An application of an environmentally extended input-output model to the assessment of CO2 emissions of Croatian economic sectors

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Abstract. The adverse effects of pollution and the impacts of different productive sectors on the degradation of the environment have become important issues in economic development analysis. This study aims to estimate the overall carbon footprint of different economic sectors of the Croatian economy. Total CO2 emissions are decomposed by direct and indirect emissions of productive sectors and final demand by applying the environmentally extended input-output analysis (EEIO). EEIO approach enables the decomposition of the total CO2 emissions of specific sectors into emissions related to the production of final goods and services and the production of intermediate inputs delivered to other economic sectors. The highest level of direct emissions has been generated by sectors producing energy products and transportation. As the output of those sectors is required as intermediate inputs used by the other sectors, the EEIO model redistributes emissions to other sectors, delivering final products to domestic users and abroad. Besides transport and electricity, Croatia's highest level of total direct and indirect emissions is found in the construction sector, production of non-metallic mineral products and food industry.

Keywords: CO2 emission, environmentally extended input-output model, Republic of Croatia, total effects

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1. Introduction

In the ever-increasing changes and dynamics of changes in all spheres of peoples' lives, the topical issue of sustainability and sustainable growth is inevitable. Moreover, considering how climate change and environmental degradation impact the world in a myriad of ways, it is apparent that policymakers, government bodies, entrepreneurs and corporations are highly interested in ways to identify what are the productive sectors that cause the most damage and are the least sustainable. The environmentally extended input-output analysis (hereafter EEIO) represents a potent technique used to evaluate the influence of certain economic activities on environmental degradation, depletion of natural resources and emission of pollutants. Moreover, EEIO provides "a simple and robust method for evaluating the linkages between economic consumption activities and environmental impacts, including the harvest and degradation of natural resources" that assesses the relationship between economic activities and sectors and downstream environmental and ecological impacts [16]. The underlying concept of EEIO methodology is

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to develop and replace previously used production and diagram trees with an input-output matrix that shows flows, usually monetary, but sometimes physical, between economic sectors [16], therefore developing a quantitative framework for the identification of sustainable and unsustainable national industries, in terms of direct and indirect environmental and ecological impact [9].

The main objective of this study is to estimate the overall carbon footprint of productive sectors of the Croatian economy and to distribute the total CO2 emissions to individual components of final demand. The EEIO approach regarding the Croatian economy has been applied to study wastewater discharges, revealing that industrial sectors generate significantly more wastewater than in comparable European countries [7]. The EXIOBASE 3 database provides a comprehensive time series of EE MRIO tables for global economic and environmental analysis, including data for Croatia [31]. Input-output analysis has also been used to assess the economic impact of the transportation sector in Croatia, showing significant multiplicative effects, particularly in air transport [34]. These studies demonstrate the versatility of EEIO methods in examining various aspects of the Croatian economy, from environmental impacts to sectoral interdependencies, providing valuable insights for policymakers and researchers. However, to the best of the authors' knowledge, this article is the first to quantify Croatian productive sectors' direct and indirect CO2 emissions using the EEIO approach.

The structure of the paper takes the form of five parts. Section 2 provides a literature review of the EEIO method and greenhouse gas emissions (GHG) emissions. Section 3 unveils the methodology. The research results are presented in Section 4, and a discussion and conclusion are provided in the last section.

2. Literature review

A literature review is focused on previous studies that use the EEIO model and are relevant to the objective of this study. Thus, it includes the literature developing EEIO methodology, empirical studies for other economies that identify industries related to the most severe environmental degradation, and literature that provides policy recommendations for efficiently reducing CO2 emissions proposed in the previous empirical studies for other economies. Findings from previous studies could be helpful in formulating the optimal model for assessing sources of CO2 emissions in Croatia, identifying similarities and differences in the economic structure, and formulating adequate policy recommendations based on specific national conditions.

Modifications to standard IO tables with ecological indicators were first introduced in [3] and [18], where authors incorporated pollution variables into the standard input-output (IO) model. The main idea behind the EEIO model is to augment the standard technical coefficients matrix with additional rows reflecting the pollutants' emissions [24]. Thus, by application of the assumption of the standard IO model, where final demand through the technological connection of economic sectors induces economic effects not only for units producing final products but along the overall supply chain, direct and indirect emissions of pollutants can also be calculated [24]. Beside analyse of GHG, the same methodological background can be used in many different applications and environmental extensions to the EEIO method, such as studies that incorporate water pollution [5, 21], carbon emissions [8, 35], waste [13] and food waste [1, 22].

Empirical studies are conducted for many economies to identify the sources of CO2 emissions based on the EEIO model. The findings of recent empirical studies are summarized in Table 1. In most empirical studies, construction, agriculture, electricity produced from fossil fuels, the metal industry, transport, and the production of construction materials are sectors with the most significant environmental footprints. At the same time, clean-electric power generation, public services, education, health and social work are associated with the lowest emissions. The negative impact of economic activity on the environment is not limited to traditional sectors.

Moon, Yun and Lee (2020) [25] concluded that the sectors with the most CO2 emissions in the Korean economy produce goods and services of the fourth industrial revolution.

Author(s) of empirical study	Country/region	Sectors with the highest CO2 emissions
Liu et al. (2020) [19]	Province Saskatchewan in Canada	Construction; crop and animal production and forestry and logging; electricity from fossil fuels
Shmelev and Brook (2021) [30]	Austria, China, France, Germany, Sweden and the USA	Production of electricity from gas, coal, oil, and other petroleum products; extraction of metals and other ores; production of cement, lime, gypsum, and air transport
Alcantara and Padilla (2006) [2]	Spain	Electricity and gas: land transport; manufacture of basic metals; manufacture of non-metallic mineral products, and manufacture of chemicals
He et al. (2021) [14]	China	Electricity/heat production; Construction
Imansyah and Putranti (2017) [15]	Indonesia	Crude oil and natural gas; commerce; thermal power; coal; non-metallic ores mining; petroleum refinery products and road transport
Othman and Jafari (2016) [26]	Malaysia	Energy industry and transportation
Moon, Yun and Lee (2020) [25]	South Korea	Manufacture of computers, electronic and optical products; chemicals and pharmaceutical products; motor vehicles, trailers and semi-trailers and construction
Beidari, Lin and Lewis (2017) [4]	South Africa	Electricity, other industries; transportation, and residential sectors

Table 1: *The results of recent empirical EEIO studies on the sectors with the highest CO2 emissions (Source: Authors' systematization)*

EEIO analysis on the sources of environmental degradation enables governments and regional leaders to assess productive sectors that harm the environment and to consider this information when developing new regulations, policies and laws. Empirical results on the sources of CO2 pollution are essential for formulating guidelines towards sustainable development and achieving the Paris Climate Agreement goals. Alcantara and Padilla (2006) [2] suggest that reducing emissions would be made possible by introducing specific measures and incentives such as increased use of renewable energy sources, innovations in the production of vehicles, and improvement of the ecological quality of fuel. He et al. (2021) [14] concluded that emission reduction policies should promote the decarbonisation of the electricity industry and improve energy efficiency by controlling carbon emissions in other productive sectors. Moon, Yun and Lee (2020) [25] pointed out that it is necessary to urgently reorganise production in modern sectors in a more environmentally friendly way without limiting their production and the possibility of losing competition. Beidari, Lin and Lewis (2017) [4] found that direct CO2 emissions are more significant than indirect CO2 emissions and proposed that the government should invest in expanding and maintaining national energy capacities and reduce coal and oil imports.

Some authors tried to answer the sustainability question: Is economic growth necessarily related to increased emissions of pollutants? Firdaus (2020) [12] compares the Indonesian economy's output and CO2 emission multipliers. The author pointed out that electricity and gas supply are sectors with a high output multiplier but also a relatively high CO2 emission multiplier, which means that increased environmental destruction may accompany economic growth. On the other hand, the rubber and plastic products sector has a high output multiplier and a very low CO2 multiplier, so it would be desirable to increase that sector's production to reduce CO2 emissions.

3. Research methodology

This research estimates direct and indirect CO2 emissions of economic sectors and final demand based on the EEIO methodology. In general, IO analysis makes it possible to determine the interdependence of productive sectors in the national economy [17, 24, 33]. IO tables describe the flow of goods and services among productive sectors. Readers can learn more about the standard IO approach [24, 33].

The standard IO table can be expanded to show the impact of individual activities on the environment, that is, the role of each economic sector in generating harmful substances that pollute the environment [24, 27, 28, 32]. A fundamental problem in models that include effects on the environment is the application of an appropriate unit of measure for the emission of harmful substances [23, 24].

In general form, the EEIO table can be presented by Table 2. The upper part is the standard IO table presenting the structure of deliveries of economic sectors (by rows) and the use of intermediate inputs and components of final demand (by columns). Intersectoral deliveries of products produced by sector i, which are used as intermediate inputs of sector j are presented by $X_{ij}, (i, j = 1, \dots, n)$. The total output of each sector $(X_i, i = 1, \dots, n)$, besides intermediate inputs, includes goods and services used by final consumers $(Y_i, i = 1, \dots, n)$. Final uses can be further disaggregated into main components: personal consumption, government consumption, gross capital formation and exports, which are here, because of clarity and simplicity, not presented in Table 2.

Columns of IO table present the structure of intermediate inputs produced domestically (X_{ij}) and imported intermediate inputs (M_i). In the fundamental IO model, the matrix A, square $n \times n$ matrix, expresses a set of technical coefficients $a_{ij} = \frac{X_{ij}}{X_j}$, $i, j = 1, \dots, n$. Each sector uses intermediate inputs from other economic sectors to deliver the required final output. An increase in the final demand for the output of one sector thus indirectly stimulates economic activities in other sectors depending on the technological connections between sectors. The lower part of the table includes set of environmental variables and their distribution by sectors and final uses.

		Economic sectors	Final uses	Output
		$1 \dots j \dots n$		
Economic sectors	1	$X_{11} \dots X_{1j} \dots X_{1n}$	Y_1	X_1
	$\vdots$	$\vdots$	$\vdots$	$\vdots$
	i	$X_{i1} \dots X_{ij} \dots X_{in}$	Y_i	X_i
	$\vdots$	$\vdots$	$\vdots$	$\vdots$
	n	$X_{n1} \dots X_{nj} \dots X_{nn}$	Y_n	X_n
Imports		$M_1 \dots M_j \dots M_n$	M_Y	M
Net taxes on products		$T_1 \dots T_j \dots T_n$	T_Y	T
GVA		$V_1 \dots V_j \dots V_n$		V
Output		$X_1 \dots X_j \dots X_n$	Y	X
Set of environmental variables				
Use of energy in MJ				
Electricity		$B_{11} \dots B_{1j} \dots B_{1n}$	B_{1Y}	$B1$
Crude oil and derivatives		$B_{21} \dots B_{2j} \dots B_{2n}$	B_{2Y}	$B2$
Gas		$B_{31} \dots B_{3j} \dots B_{3n}$	B_{3Y}	$B3$
Greenhouse gas emissions (in tonnes)				
CO2		$D_{11} \dots D_{1j} \dots D_{1n}$	D_{1Y}	$D1$
CH4		$D_{21} \dots D_{2j} \dots D_{2n}$	D_{2Y}	$D2$
SO2		$D_{31} \dots D_{3j} \dots D_{3n}$	D_{3Y}	$D3$
Use of water and waste disposal				
Water (in litres)		$W_{11} \dots W_{1j} \dots W_{1n}$	W_{1Y}	$W1$
Waste (in tonnes)		$W_{21} \dots W_{2j} \dots W_{2n}$	W_{2Y}	$W2$

Table 2: *Environmentally extended input-output model, a general case (Source: Authors systematization according to [6] and [24])*

The standard IO model can be extended by environmental variables usually available in physical units as presented in the lower part of Table 2. Analysis can include a broad set of environmental variables disaggregated by industries and final demand: use of specific energy products, GHG emissions, water use, and waste disposal. As each economic sector uses intermediate inputs delivered by other sectors, total emissions related to the production process of one sector also induce indirect emissions related to the production of required inputs. The environmental emission matrix D represents the environmental impacts related to GHG emissions associated with cross-sectoral interactions, which includes direct effect coefficients. Theoretically, matrix D is $k \times n$ matrix where k is the number of rows determined by the number of indicators of interest for environmental protection, and n is the number of economic sectors of the standard IO model [23, 24]. For each type of GHG, direct emission intensity can be calculated for each sector [6]. Elements $d_{ij} = \frac{D_{ij}}{X_j}, i = 1, ..., k, j = 1, \dots, n$ of matrix D are expressed as the ratio of a specific indicator of environmental effects or the quantity of emissions to the gross output of a particular economic sector. This study is focused on CO2 emissions only. Thus, matrix D is a row vector whose elements present the ratios of CO2 emissions to the output of each sector. Croatian IO table is available for 64 mutually exclusive sectors; thus matrix D in this study is 1×64 row vector.

Using the EEIO framework, both direct and indirect emissions of pollutants can be calculated as they relate to the production of a specific sector and the emission of pollutants in the entire value-added chain of a particular industry. The emission multiplier thus includes direct and indirect emissions of a specific sector along the supply chain. It estimates the total (direct and indirect) CO2 emissions required to produce the unit value of each sector (CO2 per EUR 1 million of sectoral output). In this study, the focus is exclusively on the CO2 emissions and matrix

$$X^{e*} = D \cdot L \tag{1}$$

1×64 row vector, where $L = (I - A)^{-1}$, square 64×64 matrix, is the Leontief inverse matrix [24], whose elements show the sum of each sector's direct and indirect output required per unit of the output produced and delivered by another industry to the final user.

Information on total emissions related to the production of individual sectors is helpful, especially for those economic sectors that do not emit significant amounts of pollutants but use intermediate inputs produced by other industries that could be essential pollutants. However, the disadvantage of this approach is potential double counting if the output of each sector is not separated into the production of final products and intermediate inputs. The CO2 emissions allocated to the output of, for example, the electricity sector could be allocated to the emissions of all other sectors producing final goods and services where energy is an essential input. The problem of double counting in the distribution of total emissions to economic industries can be solved by multiplying sectoral emission multipliers by a vector of final demand instead of a vector presenting sectoral output. In that way, emissions related to the production of intermediate inputs are redistributed from the input producer to the sector which produces the final product.

If the total pollution matrix is marked with X^* then the total emission of pollution related to the production processes necessary for the delivery of goods and services according to the given final demand equals:

$$X^* = D^* \cdot L \cdot Y \tag{2}$$

where D^* is a diagonal matrix derived from a row vector D. Matrix Y is $n \times 1$ column vector of final demand, which can be further disaggregated into components: final demand of households, government consumption, gross fixed capital formation, and exports.

Unlike the direct emissions emitted by the production sectors, the responsibility for indirect emissions, i.e. those that occur in the production chain, can be considered from different aspects. According to [29], this paper uses an approach in which emissions are allocated to industries producing final demand, with exports included. The above implies that the emissions of products intended for export abroad, where they are used both for final and intermediate consumption, are added to the total national emissions. Unfortunately, statistical data on the exact purpose of exported products (intermediate or final use of Croatian products in the country where products are exported) is unavailable. Most empirical studies focused on individual countries applied the same approach and treated total exports as the final demand. Separating exported products for intermediate or final use in the importing economy would require an abundant data set on sectoral emissions for all trade partners and the application of a world IO table.

Besides economic sectors, total emissions of CO2 from productive sectors analysed in this paper are divided into components of final demand, i.e. personal consumption, government consumption, investments, and exports. To distribute domestic emissions into components of final demand for each productive sector, formula (2) was applied where Y presents individual components of final demand.

IO data for different periods should be expressed at constant prices to estimate trends in the CO2 emission dynamics relative to actual economic activities. IO tables for 2015 and 2020 are officially published at current prices and prices of the previous year, while IO tables at constant prices of the base year are not published. Thus, the transformation of IO into constant 2020 prices is based on the approach proposed by [20] and the application of the double deflation method. The chain-linking technique estimates the total price changes over the analysed period. Based on this approach, IO data for 2015 are converted to constant 2020 prices. The ratio of the current price to the base-year price level for sector i is expressed as p_i; the crucial point in the calculation is diagonal $n \times n$ matrix P (in this study 64×64) that contains the elements p_i (cumulative price index for each sector in period 2015-2020) on the main diagonal and off-diagonal entries are zero. The following formula is applied to transform IO 2015 data to IO at constant 2020 prices:

$$X_r = A_r X_r + Y_r \tag{3}$$

where $X_r = P^{-1}X$ is $n \times 1$ output matrix, $Y_r = P^{-1}Y$ is $n \times 1$ final demand matrix and $A_r = P^{-1}AP$ is $n \times n$ matrix of IO coefficients all expressed at constant 2020 prices.

IO tables for the Croatian economy in current prices and prices of the previous period for 2015 and 2020 were downloaded from [10], and CO2 emissions per Croatian sectors from [11].

4. Research results

Results present direct, indirect and total CO2 emissions distributed to economic sectors and final demand for 2015 and 2020. Sectoral distribution and trends in direct and indirect emissions of pollutants provide an analytical background for formulating policy recommendations oriented toward reducing the negative environmental impact of economic growth.

Sector code	Sector	2015	2020	Index 2020/2015	Structure 2020
D	Electricity, gas, steam and air conditioning	3,708	3,290	88.7	19.3
C23	Other non-metallic mineral products	2,469	2,640	106.9	15.5
C19	Coke and refined petroleum products	1,409	858	60.9	5.0
H49	Land transport services and transport services via pipelines	847	909	107.4	5.3
A01	Products of agriculture, hunting and related services	645	718	111.3	4.2
C20	Chemicals and chemical products	642	604	94.2	3.5
B	Mining and quarrying	489	495	101.1	2.9
H50	Water transport services	432	257	59.4	1.5
F	Constructions and construction work	279	328	117.7	1.9
C10-C12	Food, beverages and tobacco products	273	253	92.6	1.5
Ten sectors with the highest emissions		11,194	10,355	92.5	60.8
Other economic sectors		1,804	1,809	100.2	10.6
Total emissions by producers		12,999	12,163	93.6	71.4
Heating/cooling activities by households		1,036	1,036	1,018	6.0
Transport activities by households		3,871	3,871	3,560	20.9
Other activities by households		303	303	300	1.8
Total CO2 emissions		18,208	17,041	93.6	100.0

Table 3: *Direct emissions of CO2 in 000 tonnes as recorded by official statistics, Republic of Croatia (Source: Eurostat database)*

Total CO2 emissions, as available from official statistical sources (Table 3), are recorded separately for production activities and pollution emitted directly by final consumers, who use energy products for household heating, cooling, and transportation. In 2020, the production processes of domestic companies were responsible for 71.4 percent of total CO2 emissions. It can be noticed that pollution is concentrated in a few critical sectors. Thus, electricity production is responsible for almost 20 percent of total CO2 emissions, followed by producing other non-metallic mineral products (mainly construction materials), refined petroleum products and land transport. The ten sectors with the highest emissions presented in Table 3 produce over 60 percent of total emissions. CO2 emissions related to non-productive activities are mostly related to use of personal vehicles of citizens and energy consumed for heating or cooling.

Direct emissions intensity $d_{ij} = \frac{D_{ij}}{X_j}$ is a relative indicator defined as the ratio of sectoral emissions (in physical quantities) and gross output (measured in monetary terms). It is usually expressed as Kg CO2 emitted by the production of output valued at 1 thousand EUR and based on data directly observable from official statistical data sources. On average, output valued at 1 thousand EUR in Croatia generated 144 kg CO2 (in 2020), which is significantly lower compared to 2015 when the same indicator was 171. The direct pollution intensity is the highest in producing other non-metallic mineral products, electricity, transport, petroleum and chemical products (Figure 1). Production processes used in those sectors require significant amounts of energy from fossil sources, which transformation pollutes the environment. Sectors with the best results in reducing direct CO2 emission intensity were water transport, production of coke and refined petroleum products, mining and quarrying and production of other non-metallic mineral products. Interestingly, because of the decrease in economic activity of domestic energy producers, direct emission intensity per output in electricity production increased despite the reduction in total emissions.

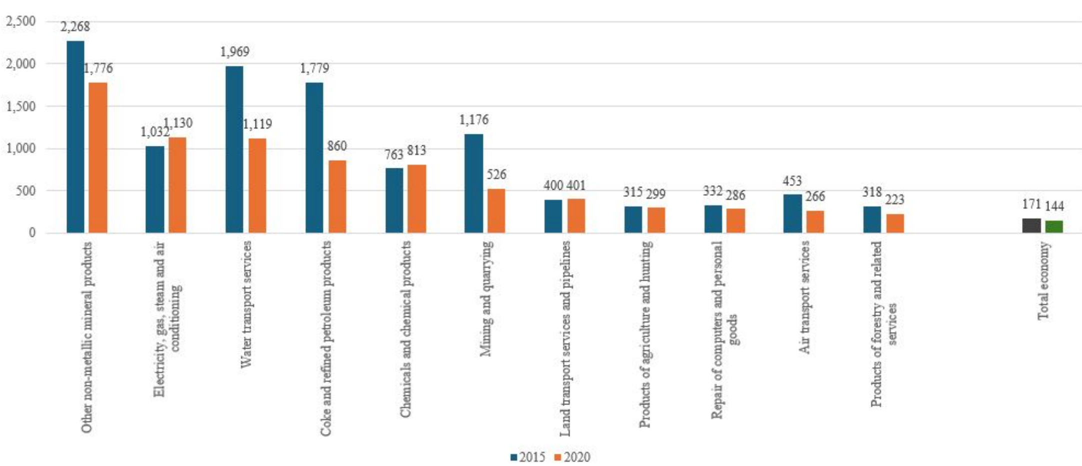

Figure 1: *Direct emissions intensity, Kg CO2 emitted by the output valued at 1 thousand EUR. (Source: Authors calculation based on Eurostat data on CO2 emissions and Croatian IO table.)*

As presented in the methodological part of the paper, the production of final products, besides direct, includes indirect input requirements for intermediary products. Thus, specific sectors do not emit significant amounts of pollutants directly but could require inputs from other sectors with much higher emissions. Thus, those sectors' final product demand contributes to the total carbon footprint along the supply chain. Total CO2 emissions, including direct and indirect emissions along the supply chain, are calculated using the formula (1) and are to be interpreted as the quantity of CO2 emitted to produce a sectoral output of 1 thousand EUR (Figure 2). Besides the sectors mentioned above with high direct emissions, the list of important pollutants includes construction, fishery and operation of travel agencies that directly record low emissions but use intermediate inputs related to higher emissions.

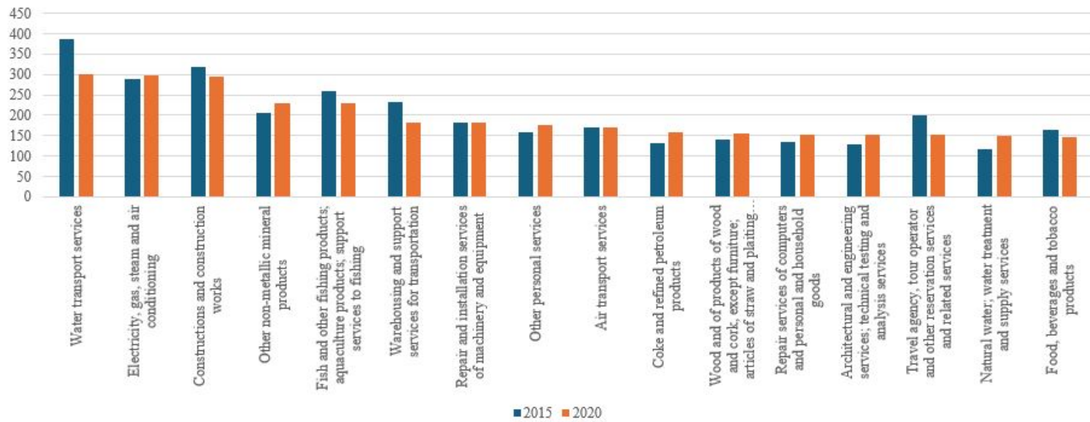

Figure 2: *Total emissions of CO2 in Kg emitted by the output valued at 1 thousand EUR. (Source: Authors calculation based on Eurostat data on CO2 emissions and Croatian IO table.)*

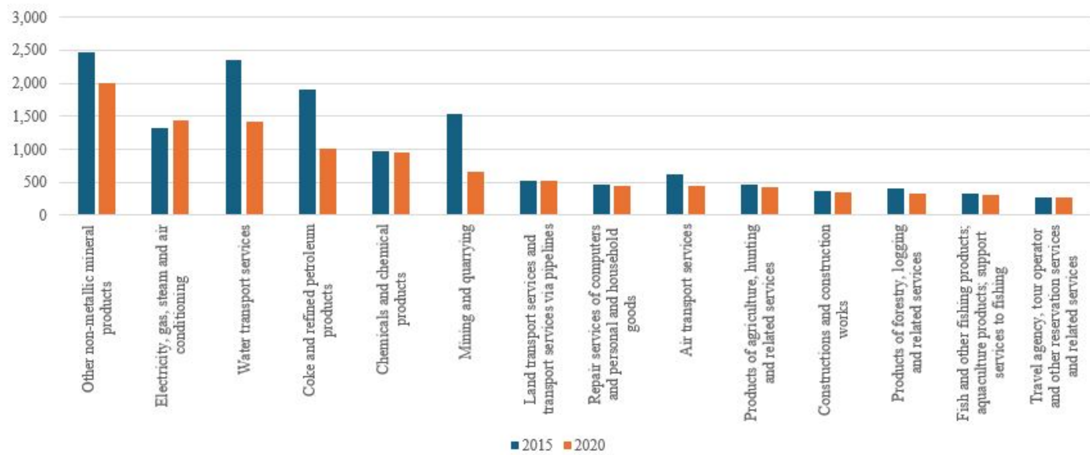

Figure 3: *Indirect emissions intensity, Kg CO2 emitted by the output valued 1 thousand EUR. (Source: Authors calculation based on Eurostat data on CO2 emissions and Croatian IO table.)*

Figure 3 presents the intensity of indirect emissions for the economic sectors with the highest indirect CO2 emissions (difference between total and direct emissions). Water transport, electricity, and other non-metallic mineral products are sectors that, besides direct emissions, also have significant requirements for inputs from different sectors with a high carbon footprint. Besides those sectors where both direct and indirect emissions are high, specific sectors such as construction, warehousing and supporting services, repair and installation of equipment, wood industry, water supply and food industry, despite low direct emissions, through the requirements for intermediate inputs, significantly contribute to the overall pollution.

An EEIO model is convenient for calculating the effects of final demand on sectoral CO2 emissions. To avoid double counting when calculating the national carbon footprint, sectoral emission intensity, as presented in Figure 2, should not be multiplied by the total value of sectoral output but by the value of the sectoral final uses. Total emissions induced by final demand for a particular sector are calculated using formula (2). By that approach, the emissions of industries that deliver intermediate inputs are distributed by EEIO analysis to sectors that produce final products. When households buy final products, such as food, it increases the output of the food industry and the revenues in sectors producing intermediate inputs, some of which, such as agricultural products or energy, could have high CO2 emission intensity. In Table 4, emissions of CO2 for electricity include only emissions incorporated in final electricity expenditures (electricity bought by households, government, and non-profit organisations). The emissions related to the production of energy, which are used as intermediate input of another sector (for example, the food industry), are in Table 4, distributed to the other sectors producing the final goods and services demanded by the final consumer.

Comparing Table 3 and Table 4, one can see that approximately one-half of direct CO2 emitted by electricity producers is generated by final deliveries of (1,605 thousand tonnes in 2020, as presented by Table 4, compared to 3,290 of direct emissions presented by Table 3). The other half of electricity emissions result from the production of intermediate inputs required by other industries. On the contrary, the construction sector emits only 328 thousand tonnes of CO2 directly, while total emissions related to final deliveries of construction services are estimated at 1,636 thousand tonnes. Thus, the construction sector is responsible for the most sizeable proportion of the total CO2 emissions. This is because of the high proportion of inputs required from other non-metallic mineral products (mostly construction materials), transport, and energy.

	2015	2020	Index 2020/2015	Structure 2020
Constructions	1,563	1,636	104.7	9.6
Electricity, gas, steam	2,366	1,605	67.8	9.4
Land transport services, pipelines	777	956	123.0	5.6
Other non-metallic mineral products	814	801	98.4	4.7
Food, beverages and tobacco products	805	779	96.8	4.6
Products of agriculture, hunting	428	518	121.1	3.0
Wholesale trade services	451	509	112.8	3.0
Retail trade services	421	481	114.2	2.8
Coke and refined petroleum products	912	423	46.4	2.5
Chemicals and chemical products	356	374	105.1	2.2
Public administration and defence	469	335	71.4	2.0
Human health services	188	298	159.1	1.8
Accommodation and food services	391	271	69.4	1.6
Imputed rents of owner-occupied dwellings	240	263	109.6	1.5
The sum of the most important sectors	10,178	9,249	90.9	54.3
Other sectors	2,820	2,914	103.3	17.1
Total emissions induced by producers	12,999	12,163	93.6	71.4
Heating and transport of households	5,209	4,878	93.6	28.6
Total emissions	18,208	17,041	93.6	100.0

Table 4: *Total emissions induced by final demand for a particular sector, CO2 in 000 tonnes, Republic of Croatia. (Source: Authors calculation based on Eurostat data on CO2 emissions and Croatian IO table.)*

Like electricity, in the case of land transport and production of non-metallic mineral products, the share of emissions induced by final demand is significantly lower than the sector's total emissions. On the contrary, sectors such as food, beverages, tobacco products, wholesale and retail trade, human health services, and accommodation and food services recorded significantly higher CO2 emissions if indirect pollution is included.

Although total emissions induced by producers decreased by 6.4 percent in the analysed period, the increase in total emissions is estimated for construction, land transport, agriculture, trade, chemicals and chemical products, human health services and imputed rents of owner-occupied dwellings. The highest reduction in total emissions is found in producing coke and refined products and electricity. In the case of the output of refined products, it is probably the result of the decreasing production of oil derivatives because of the downsizing of the domestic output in the Croatian company INA. Instead of two refineries, only one refinery (located in Rijeka) is expected to be modernised. In contrast, the production of oil derivates in the other refinery in Sisak was reduced and recently fully terminated. Reducing CO2 emissions in electricity primarily results from promoting renewable energy plants, such as wind and solar energy, which increase their share in the total electrical energy supply.

Total emissions could be decomposed into the individual components of the final demand (personal consumption, government consumption, gross fixed capital formation and exports) using formula (2). As personal consumption is the crucial component of final demand, its carbon footprint is also the highest (Table 5). In 2020, of total emissions, 29.3 percent were induced by the production of output delivered to households, while an additional 28.6 percent was emitted by household energy for heating and transport. After personal consumption, the highest contribution in total emissions is estimated for exported goods and services (19.4 percent of total emissions in 2020), while the share of government consumption and investment is slightly above 10 percent. In relative terms (emissions induced by 1 million EUR of expenses), pollution intensity is the highest for exports and investments. It is the consequence of the structure of items where the share of various manufacturing sectors is higher than that of services where production processes are more environmentally friendly.

Component of the final demand	Emissions induced by		Structure		Index 2020/2015	Emissions	
	2015	2020	2015	2020		2015	2020
Personal consumption	6,390	4,986	35.1	29.3	78.0	269.3	217.5
Government consumption	1,158	1,726	6.4	10.1	149.0	128.0	140.0
Investment	1,829	2,151	10.0	12.6	117.6	269.5	256.1
Exports	3,621	3,301	19.9	19.4	91.1	385.6	318.5
Total emissions induced by domestic output	13,001	12,165	71.4	71.4	93.6	255.1	217.1
Heating and transport	5,209	4,878	28.6	28.6	93.64		
Total	18,208	17,041	100.0	100.0	93.59		

Table 5: *Total emissions induced by individual components of final demand, CO2 in 000 tonnes, Republic of Croatia. (Source: Authors calculation based on Eurostat data on CO2 emissions and Croatian IO table.)*

5. Conclusion

An EEIO approach is applied in this research to allocate CO2 emissions in the Croatian economy to components of final demand and economic sectors which deliver final goods and services.

According to the results presented above, the production of construction materials, electricity, transport, agriculture and construction services are responsible for the most sizable proportion of the total CO2 emissions. Significant emission intensity in producing energy products and transport is usually found in all previous studies for many other economies, as presented in [2, 4, 30] and mainly include direct emissions. In the case of construction, Croatian results align with the results for Canada [19], where indirect emissions are more important than direct emissions. Construction services require intermediary inputs produced by sectors which emit significant amounts of CO2: construction materials, transport, and energy. The proportion of indirect emissions is also high in sectors such as food, beverages, tobacco products, wholesale and retail trade, human health services, and accommodation and food services. Although personal consumption, in absolute terms, is responsible for the highest share of CO2 emissions, in relative terms (emissions induced by 1 million EUR of expenses), pollution intensity is higher for exports and investments.

A decrease in the total CO2 emissions was found during the analysed period. The energy sector and the production of refined oil products and electricity are the sectors that contribute to overall ecological improvements. In the case of electricity, reducing CO2 emissions is a consequence of promoting renewable sources, such as wind or solar energy. The downsizing reduces emissions in the domestic production of oil derivatives by the INA, a leading Croatian company in the oil industry. Contrary to the general trend, the increase in total emissions is estimated for construction, land transport, agriculture, trade, chemicals and chemical products, human health services and imputed rents of owner-occupied dwellings.

The results of this research can represent guidelines for green economy policymakers in creating further measures and strategies to reduce CO2 emissions not only in production sectors with high direct CO2 emissions but also in those with a significant indirect effect on the environment. In the case of electricity, the Croatian government, by introducing specific measures and incentives, should further promote the transformation of energy production from fossil to renewable energy sources, such as wind, water and solar energy. Positive examples from other countries could be used to expand national energy capacities based on renewable sources and reduce imported fossil energy products [4]. As proposed in previous studies [25], policy measures should be introduced to improve energy efficiency in other sectors where energy is an important input. Promoting investments in modern equipment and technologies is crucial in improving energy efficiency in manufacturing. Innovations in the industry that produce motor vehicles and improvements in the ecological quality of fuel are critical in reducing carbon footprints in transport [2]. In the Croatian case, where the manufacture of motor vehicles is less developed, developing a regulatory framework favouring environmentally more efficient vehicles is more important than regulating vehicle producers.

Besides its advantages, the methodology applied in this research has some limitations. The disadvantage is related to the treatment of total exports as a final demand. However, a certain proportion of exported products is intended for intermediate consumption abroad and should be allocated to the emissions for producing final products in the importing economy. The problem of potentially double-counting CO2 emissions could arise if multipliers are applied to total sectoral output due to overlapping production chains of different sectors. As in previous studies, the problem of double counting in this research is solved by the multiplication of emission multipliers by final demand. In this way, emissions related to the production of intermediary inputs are transferred from the original producer to the producer of the final product.

For future research, the authors plan to apply the described approach to the comparative analysis of CO2 emissions between European Union economies. Also, the environmental input-output analysis framework is expected to investigate CO2 emissions embodied in international trade.

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