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Decomposition analysis from demand services to material production: The case of CO_2 emissions from steel produced for automobiles in Mexico

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HIGHLIGHTS

- Decomposition of CO_2 emissions from demand services to material production, using LMDI.
- Mobility, the main driver of CO_2 emissions for steel production for automobiles.
- The increase in automobile imports to Mexico increased CO_2 emissions.

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ABSTRACT

According to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change, several mitigation strategies for the industrial sector are needed to achieve global mitigation scenarios that include: carbon intensity, energy intensity, material intensity, product-service intensity, and the global demand for services. Under this contextual, this paper presents a decomposition analysis of energy related carbon dioxide emissions from the steel produced to manufacture new automobiles. The novelty of this analysis is that it links energy related carbon dioxide emissions from service demand to material production, breaking changes in demand for services measured as passenger-kilometers driven by new automobiles either for replacement or for new demand; steel content in new automobiles (material intensity); production process (structure); final energy intensity; and carbon intensity. The study boundaries include direct and indirect steel imports (contained in automobile imports). This analysis is applied to the Mexican case from 1993 to 2011. The results show that an increase in the pass-km followed by the growth in the vehicle size is the most important factors influencing carbon dioxide emissions. The rise of fuels with higher carbon contents in countries that export vehicles and steel to Mexico is also an important variable that had increased emissions. A projection for CO_2 emissions for 2025 was developed to understand the significance of the different variables in the reduction of CO_2 emissions related to the steel production for new automobiles.

1. Introduction

One of the main interests in the analysis of trends in energy-related carbon dioxide (CO_2) emissions and future mitigation opportunities has been the identification of drivers of energy changes. Along this line, the decomposition analysis has developed several techniques to single out this impact through decomposing changes in the aggregate energy consumption and CO_2 emissions over time [1–4].

In general, according to Schipper et al. [1,2], decomposition of CO_2 emissions related to energy use can be divided in four explanatory variables: activity, structure, energy intensity and fuel mix [1–7]. This can be express as:

$$C = \sum A * S * I * F \tag{1}$$

Applying Eq. (1) to the industrial sector, A is the activity and is related to industrial production; S refers to structure meaning the industrial activity composition of different industrial branches; I refers to the specific industrial branch energy intensity and F refers to CO_2 content of the fuel mix.

When using monetary units, A refers to the industrial value added; S represents the share of certain industrial branch in total

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industrial value added, I is the energy intensity (energy use of certain industrial branch divided by its specific value added); and F refers to CO_2 emissions of an industrial branch divided by its energy consumption.

An important debate took place in the late nineties regarding the relevance of using either monetary units or physical units for the activity as the main driver of both industrial energy use and GHG emissions. These arguments concluded that, in general, the use of physical units (metric tonnes) improves comprehension of the energy consumption, energy efficiency potential and more detailed explanations for observed changes in the energy intensity [8–10]. However, when physical production is used as the activity, creating a comprehensive decomposition analysis for the industrial sector is difficult because physical units of one industry cannot sum up with another (tonnes of steel cannot be summed with tonnes of cement). For this reason, in general, when physical units are used, a decomposition analysis based on Eq. (1) is used only for a specific industry [11–15].

Yet, an important question in the debate regarding drivers of energy use and GHG emissions in the industrial sector is whether production per se is the ultimate driver of energy consumption. In other words, is the production of cement or steel an end use itself? A few decades ago, Goldemberg et al. [16] noted that energy consumption cannot be an end itself but must be a means to achieve and fulfill basic needs. In this manner of thinking, it is possible to elaborate that industrial production is not an end itself but a means to achieve certain services.

With this in mind, it is possible to elaborate that it is the service provided by certain products that contain a certain amount of material that is the final driver of material production (activity), not production itself. For example, in the case of steel production for the automotive industry, the final end is not steel production but vehicle production that has the final end to move persons or goods. This opens the idea that industrial energy consumption cannot be analyzed in the traditional energy vision that only focuses on the industrial sector but should also explore the demand side and therefore other energy end use sectors.

This wider vision carries out the possibility to analyze energy use and GHG emissions of the industrial sector, linked to other energy end use sectors, as richly explained by Allwood [17–20] and Dahmus [21]. This was recognized in Chapter 10 of the Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [22], where an expansive visualization of industrial emissions was presented in a simplified conceptual expression:

$$G = \frac{G}{E} \times \frac{E}{M} \times \frac{M}{P} \times \frac{P}{S} \times S \tag{2}$$

where G is the GHG emissions of the industrial sector within a specified time (usually one year), E is industrial sector energy consumption and M is the total global production of materials in that period. P is the stock of products created from these materials (including both consumables and durables added to existing stocks), and S is the services delivered in the time period through the use of those products.

The aim of this paper is to present an exercise of a full decomposition of energy related carbon dioxide emissions of steel production for new automobiles, from demand services to material production. Iron and steel industry is the largest industrial source of CO_2 emissions due to the energy intensity of steel production, its reliance on carbon-based fuels, and the large volume of steel produced [23]. It is estimated that steel industry has reduced its energy consumption per tonne of steel produced by 60% from 1960 to 2014, and according to the World Steel Association (WSA) there is limited room for further improvement on the basis of existing technology [24]. For this reason, it is important to analyze CO_2 emissions of steel production in a broader system, including material intensity and service demand. Even WSA recognized that a key contribution of the steel industry is to work closely with its costumers in optimizing the design and use of steel [24].

1.1. Literature review

There are many studies that examine CO_2 emissions in iron and steel industry; from optimization of byproduct gas supply systems in the iron and steel-making process [25,26], to other technological alternatives [27,28]; or to the recovery of steel scrap [29]. Also, there is an important recent literature on energy consumption and CO_2 emissions in Chinás iron and steel industry, the country with the largest production of steel [30,14,31–34]; as well as studies from other countries [34–37].

On the other hand, decomposition analysis has been an extended methodology used to explain driving forces behind trends in energy consumption and GHG emissions. There are several decomposition methods [3] and new updates around them [38,39,7]. In particular Xu and Ang [40], reviewed 80 papers on Index Decomposition Analysis (IDA) to reveal the relative contributions of key effects on changes in the aggregate carbon intensity, and this was done by emission sector and by country. Also, Su and Ang [41] studied Structural Decomposition Analysis based on Input Output framework as an important tool to trace the final consumption to various inputs and intermediate consumptions. Zhou et al. [42] introduces a Malmquist CO_2 emission performance index (MCPI) for measuring changes in total factor carbon emission performance over time.

Furthermore, Zhang et al. [43] use the production-theoretical decomposition analysis (PDA) approach to decompose the CO_2 emissions changes of 20 developing counties into nine drivers, and the results reveal that economic growth is the main contributor to CO_2 emissions increase and good output technical change is the most important component to CO_2 emissions reduction. Zhou and Ang [44] published a comprehensive paper on PDA approach; and Zhang and Da [45] use PDA approach to decompose China's energy related CO_2 emissions changes during 2006–2010 and try to assess the driving factors of CO_2 emissions as well as the most effective ways to curb CO_2 emissions down, also this paper assessed a revision of IDA, SDI and PDA methods. In addition, several authors have developed IDA methods from vehicle emissions [46,47].

Although there has been a whole development on decomposition analysis, in this paper LMDI approach in IDA is used to analyze the Mexican case from 1993 to 2011. As explained recently by Ang [48], while the availability of quality data is a requirement for producing good empirical work, there is a strong foundation for the implementation of IDA and the LMDI decomposition approach.

The novelty of this analysis can be divided in two areas: (a) A methodology that captures changes in energy related carbon dioxide emissions from demand side to material production; and (b) The influence of direct and indirect imported steel in the estimation of CO_2 emissions for steel content in new automobiles. All of these variables, evaluated for the case of Mexico. The methodology can be used for other material industries and demand services.

2. Methodology

CO_2 emissions in year t related to energy consumption of iron and steel industry can be expressed as:

$$C_t = \sum P_t \frac{E_t}{P_t} \frac{C_t}{E_t} \tag{3}$$