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Classification of Industrial Sectors Based on Their Profiles of Greenhouse Gas Emissions and Policy Implications

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Abstract:

Purpose: This article determines the volume of greenhouse gases emitted by a range of industrial manufacturing sectors in order to give direction to public emission reduction programmes and increasing the impacts of the latter.

Design/methodology/approach: To this end, it applies a classification of industrial manufacturing sectors based on their greenhouse gas emissions profiles. By making use of economic data on the consumption of energy sources and a conversion process, we obtain an estimation of greenhouse gas emissions, and consequently a profile of the direct/indirect emissions, concentration of emissions, total emissions and electrification level of each sector. Finally, this allowed us to segment the sectors into four groups.

Findings: By grouping the sectors into four segments we reveal a series of group-specific characteristics, which serves as a basis for corresponding greenhouse gas reduction programmes. Special attention should be given to the segment that features a large amount of emissions concentrated in a relatively low number of firms and a low level of electrification, while making a disproportional use of public funds as compared to the volume of their emissions.

Research limitations/implications: This research followed an aggregate (macro) approach, which limits the possibilities to interpret the results from a NACE level towards individual companies pertaining to a specific sector. This applies also to the use of average values for conversion factors. Take note also that some big emitter sectors, such as extractive industries and petroleum refining industries, are not included in the study.

Practical implications: Public programmes should consider different approaches to reducing greenhouse gas emissions based on sectoral segmentation. General recommendations are proposed for each of the identified segments.

Social implications: Improved public programmes can foster the reduction of greenhouse gas emissions and the United Nation's Sustainable Development Goals 7 and 12.

Originality/value: The methodology proposed in this paper allows pointing out sectors where return on investments in greenhouse gas reduction would be highest.

Keywords: circular economy, green deal, sustainability, greenhouse gases

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1. Introduction

The Green Deal (European Commission, 2019) seeks to reduce the environmental footprint of economic activities. In 2020, direct industry greenhouse gas (GHG) emissions accounted for 25.8% of total emissions in Spain (INE, 2020). Similar figures can be found in other studies: industries were found to be responsible for 22% of CO_2 emissions in Hungary (Safwan, Gill, Alsafadi, Omar, Krishna, Hasan et al., 2021) and Pakistan (Mir, Purohit & Mehmood, 2017), and for 30% of GHGs in Canada (Talaei, Gemechu & Kumar, 2020). In addition, industrial processes cause "indirect" GHG emissions due to electricity consumption in such processes, and energy mix used for the generation of this electricity.

Energy consumption is the main cause of GHG emissions in industry. This implies that energy consumption reduction projects can be relevant to reduce GHG emissions.

In many countries, public institutions run energy consumption reduction programmes (Baietti, Shlyakhtenko, La Rocca & Patel, 2012). However, the emissions, costs and available technologies required to generate a positive impact are diverse. For example, the unavailability of viable alternative technologies in sectors that depend on the combustion of petroleum products can imply that if they are forced to reduce their emissions, this will be synonymous to a frosty industrial restructuring. Conversely, in highly electrified sectors, energy efficiency projects tend to focus on the energy mix underlying the consumed electricity, encouraging industrial users to make more use of renewable energy-based electricity.

In a study from the Basque Country, Fernández, Kamp and Retegi (2022) found a significant difference between the height of GHG emissions across sectors and the sectoral distribution of public funds for the sake of emission reduction, with certain high-energy-consuming sectors using less public funds than low-consuming sectors. The same was observed when the number of financed projects per sector are compared. This means that sectoral emission intensity does not correlate with the distribution of public resources for emission reduction.

Considering this fact, the implementation of numerous energy efficiency projects may target sectors and industries that only marginally contribute to GHG emission reduction. Hence, this finding could be of relevance when wanting to improve the impact of public programmes on GHG emission reduction.

Considering the above, the questions this article addresses, are:

What GHG emission levels, both direct and indirect, can be associated to respective industrial sectors, according to their use of energy sources?

Considering the findings of Fernández et al. (2022), can sectors be grouped according to shared characteristics regarding their emissions?

Consequently, is it possible to outline directions for emission reduction programmes per sectoral group rather than following a general programme for all of them?

2. Literature Review

European and state regulations associated with the promotion of sustainability affect industrial sectors differently. Elkerbout, Egenhofer, Núñez-Ferrer, Cătuţi, Kustova and Rizos (2020) found that climate-neutral energy infrastructure or the housing sector and the materials used in its value chain, such as cement or metals (steel, copper, aluminium, nickel, zinc, manganese or lead), account for 9% and 7% of total emissions, respectively. In a study by the European Commission (2021), the following 13 sectors, many of which are involved in the Industrial Emissions Directive, were analysed: energy, refineries, iron and steel, non-ferrous metals, chemicals, food and drink, cement, lime and magnesium oxide, surface treatment with solvents, pulp and paper, rendering, ceramics, glass, and textiles. In Mao, Du, Xu and Zeng (2011), the production of electric power and heat power, refineries, the smelting and pressing of ferrous metals, non-metallic mineral production, raw chemicals and chemical production and the mining and washing of coal have been identified as the most GHG-emitting sectors in China.

To implement effective emissions reduction policies, it is necessary to understand the characteristics of the emitting sectors, such as the energy consumption mix, the percentage of electrification, the total amount of emissions and the direct or indirect nature of those emissions and their concentration (in tCO_2-eq/firm).

In Aste, Buzzetti, Caputo and Del Pero (2018), the authors note that when analysing public subsidies, it is important to define key performance indicators and criteria to determine the effectiveness of public expenditure in different communities and territories in the long term.

The identification of effective GHG emissions reduction options at a firm level can be made easier using participatory methods involving stakeholders. For this reason, Stalpers, van Amstel, Dellink, Mulder, Werners and Kroeze (2008) considered the risk and feasibility of top-down designed programmes that do not consider local firm conditions and proposed a policy design methodology.

The Intergovernmental Panel on Climate Change has established standard guidelines for the estimation of GHG inventories at the country level. A preliminary version (IPCC, 2006) was published that considers fossil fuel combustion emissions, fugitive emissions and CO_2 capture and storage. The application of these guidelines requires specific data about the product of combustion and its emission factors. The IPCC (2006) did not offer guidance on the estimation of indirect GHG.

These guidelines were refined in 2019, with the new version providing information on emerging technologies and production processes, updated default values of emission factors and information clarifying the previous guidelines (IPCC, 2019).

Su, Pauleit and Xu (2016) proposed an approach to defining the spectrum of GHG emissions based on three layers: overall emissions, emissions per GHG and emissions per sector (energy, agriculture, industrial processes, solvents and land use).

The estimation methodology approach presented in this paper uses two characteristics. The first is a sectoral view of GHG emissions using economic data with the necessary level of detail (NACE 3-digit level) available from public sources. It also requires data on the indirect emissions of electricity consumption in companies and, thus, the emissions produced to generate the electricity consumed. While the estimation method is aimed to be as precise as possible, the segmentation process is not intended to be used for precise calculation of total emissions but to comparatively assess the relative importance of sectors compared to each other in terms of aspects such as total emissions, direct and indirect emissions and emission concentration per firm.

3. Methodology

Traditionally, two methodologies are used for estimating industrial GHG emissions. On the one hand, there is the life cycle assessment method that requires accurate data from the consumptions and the technologies used at firm level. On the other hand, input-output tables can be used for this purpose.

Although in the corporate context, life cycle assessment is usually applied, input–output analysis is more suitable for estimating direct and indirect GHG emissions on a sectoral scale and to determine the entire environmental effect of industrial activities (Peters, Minx, Weber & Edenhofer, 2010).

Environmentally extended input–output tables (EEIOTs) are often used to assess the impact of economic activities on the environment (Kitzes, 2013), both at regional or international levels (Alcantara & Padilla, 2019; Davidescu, Popovici & Strat, 2022; Mangir & Sahin, 2022; Schmidt, Södersten, Wiebe, Simas, Palm & Wood, 2019). At the same time, input–output analyses are considered less accurate but more comprehensive than life cycle process analyses, but a handicap of the latter is that they require more detailed major production data (Rauf, 2022), which may also be hard to aggregate.

Consequently, the present article applies a method that provides an aggregate sectoral view on GHG emissions based on expenditures by energy source per sector, allowing us to answer the above-indicated research questions with sufficient relief. Specifically, it allows to know the intra-firm emissions by source of energy used and by sector and to calculate the average electrification rate of each sector in terms of the overall electricity expenditure over the total energy expenditure.

For this study, the energy consumptions of NACE 2 digit-code sectors from 10 to 33 (excluding '19. Manufacture of coke and refined petroleum products') were analysed.

An analysis of the data obtained was conducted using the following estimation method. The total Tier I and Tier II (Pandey, Agrawal & Pandey, 2010) emissions (tCO_2-eq) due to combustion attributed to the industrial system of a country or region can be expressed as follows:

$$E = \sum_{i=1}^{n} \sum_{j=1}^{m} \left(1000.\,C_{ij}.\,K_j\right) \tag{1}$$

where E is the total amount of CO_2-eq (tCO_2-eq) emitted due to the industrial activity for a country or region for the period of analysis (in this case, the year 2019), Cij is the consumption (in thousands of euros) of energy source j done by sector i and Kj is the economic emission factor (tCO_2-eq/€) of energy source j, which determines the total emissions of CO_2-eq (in Tons) per euro.

Therefore, the total industrial emissions in Spain of GHG are calculated as the sum of the emissions of each industrial sector estimated from the consumption of the different energy sources per sector (in thousands of euros) multiplied by 1.000 and by the economic emission factor of each energy source (tCO_2-eq/€).

The economic emission factor, K_j (tCO_2-eq/€) is calculated as follows,

$$K_j = \left(EF_j/1000\right)/AP_j \tag{2}$$

where EFj is the technological emission factor of energy source j (tCO_2-eq/MWh), and APj is the average price for the year of reference of energy source j (€/KWh).

This means that the economic emission factor for an energy source is calculated by dividing the technological emission factor of that energy source (tCO_2-eq/MWh) by the average price of the energy source in the reference period and by 1.000.

Average prices were obtained mainly from the Eurostat Data Browser. Emission factor values were obtained from Krey, Masera, Blanford, Bruckner, Cooke, Fisher-Vanden et al. (2014), López-Martínez, Flores, Lumbreras, Villimar and Pascual (2010) and Red Eléctrica Española, REE (2021). Data related to the Survey of Energy Consumption for Spain (in thousands of euros) classified by energy source (C_{ij}) at a 3-digit NACE code level was obtained from the National Institute of Statistics (INE). The analysis presented in this paper was made at a 2-digit level.

The consumption of energy obtained was classified by the energy source (electricity, gas, gasoil, fuel oil, other crude oil products, coal and coke, biofuels, heat and other energy consumption sources). Considering the variety of technologies used, some assumptions were necessary to group the energy sources and to consider their emission factors. The grouping used is as follows: electricity, which includes electricity consumption; gas, which includes gas consumption; petroleum products, which includes gasoil, fuel oil and other crude oil products; and other, which includes coal and coke, biofuels, heat and other energy consumption sources. Emission factor estimations were made per individual energy source.

It was assumed that electricity, heat and other energy consumption sources produce indirect emissions, and gas, gasoil, fuel-oil, other petroleum products, coal and coke and biofuels produce direct emissions. Indirect GHG emissions are not produced in the consuming companies' facilities but in external facilities, such as electricity-producing utilities. In 2020, 16% of electrical energy in Spain was produced from gas in combined-cycle plants, 2% from coal, 0.8% from non-renewable waste and 1,9% from other renewables (REE, 2021).

To assess the sectoral concentration of emissions per firm, the number of firms per sector was obtained from Directorio Central de Empresas (DIRCE), the Firm Central Directory of the INE.

The activities of extractive industries corresponding to the statistical classification of economic activities in the European Community (NACE) codes 051 to 099 and '19. Manufacture of coke and refined petroleum products' were not considered, as they were not included in the official data obtained from the INE.

Considering that each energy source emits a different amount of GHG during its use, the energy consumption variables per energy source are needed to obtain estimations of emissions. The percentage of electrification is necessary to estimate the amount of indirect emissions and the degree to which projects to reduce GHG footprints should consider a change in energy source or a reduction in the consumption of electricity. Information on generation mix is necessary to account for the GHG emissions of electricity production companies' facilities due to the consumption of electricity in industrial companies.

Considering that the calculations necessary to obtain the conclusions of this article are based on information available from public sources in the form of spreadsheets of limited size (matrix 95 x 10), computational needs are solved with basic means.

As a limitation, considering the aggregate nature of the method used, it is not possible to consider the particularities within the same NACE code in terms of emissions per company, average prices or technologies used. Therefore, the emission values obtained should not be considered as actual emissions per sector. However, they are useful for the comparative analysis of this article.

4. Results

Industrial sector-specific expenditure on energy sources (in thousands of euros) is presented in the below table.

Group	Electricity	Gas	Petroleum products	Other	Total
Manufacture of food products	1.073.428	509.278	215.923	29.982	1.828.611
Manufacture of basic metals	1.113.460	441.516	27.925	89.315	1.672.216
Manufacture of chemicals and chemical products	720.192	589.241	74.252	197.887	1.581.572
Manufacture of other non-metallic mineral products	566.445	626.377	108.578	114.893	1.416.293
Manufacture of paper and paper products	399.019	231.198	30.518	21.070	681.805
Manufacture of rubber and plastic products	424.717	48.921	27.223	18.880	519.741
Manufacture of motor vehicles, trailers and semi-trailers	372.112	100.795	27.410	961	501.278
Manufacture of metal products, except machinery & equipment	307.051	98.755	60.681	5.847	472.334
Manufacture of beverages	133.368	57.609	56.116	2.228	249.321
Manufacture of wood and wood products	133.321	10.534	29.245	4.660	177.760
Manufacture of pharmaceutical products	115.367	41.979	10.415	1.541	169.302
Manufacture of textiles	101.661	52.398	6.133	432	160.624
Manufacture of electrical equipment	120.850	17.188	9.160	1.501	148.699
Manufacture of machinery and equipment n.e.c.	90.919	17.785	26.780	512	135.996
Manufacture of other transport equipment	66.772	14.125	15.213	889	96.999
Printing and reproduction of recorded media	66.381	11.069	6.725	46	84.221
Manufacture of furniture	38.619	3.442	17.850	137	60.048

Group	Electricity	Gas	Petroleum products	Other	Total
Repair and installation of machinery and equ.	23.719	4.273	27.342	90	55.424
Manufacture of leather and related products	21.160	6.391	3.745	-	31.296
Manufacture of computer, electric and optical products	24.258	2.043	2.624	177	29.102
Other manufacturing	22.495	2.510	2.655	101	27.761
Manufacture of wearing apparel	10.916	541	2.537	-	13.994
Manufacture of tobacco products	2.672	-	921	-	3.593
TOTAL	5.948.902	2.887.968	789.971	491.149	10.117.990

Table 1. Total expenditure (in thousands of euros) on energy sources per industrial sector (INE, 2019)

As the above table shows, the total bill of energy consumption on behalf of the considered sectors amounted to EUR 10.117 million, of which EUR 5.948 million corresponds to electricity and EUR 2.887 million to gas. In addition, EUR 789 million was due to consumption of petroleum products (diesel, fuel oil, gasoline, butane, propane and others), and EUR 491 million due to others (coal and coke, solid or liquid biofuels, heat and other products). Thus, electricity (58%) and gas (28%) accounted for the highest share of expenditure on energy consumption. Moreover, this was the case in most of the sectors considered (86%).

When applying the calculation method explained in the methodology section, the total emissions (tCO_2-eq) classified by energy source are as follows:

	Total emissions	% emissions/total
Electricity	7.947.733	15%
Gas	34.467.898	64%
Gasoil	3.598.476	7%
Fuel oil	2.450.531	5%
Other petroleum products	568.506	1%
Coal and coke	1.894.528	4%
Biofuels	357.808	1%
Heat, other energy consumption	2.565.661	5%
TOTAL	53.851.141	100%

Table 2. Total emissions (tCO_2-eq) by energy source

Based on estimations made using economic data and the previously presented formulae, the total emissions accounted for 53.85 $MTCO_2$-eq (NACE codes 10 to 33, excluding '19. Manufacturing of coke and refined petroleum products'). The CO_2-eq emitted in industrial facilities ($MTCO_2$-eq) were as follows: gas 34.46 Mt, gasoil 3.59 Mt, fuel oil 2.45 Mt, coal and coke 1.85 Mt, and others 3,49 Mt. The indirect emissions linked to electricity consumption and generation mix and heat accounted for 10.51 $MtCO_2$-eq. As observed, the emissions produced by the consumption of gas account for 64% of total emissions, and emissions to produce electricity represent 15%.

In the next table, the direct and indirect sectoral emissions (tCO_2-eq), as well as the level of electrification (consumption of electricity over total consumption in euros), are presented. Take note that the sectors are listed in descending order of total emissions.

	Direct emissions	Indirect emissions	Total emissions	Percentage of electrification
Manufacture of other non-metallic mineral products	10.208.145	841.042	11.049.186	40
Manufacture of chemicals and chemical products	7.587.275	2.403.489	9.990.764	46
Manufacture of food products	7.680.949	1.549.769	9.230.719	59
Manufacture of basic metals	5.863.161	2.067.247	7.930.408	67
Manufacture of paper and paper products	3.264.277	653.088	3.917.364	59
Manufacture of metal products, except machinery and equipment	1.602.091	450.395	2.052.486	65
Manufacture of motor vehicles, trailers, semi-trailers	1.402.693	502.433	1.905.126	74
Manufacture of beverages	1.534.050	178.365	1.712.415	53
Manufacture of rubber and plastic products	823.617	705.550	1.529.168	82
Manufacture of pharmaceutical products	673.723	165.534	839.257	68
Manufacture of textiles	665.376	136.922	802.298	63
Manufacture of wood and wood products	353.924	182.253	536.177	75
Manufacture of machinery and equipment n.e.c.	383.472	124.887	508.359	67
Manufacture of electrical equipment	267.277	172.563	439.840	81
Manufacture of other transport equipment	259.868	95.779	355.646	69
Printing and reproduction of recorded media	172.459	89.025	261.484	79
Repair and installation of machinery and equipment	217.194	32.355	249.549	43
Manufacture of furniture	150.052	51.787	201.839	64
Manufacture of leather and related products	104.096	28.270	132.366	68
Other manufacturing	45.887	30.801	76.688	81
Manufacture of computer, electronic and optical products	42.736	33.689	76.424	83
Manufacture of wearing apparel	22.033	14.584	36.617	78
Manufacture of tobacco products	13.393	3.570	16.963	74
TOTAL	43.337.747	10.513.394	53.851.142	

Table 3. Estimation of direct and indirect emissions and percentage of electrification per sector

When comparing the emission values obtained by applying the formula presented in the methodology section with the official data of industry estimations obtained from the Spanish government (excluding refineries), we can roughly validate our estimation method. I.e., our estimation of 43.34 $MtCO_2$-eq of total direct emissions is consistent with the 43.97 $MtCO_2$-eq of emissions due to combustion in industry obtained from MITECO (2021).

The industrial sectors emitting the largest amount of CO_2-eq are: Manufacturing of other non-metallic mineral products (11.05 $MtCO_2$-eq), Manufacturing of chemicals and chemical products (9.99 $MtCO_2$-eq), Manufacturing of food products (9.23 $MtCO_2$-eq) and Manufacturing of basic metals (7.93 $MtCO_2$-eq). The level of consumption of electricity (€) over the total energy consumption of the three most emitting sectors is lower than 70%.

In the above table it can also be observed that of the total 53.85 $MtCO_2$-eq GHG emitted by the analysed sectors, 43.34 $MtCO_2$-eq were emitted directly inside industrial premises (80.5%), and 10.51 $MtCO_2$-eq (19.5%) were emitted in power generation plants. The latter percentage may off course vary from sector to sector, as it relates to the percentage of electrification of industrial processes per sector, which ranges from 40% in the sector of Manufacture of other non-metallic mineral products, to more than 80% in the sectors of Manufacture of computer, electronic and optical products, Manufacture of rubber and plastic products and Other manufacturing.

The concentration or atomisation of emissions across firms within sectors is an important aspect that affects the possibilities to manage and reduce emissions. When faced with sectors where GHG emissions are highly dispersed, this implies that their reduction will require the efforts of many companies whereby all make only small contributions. At best, this would also require a relatively small amount of investment for each. At the other end, there may be sectors in which GHG emissions are highly concentrated and thus may allow focusing on a relatively small number of companies, entailing bigger investments on behalf of each of them.

To assess the concentration of emissions per firm in the respective sectors considered, corresponding calculations were carried out, and the results are presented below.

	Total emissions	Number of companies	Emissions per firm
Manufacture of other non-metallic mineral products	11.049.186	8.175	1.352
Manufacture of chemicals and chemical products	9.990.764	3.789	2.637
Manufacture of food products	9.230.719	25.309	365
Manufacture of basic metals	7.930.408	1.600	4.957
Manufacture of paper and paper products	3.917.364	1.642	2.386
Manufacture of metal products, except machinery and equipment	2.052.486	35.494	58
Manufacture of motor vehicles, trailers, semi-trailers	1.905.126	1.727	1.103
Manufacture of beverages	1.712.415	5.264	325
Manufacture of rubber and plastic products	1.529.168	4.597	333
Manufacture of pharmaceutical products	839.257	385	2.180
Manufacture of textiles	802.298	6.434	125
Manufacture of wood and wood products	536.177	9.961	54
Manufacture of machinery and equipment n.e.c.	508.359	6.552	78
Manufacture of electrical equipment	439.840	2.138	206
Manufacture of other transport equipment	355.646	966	368
Printing and reproduction of recorded media	261.484	14.761	18
Repair and installation of machinery and equipment	249.549	15.260	16
Manufacture of furniture	201.839	11.884	17
Manufacture of leather and related products	132.366	4.451	30
Other manufacturing	76.688	10.646	7
Manufacture of computer, electronic and optical products	76.424	2.490	31
Manufacture of wearing apparel	36.617	9.221	4
Manufacture of tobacco products	16.963	50	339
TOTAL	53.851.142	182.796	295

Table 4. Estimation of sectoral concentration of emissions per firm (tCO_2-eq/firm)

From the above table, it can be observed that Manufacture of basic metals, Manufacture of chemicals and chemical products, Manufacture of paper and paper products and Manufacture of pharmaceutical products are the sectors where the emission of GHGs are most concentrated.

5. Discussion

Figure 1 shows the emissions per sector (portrayed by the size of the respective bubbles) in tandem with their concentration levels (emissions per firm on the x axis) and electrification percentage (y axis). As our study intends to provide insights and guidance for public GHG emission reduction programmes, the percentage of electrification is used to assess whether such investments should be made in/by industrial companies or in/by electricity production companies.

For the same reason, we determined whether the emissions are concentrated in a small number of companies (each with a high amount of emissions) or dispersed among many firms (with few emissions each). Evidently, the size and cost of emission reduction projects will vary along the continuum between both extremes.

Accordingly, it was possible to segment all sectors across four quadrants, using the level of electrification of industrial processes (vertical axis) and sector-specific emission concentration per firm (horizontal axis) to allocate each sector.

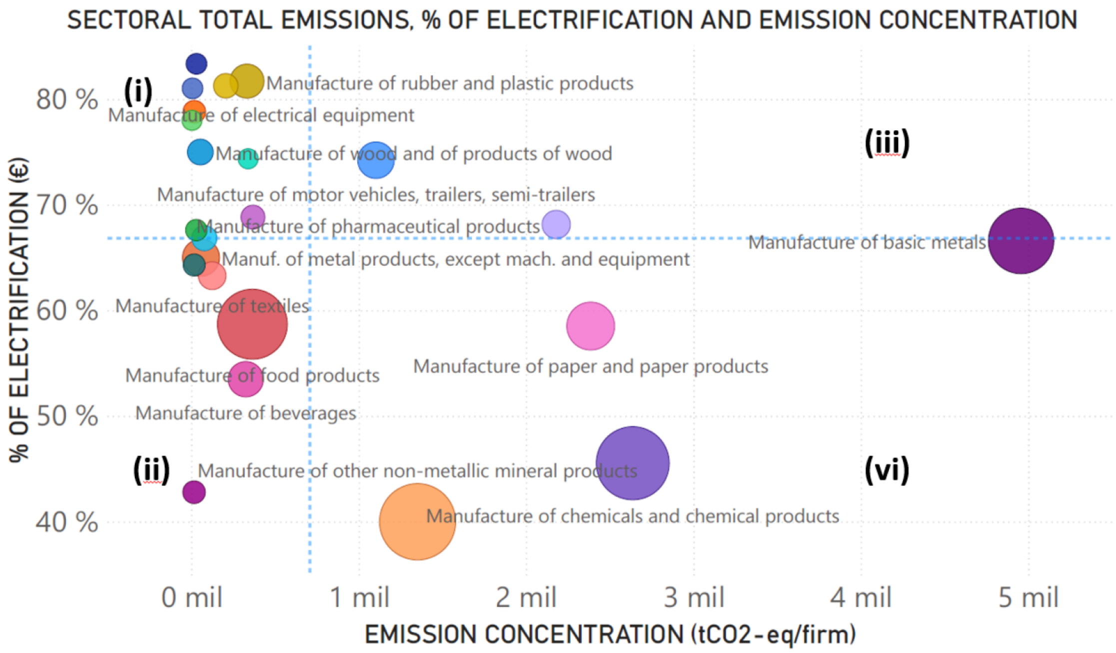

Figure 1. Estimation of sectoral total emissions, percentage of electrification and emission concentration

As stated, our segmentation grid led to four quadrants. In what follows, we will characterize each of them.

Quadrant I is the top left of the image. It includes 11 sectors (48%) that emit 7% of the total emissions. The emissions are widely dispersed in firms with a high level of electrification. On average, cost-oriented, energy-efficiency projects with low emission reductions and investments per firm should be considered.

Quadrant ii is the bottom left of the image. It includes six sectors (26%) that emit 26% of the total emissions. The emissions are very dispersed in firms with a low level of electrification. 'Manufacture of food products' is included in this section and represents 65% of the emissions of this quadrant. Projects for energy efficiency, electrification or low emission alternative energy sources with relatively low levels of investment are suitable for companies represented in this quadrant.

Quadrant iii is the top right of the image. It includes two sectors (9%) that emit 5% of the total emissions. The emissions are concentrated with a high level of electrification. Manufacture of pharmaceutical products and Manufacture of motor vehicles, trailers and semi-trailers are included in this quadrant. Cost-oriented energy-efficiency projects with a relatively high level of investment per firm can be applied.

Quadrant iv is the bottom right of the image. It includes four sectors (17%) that emit 61% of the total emissions. The emissions are highly concentrated in firms with a low level of electrification. The sectors that comprise this quadrant are as follows: Manufacture of basic metals, Manufacture of chemicals and chemical products, Manufacture of paper and paper products and Manufacture of other non-metallic mineral products. Alternative energy source projects (electricity or other non-GHG-emitting sources) can contribute strongly to the reduction of emissions of firms in this section.

6. Conclusions

The present paper has tried to put the energy-related emissions of industrial sectors into perspective. Emissions at sectoral level were estimated based on economic consumption data obtained from official sources at a NACE 3-digit level, average energy prices and average emission factors. The results show how four sectors are responsible for emitting most GHG: Manufacture of other non-metallic mineral products, Manufacture of chemicals and chemical products, Manufacture of food products and Manufacture of basic metals. Together they account for 71% of all Spanish industrial emissions.

As a next step, the industrial sectors considered were segmented according to: the emissions per firm ($MtCO_2$-eq/firm) as a measure of concentration or atomisation of emissions and the level of electrification of industrial processes per sector (electricity consumption over total energy consumption in euros). This allowed us to allocate all sectors into four quadrants.

The percentage of electrification was used to determine whether projects to reduce the GHG footprint of industrial companies should focus on changing from a non-electricity energy source to electricity or other non-GHG-emitting sources or on a reduction in the consumption of electricity.

The concentration of emissions at company-level was used to determine whether emissions were concentrated in companies with a high amount of emissions or dispersed in many sites and locations with few emissions. The size and cost of emission reduction projects will vary along the continuum between both extremes.

The main advantages of the method used in this research are as follows: It provides an aggregate sectoral perspective on GHG emissions by analyzing expenditures by energy source per sector. This approach enables us to address the research questions mentioned earlier with significant clarity.

Specifically, it facilitates the determination of intra-firm emissions based on the energy sources utilized within each sector. It also allows for the calculation of the average electrification rate of each sector, which compares the electricity expenditure to the total energy expenditure. Furthermore, the method enables the estimation of the proportion of indirect emissions resulting from the activities of each sector.

However, the method used has some limitations. Considering the aggregate nature of the method employed, it is not possible to account for specific variations within the same NACE code regarding emissions per company, average prices, or technologies used. Therefore, the emission values obtained should not be regarded as actual emissions per sector or for individual companies. Nevertheless, they prove useful for the comparative analysis between sectors presented in this article. Additionally, it is important to note that certain major emission-intensive sectors, such as extractive industries and petroleum refining, have not been included in the study.

7. Policy Recommendation

As mentioned in the introduction, this study aimed to provide insight into the development of public programmes for GHG emission reduction. These programmes should be adapted to the characteristics of the emitting sectors. Here, four quadrants were defined based on the similarity of emission characteristics. Thus, a short description of the kind of GHG emissions reduction programme appropriate for the sectors in each quadrant is presented below.

Based on the former, we imply that for sectors located in quadrant i, public programmes should focus on cost-oriented, energy-efficiency projects with low emission reductions per firm. No major emission reduction can be expected in absolute figures.

For sectors located in quadrant ii, public programmes should focus on energy efficiency, electrification or low emission alternative energy sources with relatively low levels of investment.

For sectors located in quadrant iii, public programmes should support cost-oriented energy efficiency projects with a relatively high level of investment per firm.

For sectors located in quadrant iv, alternative energy source projects (electricity or other non-GHG-emitting sources) may contribute significantly to the reduction of emissions. The reduction of emissions in these sectors requires major technological transformation and reconversion that could come from the use of alternative sources of energy, such as hydrogen, if the technology is available at an affordable cost. The execution of these projects could include reconsidering the industrial footprints of the companies and large investments. These sectors should be prioritised to reduce the total amount of emissions. They require intense sources of heat for their processes, and electrification does not seem to be a solution.

The high-energy-consuming sectors found in quadrant iv are, in some cases, not using public funds for emission reduction as often as less-consuming sectors (Fernández et al., 2022). The type of projects to be undertaken in these sectors (in terms of investment level, technology development, skills and experience) are distinct from the energy efficiency projects that are appropriate for highly electrified and low-consumption companies. Consequently, public support programmes aiming to foster such investments should nudge actors accordingly.

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