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CO2 Embodied in Trade between Poland and Selected Countries

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Abstract !is study is aimed at analysing the carbonembodied in trade "ows between Poland

and its major trade partners. Calculations are based on the data from the GTAP database for the year 2004. !e study usesan input-output analysis, which allows responsibility to be assigned to individual "ows for generating speci#c amounts of emissions in the economy. Itis shown that Polish exports contain signi#cantly more embodiedcarbon than Polish imports, despite the fact that the value of the imports is higher. Moreover, it is found that among the surveyed countries, only three were net importers of carbon emissions to Poland. Export to Germany is responsible for the most of emissions in Poland. In turn, Poland receives the most emissions from imports from Russia.

Keywords: Carbon dioxide, embodied emission, Input–Output analysis

Introduction !e growing interest in climate change serves the development of interdisciplinary

research combining various areas of interest in this phenomenon. Economic science bene#ts heavily from this,most o$en addressing issues concerning the economic impact of climate change and of climate policy. Since the primary goal of climate policy is the reduction of greenhouse gases, the study of the causal relationships between emissions of these gasses and the economy is of interest to economics. !ose relationships can be studied undervarious aspects, one of which is foreign trade. !e problem was #rst approached a$er the adoption of the United Nations Framework Convention on Climate Change (UN FCCC) in 1992, which aimed at stabilizing anthropogenic greenhouse gas emissions, especially carbon dioxide (CO2) (1992). Precursors of the current studyhave addressed the fac%hat developed countries, when obliged to reduce their emissions, import many goods and services from developing countries, thereby contributing to the growth of greenhouse gas emissions in those countries(Wycko& and Roop 1994; Subak

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1995; Schae&er and André 1996; Lenzen 1998). !is was, as it turned out, a real threat to the e&ectiveness of global e&orts to reduce emissions. It is di*cult to treat the reduction of emissions in one country as e&ective if it entails a growth in imports and an accompanying increase in indirect emissions in the exporting countries. !is has been observed in the case of the emissions of the United Kingdom (Helm, Smale et al. 2007). In this way, emission sources are merely moved from one country to another. Trade here acts not only as a factorleading to economic growth through increasing e*ciency of resource allocation, but also as a mechanism which allows environmentally burdensome production to move to countries with lower environmental standards(Rhee and Chung 2006). One method of measuring the indirect responsibility for pollution emissions, including greenhouse gas emissions, outsidea given country, is to measure the so-called emissions embodied in trade. Emissions embodied in trade include all emissionswhich were emi%ed in country A in order to generate trade "ows from country A to country B.

One of the important reasons for studyingthe greenhouse gas emissions embodied in trade is to identify the e&ect known as carbonleakage. !is phenomenon is based on the growth of greenhouse gas emissions in countries with have noemission reduction commitments, thanks to the reductive measures takenby other countries. !is issue is o$en discussed in the literature of climate change economics(Metz, Davidson et al. 2007; Peters and Hertwich 2008; Bernard and Vielle 2009; Kuik and Ho+es 2010).
Apart fromthis, there are also practical reasons for conducting this research. Peters andHertwichconvincingly argue that emissions embodied in trade have a signi#cant impact on participation in and the e&ectiveness of global climate policies such as the Kyoto Protocol (2008). Furthermore, knowledge about them can be applied in creating national and regional policies for climate change mitigation. !is con#rms the growing interest in adapting trade policy measures for climate policy purposes. (Neuhof 2007; Zhang 2009; Dissou and Eyland 2011). Besideswhat has already been indicated, an inventory of emissions induced abroad is useful in determining the indirect responsibility for their formation. !is allows us to observe the actual reduction e&orts of di&erent countries and groups of states.

In recent years, the number of works on embodied emissions has systematically increased. A review of over 50 paperson this topic from the period 2007–2009 has been wri%enbyWiedmann(2009). Since that time,many new articles have been published. A signi#cant number of them focus on emissions embodied in trade "ows. !e vast majority of published works concern China, and analyse the in"uence on worldwideCO2emissionsof exportsfrom that country(Yunfeng and Laike 2010), the in"uence of individual sectors on

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the emissions embodied in Chinese exports(Lin and Sun 2010; Su, Huang et al. 2010), and the way in which carbon emissions are embodied in China's trade with Japanand the USA (Dong, Ishikawa et al. 2010; Guo, Zou et al. 2010; Liu, Ishikawa et al. 2010).
Among the studies focused on other countries, one can#nd analyses of CO2emissions implicated in Austria's trade(Gavrilova, Jonas et al. 2010; Muñoz and Steininger 2010), as well as publications presenting global emission "ows between individual countries and groups of countries(Chen Z. and Chen G.Chen, Chen et al. 2010; Atkinson, Hamilton et al. 2011; Chen and Chen 2011). So far, there is a lack in the literature of a study that would in particluar focus on emissions embodied in trade with Poland. !is is the goal of this article.

!e study presents the in"uence that multilateral trade relations have on CO2 emissions in Poland and abroad.To this end, the 20 countries with which Poland has the greatest volume of trade are analysed here. !e basic research questions concern the amount of CO2emissions in Poland resulting from the export of Polish goods and services to those countries, and the emissions in those countries resulting from the export of their goods and services to Poland. Questionsare raisedconcerning the direct and indirect e&ectsof trade-associated emissions, and about the level of carbon intensity in trade "ows between Poland and the analysed countries.

!e outline of the work is as follows: section 2 describes the applied methodology and data sources, section 3 presents and discusses the results of the analysis of the emissions embodied in trade between Poland and its major trade partners,and the last section contains the conclusions of the study.

Methods !is study uses the methodology for calculating emissions embodied in bilateral

trade (EEBT) (Peters 2008). !e EEBT is calculated based on data from international trade statistics in monetary units. Because the method does not distinguish trade "ows satisfying #nal consumption from those satisfying intermediate consumption, but treats them together, its usefulness for evaluating the emissions resulting from consumption is limited. It allows the calculation of the emissions generated in a given region in order to produce goods and services destined for export. !is is not, however, the total emissions embodied in exported goods and services, because imported intermediate goods and services are usually usedduring the production, which cause emissions elsewhere. Since this method does not take into account emissions associated with the production of imports, its results cannot be equated with the carbon footprint.

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!e EEBT methodology is based on the input-output (I-O) analysis developed by Leontief(1941). Since its main assumptions have been described in detail by, among others,Miller and Blair(2009), herea$er only the main formulas are presented.

!e economy can be divided intoa number nof interrelated industries, whose total output is expressed by:

!e vector x represents the total output in each sector; Ais a technical coe*cient matrix, whose general elements a

ij indicates the demand per unit of production of sector iin sector j.!en Ax is a vector representing the total intermediate consumption.

!e elements of the vector y indicate the size of the #nal demand for the production of each sector. All scales used in the calculations are expressed in terms of value. In order to calculate x, the following transformations have to be performed:

In the sequence of Eq. (2),I is the identity matrix, i.e.,the matrix with ones the main diagonal zeroes everywhere else. !e matrix is (I-A)-1"Leontief 's Inversematrix",

and is fundamental for the input-output analysis. !e values in this matrix describe the in"uence of the exogenous change of the #nal demand on the totalproduction. It allows tracking of mutual interactions between the elements of the production system, including the analysis of "ows between the sectors. Based on Eq. (1), the total production of a country r, denote dxr,can be described with

the formula:

whereyris the vector of the #nal demand on domestic production, Arr is a matrix in which the entry arr

ij is the amount of input from sector i in country r per dollar's worth of output of sector j in r. !en, Arrxr expresses the total intermediate demand in country r for domestic

production.

x=Ax+y (1)

x-Ax=y (I-A)x=y

x=(I-A)-1y (2)

xr=Arrxr+yrr (3)

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!e #nal demand in Eq. (3) can be expressed as

where crr is the vector of the #nal consumption of domestic production, grr is the vector of government expenseson domestic production, and er is the vector of export. !erefore,

the output equation can be rewri%en as

and according to Eq. (2),

In order to evaluate the total CO2 emissionscreated during the production processes in country r,the total production has to be multiplied by the CO2 emission factor:

where f rco2 is the total CO2 emission in country r, is a row vector whose elements indicate the amount of CO2 emission per dollar of total output ofeach sector in countryr.

!e assumption of linearity accompanying the input-output approach allows Eq.
(7) to be decomposed and permits evaluation of the e&ect of each component of the #nal demand individually. However, because the study focuses on identifying the emission e&ect caused by export, only this aspect is further considered.

Total CO2 emission generated in country r to meet the total external demand,

denoted by, can be expressed as

yrr=crr+grr+er (4)

xr=Arrxr+crr+grr+er (5)

xr=(1-Arr)-1(crr+grr+er) (6)

f rco2=Frco2xr=Frco2(I-Arr)-1(yrr+grr+er) (7)

fexco2=Frco2(I - Arr)-1er (8)

er=∑ ers (9) s

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Because the export vector er is the sum of trade "ows from country r to country s:

With a further break-downof Eq. (8) it is possible to capture the emissions embodied in individual trade "ows, according to the relation Where frsco2 is the emission embodied in exports fromcountryrto country s.

At the same time, Eq. (10) allows the derivation of the emission intensity factor

for exports from country r to country s, denoted Eirsco2, which can be calculated using the formula

Moreover, in the total emission e&ect of exports from country r to country s calculated according to Eq. (10), the direct and indirect e&ect is highlighted. !e direct e&ect, denoted by fdrsco2 in Eq. (12), concerns CO2 emissions in exporting sectors

during the production of goods and services destined for export, and is connected with primary demand.

!e methodology of calculating emissions embodied in bilateral trade also covers emissions generated throughout the whole supply chain of the exporting sectors. !ese are caused by intermediate demand for domestic goods and services, and constitute an indirect emission e&ect of exports from country r to country s, denoted in the following equation by:

!e data used in the studyare the latest available, and are widely used in contemporary published works (Atkinson, Hamilton et al. 2011; Chen and Chen 2011).
!e main source of these data is the Global Trade Analysis Project (GTAP),database version 7.0.!is is a fully documented, publicly available database representing the state of the world economy in 2004.It consists of113 countries and regions, as well as 57 sectors.

frsco2=Frco2(I - Arr)-1ers (10)

"rsco2 =frsco2 - fdrsco2 (13)

fdrsco2=Frco2ers (12)

Ei rsco2= (11)ers

frsco2

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!e main #le contains the values of "ows of goods and services expressed in millions of American dollars ($m), according to the 2004 exchange rate (Badri Narayanan and Walmsley 2008).All values used in the calculations are in market prices without taxes.
Emission factors were obtained on the basis of estimations performed by Lee (2008).
!ese data are fully compatible with the GTAP 7.0 database, and were acquired based on fuel emission factorscalculated according to the Tier 1methodology of the IPCC(Simon Eggleston, Leonardo Buendia et al. 2006).

Results and discussion !e emissions embodied in the total export of Poland were calculated using the

relationship shown in Eq.(8), while the individual trade "ows between Poland and the countries examined were calculated in accordance with Eq.(10). !e aggregated results are shown in Table 1. In 2004, the emissions embodied in the total export from Poland to other countries equalled78,320.20GgCO2,of which 82%, or 64,346.29Gg CO 2,was

exported to Poland’s 20 most important trade partners. Chinese researchers(Chen, Chen et al. 2010)using the MRIO methodology (Multi-Regional Input–Output), which includes the emissions embodied in the intermediate use of imports, obtained the total value for Polish exports. !e result was over 18% higher than the value obtained with EEBT.

Among the examined export "ows, the greatest amount of emissions were clearly embodied in exports to Germany, coming to a total of 17,944.98 GgCO2, which

constitutes 23% of the total emissions embodied in Polish exports at that time.!is is associated with the fact that Germany is the biggest recipient of Polish exports.

In the case of imports to Poland, the greatest amount of emissions was embodied in the trade with Russia, equalling13,930.50 GgCO2.!is is a consequence of the

structure of Polish importsfrom Russia, which mainly consists of natural resources which involve very high emission levels in Russia during their extraction and transportation.
!e second most carbon-intensive source of Polishimportsis China,which accounts for7,654.78 GgCO2.In this case, it is di*cult to distinguish groups of goods whichmight

have a signi#cant in"uence on this result. Probably the low energy e*ciency standards combinedwith the high emission intensity of the energy sector in China have crucial signi#cance here. However, examining the co-responsibility for CO2emissions created as

a result of bilateral trade relations, the most burdened of Poland'strade relations are those with Germany, Russia, the Czech Republic, and China.

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Table 1 CO2 emissions embodied in trade between Poland and selected countries in the light of trade volumes in 2004 in Gg

Country CO2emissions in exports from Poland

CO2emissionsin importsto Poland

Total CO2emissionsinbilateral

trade

Trade balance of Poland

Volume of exports from

Poland

Volume of imports to

Poland Trade turnover

DEU 17 944.98 5 111.58 23 056.56 -3 773.22 18 577.90 22 351.12 40 929.02

ITA 3 827.99 1 998.14 5 826.13 -2 224.61 4 658.48 6 883.09 11 541.57

F? 4 235.02 1 161.99 5 397.01 -1 234.74 4 695.10 5 929.84 10 624.93

RUS 2 881.29 13 930.50 16 811.79 -3 643.90 2 750.22 6 394.12 9 144.34

GBR 3 782.90 1 382.15 5 165.05 494.56 4 072.62 3 578.06 7 650.68

USA 3 198.31 2 153.65 5 351.96 -285.74 3 010.10 3 295.84 6 305.94

CZE 6 203.39 2 346.92 8 550.31 -172.06 3 023.96 3 196.01 6 219.97

BEL 2 273.58 395.41 2 668.99 -162.11 2 633.04 2 795.14 5 428.18

SWE 4 149.53 259.45 4 408.98 264.43 2 671.58 2 407.15 5 078.73

ESP 1 681.01 1 004.83 2 685.84 -714.67 1 999.93 2 714.60 4 714.53

NLD 1 937.98 814.78 2 752.76 -459.59 1 940.08 2 399.67 4 339.75

AUT 2 561.17 313.51 2 874.68 -331.23 1 582.14 1 913.38 3 495.52

HUN 1 652.24 440.74 2 092.97 126.56 1 735.09 1 608.52 3 343.61

CHN 781.09 7 654.78 8 435.87 -1 741.29 637.44 2 378.73 3 016.17

DNK 1 235.69 219.21 1 454.90 -108.93 1 338.85 1 447.78 2 786.63

NOR 1 283.36 256.08 1 539.45 81.69 1 339.41 1 257.71 2 597.12

JPN 871.09 698.23 1 569.32 -921.88 821.42 1 743.30 2 564.73

UKR 1 551.96 2 730.56 4 282.51 756.02 1 653.75 897.73 2 551.48

SVK 1 468.30 810.00 2 278.30 -254.94 1 049.49 1 304.43 2 353.91

TUR 825.41 634.72 1 460.13 -149.00 948.33 1 097.32 2 045.65

Total 64 346.29 44 317.22 108 663.51 -14 454.64 61 138.91 75 593.56 136 732.47

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Among the 20 countriesexamined, the balance of CO2 emissions embodied in Polish foreign trade (Fig.1.) was negative only for Russia, China, and Ukraine. !is means that, as a result of the bilateral trade exchange with Poland, these countries release more CO2 than Poland. Ukraine emi%ed more,

despite its negative trade balance with Poland.
In other 17 cases, Poland wasa net exporter of carbon emissions. It can be seen that the transfer of net emission to Poland comes from an eastern direction, from countries of lower environmental protection standards, whereas Poland's net carbon emissions were transmi%ed to wealthier western countries with higher environmental standards than Poland. Altogether, CO2emissions embodied in Polish exports to the countries examined here were 45% higher than those calculated in imports, despite the fact that the value of Polish imports exceeded the value of exports by23%.!is was the result of much higher intensity ofemissions of Polish exports, in comparison with the intensity of emissions of imports.

Figure 1. Net "ows of CO2 embodied in bilateral trade between Poland and selected countries in 2004 in Gg

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The emission factor of Polish exportsranged from 0.82 to 2.05 Gg CO

2

/$m (Fig. 2). This

results from the diversified structure of Polish exports to individual countries. Exportsto Italy

had the lowest emission intensity, which is linkedto the relatively large share of low carbon

production in Polish exports to this country. Exportsto the Czech Republic were the most

emission-intensive, this being caused by the significant amount of electricity and other

energy-intensive productsinvolved in the exported goods and services. From among the 20

Net flows of CO

2

embodied in bilateral trade between Poland and selected countries in 2004 in Gg

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Figure 2. CO_2 emission intensity factors of foreign trade "ows of Poland inGg/$min 2004

!e obtained emission intensity of imports from China of 3.22 Gg CO_2/$m issigni#cantly di&erent from the result obtained by Liu at al., which considers export from China to Japan in 2000 (Liu, Ishikawa et al. 2010). According to those authors, this factor in 1990 amounted to3.84 Gg CO_2/$m, and then it decreased, so that in the years

1995 and 2000 it amounted to1.85 and 0.98 Gg CO_2/$m, respectively. Unfortunately this decrease was not explained, so it is di*cult to point out the potential causes of these di&erences. Divergences are even more puzzling, as the emissions intensity of Japanese exports to China in the years 1995–2000 (quoted in that publication and obtained by the

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same method) "uctuated in the rangeof 0.39–0.47 Gg CO_2/$m, and can be compared with the resultsacquired for "ows from Japan to Polandof 0.40 Gg CO_2/$m.

In the next part, based on Eqs. (12) and (13), the emissions embodied in the international trade were divided into indirect and direct emissions (Table 3). !ese results show that indirect CO_2emissions induced by Polish exports are almost three times higher than the direct emissions. !is means that companies exporting their products from Poland have a much lower in"uence on emissions embodied in export than their national suppliers. Only exports to the Czech Republic and to Sweden cause a higher direct e&ect than indirect e&ect. For other export "ows, the relation of the evoked direct emissions to the indirect emissions "uctuated from 1.26 for Austria to 5.93 for Turkey. In case of "ows in opposite directions, the direct e&ect was in every case higher than the indirect one, and its power was almost as much as 10 times higher for imports coming from the United Kingdom. Both in Poland and in its biggest trade partners, the results indicate indirect emissions to be the key emissions source.

Table 2 Direct and indirect CO_2 emissions embodied in bilateral trade of Poland in 2004 in Gg

Country

Export Import

Direct emissions Indirect

emissions

Ratio of indirect to direct

emissions Direct emissions

Indirect emissions

Ratio of indirect to direct

emissions

DEU 3 542.45 14 402.54 4.07 917.80 1 429.12 1.56 ITA 689.83 3 138.16 4.55 192.19 203.21 1.06

F? 710.99 3 524.03 4.96 1 004.27 4 107.31 4.09 RUS 634.33 2 246.96 3.54 130.58 182.93 1.40

GBR 816.53 2 966.37 3.63 706.32 6 948.47 9.84 USA 1 007.50 2 190.81 2.17 62.06 157.15 2.53

CZE 3 140.02 3 063.37 0.98 302.14 702.69 2.33 BEL 382.18 1 891.40 4.95 396.32 765.67 1.93

SWE 2 091.61 2 057.92 0.98 301.37 1 080.77 3.59 ESP 298.98 1 382.03 4.62 115.56 325.18 2.81

NLD 538.05 1 399.93 2.60 395.89 1 602.25 4.05 AUT 1 133.76 1 427.41 1.26 97.03 601.19 6.20

HUN 264.13 1 388.11 5.26 272.16 542.62 1.99 CHN 224.43 556.66 2.48 115.18 140.90 1.22

DNK 224.56 1 011.13 4.50 3 041.67 10 888.83 3.58 NOR 231.81 1 051.55 4.54 379.74 430.26 1.13

JPN 273.99 597.10 2.18 95.14 164.30 1.73 UKR 288.92 1 263.03 4.37 202.88 431.84 2.13

SVK 440.04 1 028.25 2.34 888.35 1 842.21 2.07 TUR 119.06 706.34 5.93 697.34 1 456.31 2.09

Total 17 053.17 47 293.11 2.77 917.80 1 429.12 1.56

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Conclusions Poland exports signi#cantly more emissions than it imports. However, this does

not provide us with evidence that trade contributes to larger emissions in Poland than would be the case were there no trade exchange. !e negative trade balance of Poland, together with the low emission intensity of imports, suggest that importsmay contribute to the signi#cant reduction of emissions, in comparison to the situation where imported goods are produced in Poland. Even so, taking into consideration the structure of Polish exports, which consist of many products from energy-intensive industries, it is possible that emissions created as a result of export exceed the potential bene#ts of import.

!is study has indicated that the largest amount of emissions was created as a result of Poland's trade with EU Member States. !ese emissions remain under the control of EU climate policy, which aim to reduce them. In the case of the EU countries neighbouring Poland, which by their trade with Poland contribute to the generation of signi#cantCO2 emissions, bilateral e&orts to curb the emission impact should be considered. Implementing these additional measures could be particularly bene#cial in sectors not covered by the EU Emission Trading Scheme. !is is because emissions of these sectors are under the in"uence of domestic policies.

Regarding the phenomenon of "carbon leakage"Xunderstood rather in its "weak" sense in contrast to its "strong" de#nition (Peters and Hertwich 2008)Xwe can recognize "ows of net embodied emissions which come to Poland from Russia, China, and Ukraine.
!is is not only because of the majorityshare in emissions embodied in the bilateral trade of those countries, but also because of the lowenvironmental standardsre"ected inthe emission intensity of the imports. In order to avoid the development of this leakage, there is a need to further monitor these "ows in terms of emission embodied. !is is crucial in the context of implementing the ambitious EU climate policy. Despite the provisions in new EU legislation providing special protection to "sectors exposed to the signi#cant risk of carbon leakage", the risk of its escalation is high(2003/87/EC 2009; Clò 2010).
From the analysis presented here, it appears that, for the majority of emissions embodied in trade, indirect emissions were the main source. !is demonstrates that, in order to ef- fectively limit the in"uence of trade exchange on CO2emission in trading countries, poli- cies should concentrate on comprehensive economy-wide solutions. !e improvement of emission parameters in individual sectors,even if their role in export is signi#cant, will probably bring poor results.

Some of the conclusions presented above require further examination, in order to obtain empirical support. Certainly the sectoralanalysis of the examined carbon "ows

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would be helpful. !e issue of "carbon leakage", too, requires detailed studies. Moreover, carrying out a simulation to assess emissions in Poland under the closed economy assumption would have a crucial cognitive value.

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