%)	Services provided to companies and production (%)	Restaurant services (%)	Trade services (%)	Accommodation services (%)	Rest (%)	Total (%)
Trade services	33.3	3.6	0.2	0.0	0.1	1.6	38.7
Real estate services	12.4	2.0	0.1	0.1	0.0	0.3	15.0
Telecommunications, transmission and information services	3.0	4.2	0.7	0.2	0.3	0.3	8.6
Administrative services of the government and for the community in general	2.1	2.2	0.8	0.3	1.1	1.0	7.5
Transport and storage services	0.0	2.5	0.6	0.5	0.3	0.9	4.8
Rest	9.8	7.7	1.5	2.2	1.3	2.9	25.4
Total	60.6	22.1	4.0	3.2	3.2	6.9	100.0

component, followed to a lesser extent by the 8% concentrated in the "Trade services" sector. Although the internal feedback component is very small, its reading is interesting since it shows the strong link between the sectors. Thus, it shows how the production that originates in the transport activity feeds commerce so that the latter produces outputs that will later be sold to transportation. The sum of these interrelationships within the subsystem generates 35 Kt of CO_2.

Finally, the scale component, that is, the one caused by satisfying the final demand of each sector, is also concentrated in sector "Transport and storage services" (with 51%), but other sectors appear, such as "Restaurant services" (with 14%), "Trade services" (with 8%), and sectors "Telecommunications, transmission and information services" and "Administrative services of the government and for the community in general", with 6% each. Together they are responsible for 5964.9 kt of CO_2, which is equivalent to half of the total emissions of the subsystem. In the case of transportation and restaurant services, the scale effect represents approximately three-quarters of their total emissions. In the rest of the sectors indicated, this proportion decreases (see Fig. 5), with a greater weight of indirect pollution channels, which is usual for service sectors.

In the case of emissions generated between the subsystem and the rest of the economy, the external feedback component is concentrated in the "Restaurant services" sector with 19%, followed by "Real state services" with 13%. Likewise, public health and government services represent 12% and 11%, respectively, of this component.

The external spillover component, which corresponds to the pure pulling effect or inducing effect outside the subsystem, the sector "Transportation and storage services" is the most relevant and concentrates 31% of the subsystem's emissions of this

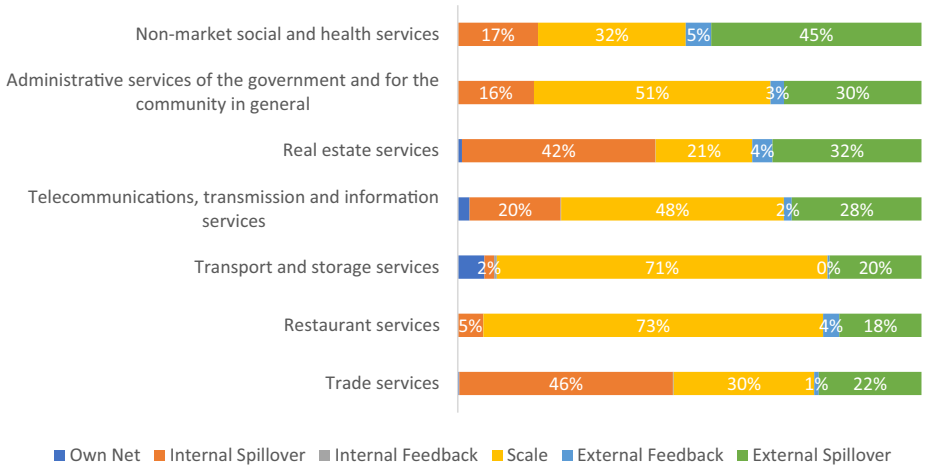

Fig. 5 Weight of the components in total emissions of the main sectors of the services subsystem. Source: prepared by the authors

component, followed by the sector "Trade services" with 13% of those emissions. A set of five sectors that each concentrate 8% of emissions are also significant: "Restaurant services", "Telecommunications, transmission and information services", "Real estate services", "Administrative services of the government and for the community in general", and "Non-market social and health services" (public health).

As shown in Fig. 5, the weight of the external spillover component is very different for each service sector. It represents almost half of the total emissions generated by the sector "Non-market social and health services" (public health), with 45% of the 572 kt of CO_2 that this sector emits, while for the sector "Trade services", it represents 18% of its 1338 kt of CO_2 of total emissions. For the rest of the service sectors, the weight generally fluctuates between 20 and 30% of their total emissions, of which it is worth highlighting the 20% of the spillover component of the sector "Transportation and storage services", which, in absolute terms, constitutes the most important spillover effect (975.3 kt of CO_2).

To delve into the external spillover component, Table 4 presents the distribution of this component among the activities that are outside the services subsystem. The sectors that are induced to emit to a greater extent by the services subsystem are the sector "Refined petroleum oils and other products" and the sector "Electricity", with 57.8% and 19.2% of the external spillover component, respectively. Both activities are transversal in the generation of inputs for the entire subsystem, since in one way or another they are the ones that provide energy to the entire productive apparatus.

Transportation is the sector that generates the greatest impact of the external spillover component (28.4%) due to the link it has with oil refining, followed by trade services, which, given its high link with transportation, also induces oil refining to generate 8.4% of the component's emissions, followed by the emissions that it also induces in the electricity sector (3%).

"Administrative services of the government" and "Telecommunications" also concentrate their emissions with oil refining (4.2% and 3%, respectively) and with electricity (3% and 4.3, respectively).

Table 4 Distribution of the external spillover component among activities outside the services subsystem

Sectors of the services subsystem	(38) Refined petroleum oils and other products (%)	(51) Electricity (%)	(40) Other chemical products (%)	(44) Cement, articles of concrete and stone (%)	(53) Construction and construction works (%)	(12) Crude oil and natural gas (%)	Rest (%)	Total (%)
Transport and storage services	28.4	1.4	0.1	0.0	0.0	0.7	0.4	31.1
Trade services	8.4	3.0	0.2	0.1	0.0	0.2	0.6	12.5
Administrative services of the government and for the community in general	4.2	2.7	0.3	0.1	0.1	0.1	1.6	9.1
Telecommunications, transmission and information services	3.0	4.3	0.0	0.0	0.0	0.1	0.7	8.2
Real estate services	3.9	0.7	0.1	1.2	1.1	0.1	0.8	7.8
Non-market social and health services	1.9	1.4	3.4	0.1	0.1	0.1	0.7	7.6
Restaurant services	1.9	1.2	0.1	0.0	0.0	0.1	4.2	7.6
Rest	6.0	4.6	1.5	0.4	0.3	0.2	3.1	16.1
Total	57.8	19.2	5.7	2.0	1.7	1.5	12.2	100.0

Source: prepared by the authors

Another sector whose inputs are demanded by the subsystem is "Other chemical products", which has a strong link with the sector "Non-market health and social services". Although the magnitude of the component is not high, this information enables us to see how the public sector has another way of reducing emissions indirectly.

In the case of the relations of the subsystem with the sector "Cement, concrete and stone articles" and the sector "Construction and construction works", the chain is due to the activity "Real estate services". In both cases, the percentage and magnitude are similar, which implies that the propagation of the effect is maintained throughout the chain until reaching the stage of the sale of real estate.

In the column of the rest of the sectors that are outside the subsystem, the relationship with the sector "Restaurant services" stands out, since in that column there are primary sectors such as: "Live animals and animal products", "Live or fresh shrimp and shrimp larvae" and "Fish and other aquatic products (except shrimp)".

5 Conclusions and policy implications

The main planning instrument for the efficient use of energy in Ecuador is the National Energy Efficiency Plan 2016–2035 PLANEE, where four planning axes are established (Residential, Commercial and Public Axis; Industrial Axis; Transport Axis; Consumption Axis of the energy sector). Its lines of action are focused on reducing the demand for fossil fuels with energy efficiency and, therefore, reducing CO_2 emissions (MEER 2017). However, we consider that our findings can give a broader vision to policymakers, since the approach with which that planning is developed does not observe all the productive chains that the established axes imply. This limits the possibilities of analysis for the generation of energy policies and the reduction of CO_2 emissions. In addition, knowing the indirect channels of pollution can help to establish standards or incentives so that, when possible, polluting inputs are replaced by cleaner ones.

An example of this is the public administration itself. Thus, for the Residential, Commercial and Public axis, policies are established such as labeling programs, the replacement of equipment with lower energy use, continuous improvement programs and inspection and control measures for the implementation of the Ecuadorian Construction Standard (Energy Efficiency, Air Conditioning and Renewable Energy). We consider these policies adequate, but the public administration has important linkages within the services subsystem itself, as it induces the emissions of sectors, such as transportation, professional services, restaurant services and accommodation services. Both public administration and the sectors mentioned, in turn, have linkages with sectors outside the subsystem (external spillover effect), especially with oil refining and electricity. In this sense, an optimization of the resources used by the public administration could have a domino effect on energy consumption and the CO_2 emissions it generates, both directly and indirectly. For this reason, aspects that could be considered at the policy level are those related to "Green Public Administration". As the European Committee for Democracy and Governance (Council of Europe 2023) points out, the public administration must lead the way in promoting and enforcing emission reductions, protecting the environment, and improving the management of natural resources. Lipinski et al. (2021) consider that the bureaucracy and the public administration cannot be left out of change and some measures that must be adopted include moving to a smaller fleet of vehicles, the adoption of electric vehicles, the energy efficiency of their buildings, as well as the digitization of work that would drastically reduce travel needs.

In a similar vein, telecommunications also have a significant indirect effect, particularly due to the high demand for electricity, which has been increasing as the sector grows. For policymakers, this activity goes unnoticed, but several lines of action could be defined. Although this sector is experiencing very rapid advances, several less energy-efficient technologies (such as 2G or 3G networks) also tend to coexist, which prevents energy consumption from being reduced. Another problem that usually occurs in this sector is that, although efficiency gains are experienced, increases in computing demand and the number of devices can exceed these energy efficiency improvements, causing a rebound effect (Freitag et al. 2021). Therefore, it is important that policies begin to consider this activity in terms of energy consumption and reduction of CO_2 emissions. Wang et al. (2021) analyzed the dissociation between

investments in information and communications technology (ICT) and the intensity of CO_2 emissions for OECD countries, finding that, in most of the countries analyzed, this increase in ICT investments significantly inhibits the increase in emissions, but this depends on the structure and efficiency of the investments. In those countries where the increase in ICT investments has generated a significant increase in CO_2 emissions, it is necessary to increase the proportion of clean and renewable energies and promote energy optimization to achieve the desired objective. This can be a guideline in our analysis case. To promote these investments in ICT and generate the desired multiplier effect, it may be useful to promote credit with preferential interest, terms, and guarantees to finance and promote this development.

Another case is the sector of real estate services, which has a strong link within the subsystem itself with transport and professional services, and outside the subsystem with electricity, cement, and construction. It is clear that real estate services constitute a complex industry that involves several actors that range from the procurement of raw materials to the sale of real estate and includes other activities such as the financial and insurance sectors. For this reason, policies cannot be seen and designed exclusively for the cement industry or isolated standards for construction. As Hoskins (2021) points out, general zero-pollution construction standards should be designed, including all market participants, investors, developers, designers, and occupants, promoting the demand for this type of building. This is precisely where real estate services could contribute to the solution, providing information to owners and investors on the financial and climate impact of projects. Policymakers could drive the generation of such information through incentives or regulations. Authors such as Qashou et al. (2022) in Turkey and Jahanger et al. (2022) in South Africa analyzed the impact of the real estate market on CO_2 emissions and agree that the real estate sector tends to go unnoticed in environmental issues; however, due to its upstream and downstream linkages, it is a sector that must be considered for mitigation. Therefore, policymakers must promote sustainable real estate markets, support green investments in the real estate market, as well as support companies that use and incorporate green energy resources in their investments in the real estate sector.

Another example arises considering one of the results within the subsystem (the internal spillover component) with the activity "Services provided to companies and production", which is one of the activities that suffers the greatest "pull" effect due to the demand from the rest of the activities of the subsystem. In this regard, international experiences indicate that the provision of professional services usually represents an untapped area for reducing greenhouse gas emissions (as in the present case study). However, it is important to take it into account since when a professional services provider is contracted, it becomes part of an organization's supply chain and the greenhouse gas emissions associated with that provider become part of the total emissions of the company's supply chain, becoming shared emissions between the supplier and the organizations that contract it. It is therefore important to encourage professional service providers to adopt more sustainable operational practices through contracting and engagement strategies; for example, reducing business travel and accommodation; or modifying the contract deliverable, which is usually a paper document, plan or report. Even for certain service contracts, such as office supply services and cleaning services, there is an important operational component that could be improved to reduce the emissions they

Table 5 Direct and total emissions from sectors outside the services subsystem

Cod	Activity	Direct emission (KtCO2)	%	Total emission (KtCO2)	%
1	Banana, coffee and cocoa	181	0.5	533	1.5
2	Cereals	60	0.2	13	0.0
3	Flowers and buds	61	0.2	242	0.7
4	Tubers, vegetables, melons and fruits	113	0.3	201	0.6
5	Oilseeds and industrialized products	313	0.9	47	0.1
6	Services related to agriculture	124	0.3	4	0.0
7	Live animals and animal products	390	1.1	387	1.1
8	Forestry products	41	0.1	54	0.1
9	Live or fresh shrimp and shrimp larvae	904	2.5	48	0.1
10	Fish and other aquatic products (except shrimp)	496	1.4	214	0.6
11	Aquaculture products (except shrimp)	37	0.1	42	0.1
12	Crude oil and natural gas	1610	4.5	2809	7.8
13	Services related to oil and natural gas	146	0.4	0	0.0
14	Metallic minerals	116	0.3	53	0.1
15	No metallic minerals	104	0.3	0	0.0
16	Meat, meat products and by-products	192	0.5	724	2.0
17	Elaborated shrimp	281	0.8	1,745	4.8
18	Fish and other processed aquatic products	76	0.2	227	0.6
19	Prepared and preserved fish and other aquatic species	115	0.3	424	1.2
20	Crude and refined oils	39	0.1	159	0.4
21	Processed dairy products	59	0.2	300	0.8
22	Grain mill products	30	0.1	103	0.3
23	Bakery products	61	0.2	166	0.5
24	Noodles, macaroni and other similar farinaceous products	42	0.1	60	0.2
25	Sugar, brown sugar and molasses	86	0.2	129	0.4
26	Elaborated cocoa, chocolate and confectionery products	25	0.1	111	0.3
27	Animal food	14	0.0	28	0.1
28	Processed coffee products	26	0.1	55	0.2
29	Various food products	89	0.2	280	0.8
30	Alcoholic beverages	63	0.2	186	0.5
31	Non-alcoholic beverage	37	0.1	169	0.5
32	Elaborate tobacco	0	0.0	8	0.0
33	Threads, spinning, weaving and confection	97	0.3	86	0.2
34	Clothing	23	0.1	98	0.3
35	Leather, leather products and footwear	17	0.0	53	0.1
36	Products of treated wood, cork and other materials	411	1.1	120	0.3
37	Pulp, paper and cardboard, editorial products and others	103	0.3	59	0.2
38	Refined petroleum oils and other products	9023	25.0	4980	13.8
39	Basic chemical products, fertilizers and primary plastics	27	0.1	12	0.0
40	Other chemical products	540	1.5	351	1.0
41	Rubber products	10	0.0	17	0.0
42	Plastic products	110	0.3	32	0.1
43	Glass, ceramics and refractories	305	0.8	55	0.2
44	Cement, articles of concrete and stone	1234	3.4	0	0.0
45	Common metals	95	0.3	112	0.3
46	Processed metal products	152	0.4	217	0.6
47	Machinery, equipment and electrical appliances	149	0.4	244	0.7
48	Transportation equipment	46	0.1	93	0.3

generate due to transportation logistics. Many of these changes can be achieved with direct influence from buyers, where many times the public administration itself is one of the most important buyers and could promote these contracting practices (West Coast Climate and Materials Management Forum 2023; World Economic Forum 2021).

The policy on sectors such as oil refining or electricity, which are induced to generate emissions to meet the demand for polluting inputs, must be established with measures that generate technological and efficiency improvements, to reduce the pollution generated by those inputs. Such is the case of refined oil and electricity, where the PLANEE lines of action (MEER 2017) indicate working on improving fuels (through partial substitution of fossil fuels with mixture with diesel–biodiesel and extra-ethanol gasoline, using surplus vegetable oil from the African palm industry and the country's sugar industry as raw material), the reduction of energy losses and the implementation of ISO 50001 standard in thermal generation plants, among others, would be in line with the indicated measures, since they would reduce both the direct and indirect emissions to which these activities are being induced. Together with measures such as the vehicle renewal plan, incentives for the incorporation of hybrid and electric vehicles, improvement of fuels and improvement of infrastructure and transport operation would also have a significant impact on the main direct generator of CO_2 emissions, which is transport. A space of opportunity in public policy is the Law for the Promotion of Sustainable Mobility and Electromobility, which has been worked on since 2019. In this, the incorporation of elements such as subsidies conditioned to the importation of imported electric vehicles and the inclusion of tax incentives for the manufacture of electric vehicles as in Thailand or the US can be useful. An environmental bonus for the purchase of an electric vehicle as in France and Germany (REN21, 2023) could also be useful. It should be noted that these measures must focus on small electric vehicles, cargo, and passengers, so that it is in tune with the sustainability and energy efficiency that is sought and taking advantage of the fact that it is a small country that has short distances. Other complementary actions that are not observed in the design of policies should be oriented to issues of education and communication of transportation alternatives, such as minimizing the use of single-occupant vehicles and providing information on alternative transportation.

In summary, several policies implemented and that are being implemented seem to be on the right track, particularly those that directly attack the sources of pollution. However, the use of the tools applied in this article enables to enhance the effectiveness of the policies and the design of new measures on other sectors, since there is disaggregated information that sheds light on the effects that these measures would have.

Abbreviation

BOE Barrels of oil equivalent

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Author contributions

Edwin Buenaño: conceptualization, methodology, formal analysis, investigation, writing—original draft, writing—review and editing. Emilio Padilla: conceptualization, formal analysis, writing—review and editing, supervision. Vicent Alcántara: conceptualization, methodology, formal analysis, writing—review and editing, supervision.

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Availability of data and materials
The vector of total primary and secondary energy used by each sector built for this study is available on request from the authors. The vector of CO2 emissions estimated for the year 2018 is presented in the Annex.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors report there are no competing interests to declare.

Annex
See Table 5.

Table 5 (continued)

Cod	Activity	Direct emission (KtCO2)	%	Total emission (KtCO2)	%
49	Furniture	32	0.1	237	0.7
50	Other manufactured products	89	0.2	20	0.1
51	Electricity	3275	9.1	2345	6.5
52	Water, sanitation and gas services (oil exc)	44	0.1	37	0.1
53	Construction and construction works	1091	3.0	4576	12.7
	Total not services	22,804	63.2	23,266	64.5
	Total	36,088		36,088	

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