



Carbon footprint accounts of Pakistan: an input-output life cycle assessment model

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Abstract

The Paris agreement (2015) seems a significant achievement towards a global mitigation policy to climate change. However, implementing the promised Intended Nationally Determined Contribution (INDC) targets by the participating countries has become a real challenge. In this aspect, the input-output life cycle assessment (IO-LCA) model provides an important assessment mechanism to design suitable abatement policies limiting the rising greenhouse gas (GHG) emissions. The present paper develops an IO-LCA model for Pakistan and estimates all the direct and indirect GHG emissions caused by all the production activities during all the stages of production. This task is achieved in three phases. In phase 1, the Pakistan input-output table (IOT) is constructed. In phase 2, the GHG environmental satellite accounts are created for each sector in the economy. In phase 3, the GHG emissions are linked to different categories of final demand.

Keywords Climate change · Mitigation · INDC · Carbon footprints · Energy · Input-output table

Introduction

Environmental deterioration is causing global warming, and this issue has gotten a lot of attention at the national and global level. Many governments and global organizations are trying to control the rising greenhouse gas (GHG) emissions worldwide. In December 2015, around 164 countries across the globe embraced a global climate protocol at the United Nations Framework Convention on Climate Change (UNFCCC) in Paris. In this agreement, they publicly outlined their intended mitigation actions to climate change, known as the Intended Nationally Determined Contributions (INDCs). Achieving the INDC target will symbolize the serious efforts of a country towards the issue (Wu et al. 2016; Zeshan and Ko 2016; Rogelj et al. 2016; Jackson et al. 2015).

The two main accounting approaches addressing environmental issues are the production-based and consumption-based approaches. The former method allocates GHG emissions to the place of production while the latter method allocates it to the final consumption (Peters 2008). However, the

quantification of GHG emissions through the consumption-based method is getting more attention because it offers complementary evidence for an effective policy-making process (Wiedmann and Lenzen 2018; Mieke et al. 2016), which is not easy in case of production-based method (Barrett et al. 2013). Further, rising global trade along with increasing demand in the developed countries both have led to a higher level of GHG emissions from the production process in exporting countries (Fernandez-Amador et al. 2017; Mi et al. 2019). Hence, the literature emphasizes that the final users are more responsible for the rising GHG emissions than the producers (Table 1).

Life cycle assessment (LCA) and input-output (IO) models are widely used to analyze the consumption-based environmental policies (Zhang et al. 2018; Aguilar-Hernandez et al. 2018; Hertwich 2005; Ghertner and Fripp 2007). However, there are two main challenges associated with the LCA method, i.e., defining a concrete boundary of analysis and circularity effects. The former needs to specify what is included or ignored in the analysis to keep the analysis manageable, which, however puts limitations to the results and generates an underestimated life cycle of a product. The latter indicates that the production of output requires other machinery, and a complete life cycle assessment is required for all related materials used in the production process. Hence, the LCA model requires many

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Table 1 Environmentally extended input-output table (EEIOT)

Domestic production: (million PKR)									
Sector/sector	Agriculture	Land	Energy	Chemicals	Metals	Manufacturing	Transport	Minerals	Others
Agriculture	1,308,454	2941	5	122	–	2,667,221	259,888	277	96,562
Land	29	154	–	1825	–	13,583	275	2396	1066
Energy	28,200	1354	1,344,013	16,285	8773	198,029	212,973	41,143	234,567
Chemicals	105,158	4049	38,328	33,360	1285	45,386	101,746	2076	94,159
Metals	–	–	428	1484	5449	40,297	54,183	1243	2673
Manufacturing	28,316	1599	95,209	77,223	10,757	577,896	462,676	22,400	322,492
Transport	178,021	1758	352,894	98,988	76,496	950,400	762,492	60,635	266,719
Minerals	7813	372	316,245	11,138	60,353	190,205	43,161	45,298	32,235
Others	42,114	13,849	34,411	26,832	7495	296,448	431,395	71,264	741,802
Imports	92,195	2159	449,215	123,401	18,864	405,480	542,083	55,359	168,277
Net taxes on production	57	332	120,395	8570	3809	92,332	80,063	12,303	13,460
Total at purchasers' price	1,790,357	28,569	2,751,143	399,229	193,280	5,477,278	2,950,935	314,395	1,974,014
CE	1,613,980	32,038	77,007	56,172	25,662	706,144	1,202,972	70,915	1,169,453
CFC	210,534	654	47,347	12,839	5866	154,226	192,426	36,061	379,329
Operating surplus, net	2,678,820	56,700	362,003	120,923	55,243	1,326,889	3,670,065	588,218	2,795,065
Operating surplus, gross	2,889,354	57,354	409,350	133,762	61,109	1,481,115	3,862,491	624,279	3,174,394
Value-added, gross	4,503,334	89,392	486,357	189,934	86,771	2,187,259	5,065,463	695,194	4,343,847
Total inputs at basic prices	6,293,690	117,960	3,237,500	589,163	280,051	7,664,536	8,016,398	1,009,589	6,317,861
Emission satellite: (Gg/kt of CO ₂ equivalent)									
CO ₂	–	9671	47,251	3278	598	37,651	37,181	15,535	27,641
CH ₄	83,790	–	21,903	–	–	63	189	–	,302
N ₂ O	78,120	–	1860	–	–	–	–	–	310
CO	950	–	21	–	–	67	2470	–	2432
NMVOCs	–	–	51	–	–	17	816	184	439
Final demand: (million PKR)									
Sector/sector	HC	CCEG	ICEG	GFCF	CI	EXPG	EXPS	Total output	
Agriculture	1,728,880	–	–	38,092	71,832	119,246	168	6,293,690	
Land	94,726	–	–	–	3686	220	–	117,960	
Energy	1,118,449	139	59	–	7302	26,083	130	3,237,500	
Chemicals	141,797	–	–	–	8409	13,411	–	589,163	
Metals	25,944	–	–	135,590	3351	9406	2	280,051	
Manufacturing	3,667,691	17,649	7505	1,101,774	90,494	1,155,114	25,742	7,664,536	
Transport	4,099,920	–	–	446,468	59,690	511,242	150,674	8,016,398	
Minerals	247,734	–	–	298	9345	43,715	1676	1,009,589	
Others	2,681,121	1,174,679	499,491	29,007	440	1143	266,369	6,317,861	
Imports	869,298	54,537	23,190	447,019	30,699	141,012	44,845	3,467,633	
Net taxes on production	155,731	1525	648	90,076	7776	38,854	3556	629,487	

Own calculations, base year: 2010–2011

assumptions to make it less complicated and time-consuming. On the other hand, the input-output-based LCA method solves these issues. First, it specifies how much output of a sector is needed as input in the same sector and other sectors, which properly documents all the sales of a sector. Secondly, it provides the total (direct and indirect) effects of changes to the economy if there is any change in final demand.

The input-output tables (IOTs) provide a snapshot of an economic structure (Dietzenbacher et al. 2013; Miller and Blair 2009). They explain macroeconomic interactions of a region in an accounting framework by tracing the financial flows from activities using the goods and services to other sectors supplying these resources (Zeshan and Nasir 2019). IOTs state the sale and purchase accounts between various sectors in an economy. Many sectors of the economy are

highly interdependent as different industries purchase various inputs from other industries, while the rest is imported. Other industries sell their products to domestic and foreign consumers. To make all these economic records consistent, economic flows are uniformly recorded in an IOT following a product-by-product or industry-by-industry approach.

These monetary tables can be supplemented with satellite data accounts describing the GHG emissions. The resulting models are helpful to examine the economy-wide environmental implications of final demand for goods and services by final consumers. It links the GHG emissions with the final demand and provides a basis for mitigation policy. The EEIOA is a widely used tool in literature to examine carbon footprints (Baumann 2013; Zeshan 2013; Peters et al. 2011; Lenzen 2011).

This paper develops an input-output life cycle assessment (IO-LCA) for Pakistan, and this task is achieved in three phases. In phase 1, the Pakistan IOT is constructed. In phase 2, the GHG environmental satellite accounts are created for each sector in the economy. The GHG environmental accounts are maintained for carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), carbon monoxide (CO), and non-methane volatile organic compound (NMVOC). These emissions are generated by different production activities such as agriculture, land, energy, chemicals, metals, manufacturing, and other products, known as the carbon footprints.¹ Wiedmann (2009), Druckman and Jackson (2009), Wiedmann and Minx (2008), and Wiedmann et al. (2007) provide a brief review of this topic.

In phase 3, these emissions are linked to different categories of final demand, including household consumption expenditure (HC), collective consumption expenditure of government (CCEG), individual consumption expenditure of government (ICEG), gross fixed capital formation (GFCF), changes in inventories (CI), net exports of goods (EXPG), and net exports of services (EXPS). This approach is helpful to design abatement policies to fulfill the INDC targets committed in the Paris Summit (2015) as it provides the total (direct and indirect) amount of GHG emissions caused by activity during all the stages of production.

At present, there is a severe knowledge gap in Pakistan and there is a dire need for research work which could facilitate the formulation of environmental policies based on environmental economics. To achieve this goal, this paper combines two accounting frameworks such as Pakistan IOT based on the most recent 2008 System of National Accounts (SNA) and the System of Environmental-Economic Accounting (SEEA). Hence, it develops national accounts of environmental indicators providing a detailed interrelationship between the economy and environment.² This goal is achieved by combining the

standard IOT (measuring the economic activities of key industries) and the relevant physical flow of GHG emissions.

Supply-use data accounts and emission inventory

The present IO-LCA is based on the environmental data compiled by the Pakistan Ministry of Climate Change (Mir and Ijaz 2016) and the supply and use tables (SUTs) prepared by the Pakistan Bureau of Statistics (Asian Development Bank 2017). The 4th revision of the Pakistan Standard Industrial Classification (PSIC) is used to define the industries/sectors/activities (Pakistan Bureau of Statistics 2010), whereas the 2nd version of the Central Product Classification (CPC) is used to describe commodities/goods/services in these SUTs (United Nations 2015).

The 2008 SNA prefers the basic prices over producers' purchasers' prices for valuing production in national accounts. Hence, the SUTs are transformed from purchasers' prices to basic prices. The basic price is defined as the amount receivable by a producer for one unit of goods/services from a purchaser, excluding taxes paid and including all the subsidies received on the products. Producers' price is defined as the price of goods/services at the factory gate including all the taxes less subsidies on different products. Further, purchasers' price is defined as the price paid by purchasers, including all the remaining taxes, trade margins, and transportation costs, also called the market price.

The data on trade and transport margins, imports, taxes, and subsidies are adjusted accordingly during the conversion to basic prices. This task is easier in case of the supply table; however, such a conversion process is relatively complicated in case of the use table. Each component of the use table needs to be adjusted for this conversion. Other than the margins, all elements discussed above are labeled separately in the row form. However, this practice does not involve margins as they are reallocated across the related services.

Normally, the source data of all margin types, taxes, subsidies, and imports are available in the supply and use tables. However, such data is not available in the case of Pakistan. Therefore, the present paper estimates the values of these components as they are important for the conversion process. This estimation assumes that these components change in proportion to an industry's total output spread across different markets.

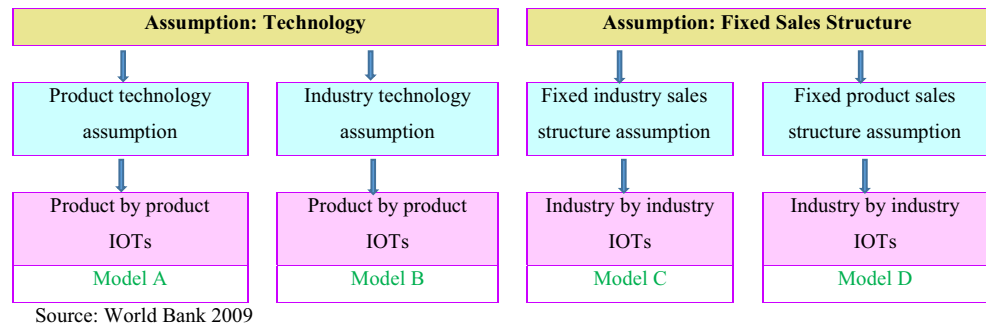
Methodology

The main characteristics of an IOT are transparency, comparability, inputs, resources, timeliness, and analytical potential (Raa 2017). Transparency dictates that industry-by-industry

¹ A detailed aggregation scheme is provided in the Appendix.

² The basic structure of the input-output tables is discussed by Miller and Blair (2009) in detail.

Fig. 1 Transformation of the SUTs into IOTs. Source: World Bank 2009



IOTs are better than the product-by-product IOTs. The former is based on the fixed product sales structure assumption, which does not produce negative values in an IOT. On the other hand, the latter is based on the product technology assumption, which needs balancing of negative values. It implies that the results in the latter are lesser transparent than the former.

Comparability defines that industry-by-industry IOTs can be compared with national accounts, whereas the product-by-product IOTs cannot. Nevertheless, the latter promises better comparability between different products across different countries. The product-by-product IOTs state a clear input structure whereas the industry-by-industry IOTs state a mixed group of goods and services.

Resources and timeliness indicate that the IOT built on product technology assumption requires more time (and resources) as it needs balancing of the negative elements. Conversely, an industry-by-industry IOT does not necessitate any such treatment, which saves time (and resources). Further, analytical potential clarifies that industry-by-industry IOTs are more suitable for policy analysis (such as tax reforms, monetary and fiscal policies). In contrast, the product-by-product IOTs are mainly used to examine the homogeneous production units for instance productivity, employment effects, and cost structure.

From the above analysis (also see Fig. 1), the fixed product sale structure assumption serves our purpose better. It assumes that each product follows a specific sales structure, irrespective of the industry where it is produced (World Bank 2009). It results in an industry-by-industry transformation matrix, such that:

$$T = Vx^{-1} \quad (1)$$

where V and x denote domestic make matrix and a diagonal matrix of product output, respectively. Further, T transforms the domestic use and final demand matrices into a symmetric IOT. Henceforth, the matrix of coefficients is defined as:

$$A_- = TUx^{-1} \quad (2)$$

where U and A_- denote domestic use matrix and inputs required per unit of production (matrix), respectively. The latter encompasses two parts, where the top segment is a square matrix of domestic intermediates used by different industries and the bottom segment comprises the matrix of primary inputs and GHG Emission satellite accounts.

Cost and market shares

This section discusses the input coefficients, backward linkages, output coefficients, and forward linkages of Pakistan's economy. Input coefficients state inputs required per unit of output, and they are obtained by dividing each cell of the EEIOT by the relative column total. They also indicate the relative cost shares for different sectors and primary inputs in the total production. From Table 2, it is obvious that 1 unit of agricultural output requires 0.2079 units of inputs from the agriculture industry, 0.2564 units of compensation of employees (CE), 0.4256 units of operating surplus, net.

Further, examining the linkages of a sector with its suppliers is very crucial. If a sector k boosts its output level, it will enhance the demand of many other sectors whose products are consumed as inputs in production, also known as the direct backward linkage of an industry. An industry with stronger direct backward linkages is considered more important in the economy compared with another industry. Energy, manufacturing, and metal sectors are the top three sectors with stronger direct backward linkages compared with other sectors in Pakistan (Table 2).

The output coefficients indicate the market shares of total output in different industries. These coefficients can be obtained by dividing each cell of the EEIOT by its relative row total. The results in Table 3 show that the manufacturing sector is the biggest market (42%) for agricultural products, whereas 21% of agriculture output is distributed in the agriculture sector. On the other hand, private consumption has a 27.7% market share in agriculture production.

The supply of output in the market has many implications, and direct forward linkages are really important in this regard.

Higher production activity in the k industry increases its output supply in the market, also known as the direct forward linkage. Hence, a sector with higher forward linkage has more significance in an economy compared with another sector as one additional unit of output in that sector would provide it a comparative advantage (economies of scale) compared with other sectors. In the present situation, chemicals, minerals, and agriculture sectors have stronger direct forward linkages compared with other sectors (Table 3).

Input-output life cycle assessment model

An IO-LCA facilitates us to examine the impact of a change in final demand on total demand and how the change in final demand is related to the GHGs emitted (extended Leontief inverse) at all the stages of production in various sectors. The standard Leontief inverse is used, such that:

$$x = (I-A)^{-1}y \tag{3}$$

In matrix algebra, matrices and vectors are denoted by capital and small letters, respectively. In the above equations, Ax , y , and x denote the vectors of intermediates, final demand, and total production, respectively. For a specific sector, the output multiplier is stated as the sum of all outputs from each domestic sector to produce an extra unit of production, denoted by the column sum of the Leontief inverse matrix (Table 4).

In the present case, the energy sector has the highest output multiplier (2.39), see Table 4. It indicates that PKR 1 million increase in the final demand of the energy sector would enhance the total production by 2.39 million. The overall (direct and indirect) increase in energy output is 1.74 million, whereas the remaining increase is added from higher production levels in other industries. In other words, a unit increase in final demand requires 0.74 units of energy sector output indirectly in its production process to meet the final demand. In addition, if the final demand for the energy sector elevates by 1.0 million, it would raise the cumulative economic revenues by 2.39 million in Pakistan.

The IO-LCA facilitates to evaluate the total (direct and indirect) effect of economic policies on environmental indicators. In essence, this method allows us to examine the total GHG emissions generated at all the levels of production, which is provided in the following extended input-output equation system:

$$Z = B(I-A)^{-1}f \tag{4}$$

where B , f , and Z indicate input coefficients for GHG emissions, final demand, and resulting matrix for total (direct and indirect) GHG emission requirements, respectively.

Table 2 Input coefficients and direct backward linkages (%)

Sector/sector	Agriculture	Land	Energy	Chemicals	Metals	Manufacturing	Transport	Minerals	Others
Agriculture	0.2078992922	0.0249353271	0.0000014319	0.0002078188	0.0000000000	0.34799513	0.032419579	0.000274775	0.015284044
Land	0.0000046073	0.0013092682	0.0000000000	0.0030975039	0.0000000000	0.001772212	3.42851E-05	0.002373296	0.000168722
Energy	0.0044806849	0.0114813065	0.4151392785	0.0276415508	0.0313246603	0.025837039	0.026567188	0.04075262	0.03712767
Chemicals	0.0167084372	0.0343269532	0.0118386249	0.0566221823	0.0045875342	0.005921619	0.012692281	0.002055984	0.01490365
Metals	0.0000000340	0.0000004190	0.0001322146	0.0025193917	0.0194564533	0.005257566	0.006759038	0.001231343	0.000423114
Manufacturing	0.0044990477	0.0135529256	0.0294081667	0.1310726031	0.0384118718	0.075398628	0.0577716181	0.022187579	0.051044531
Transport	0.0282856634	0.0149037741	0.1090019588	0.1680154428	0.2731500500	0.123999633	0.095116505	0.060059338	0.042216715
Minerals	0.0012413636	0.0031534261	0.0976819260	0.0189042676	0.2155087706	0.024816289	0.005384101	0.044867915	0.00510216
Others	0.0066915208	0.1174056761	0.0106289255	0.0455429699	0.0267618079	0.03867789	0.053814082	0.070587458	0.117413462
Direct backward linkages	0.2698106511	0.2210727758	0.6738325269	0.4536237310	0.6092011482	0.649676006	0.29050324	0.244390308	0.283684069

Own calculations

Table 3 Output coefficients and direct forward linkages (%)

Sector/sector	Agriculture	Land	Energy	Chemicals	Metals	Manufacturing	Transport	Minerals	Others	Forward linkages
Agriculture	0.20789929221	0.00046735394	0.00000073656	0.00001945427	0.00000000000	0.42379290260	0.04129345988	0.00004407748	0.01534274132	0.68886001827
Land	0.00024582178	0.00130926818	0.00000000000	0.01547074038	0.00000000000	0.11515036661	0.00232996297	0.02031236069	0.00903662245	0.16385514307
Energy	0.00871043815	0.00041832878	0.41513927855	0.00503023259	0.00270965326	0.06116723578	0.06578321588	0.01270838684	0.07245326816	0.64412003798
Chemicals	0.17848666066	0.00687283676	0.06505423846	0.05662218231	0.00218062509	0.07703550160	0.17269648764	0.00352313313	0.15981858311	0.72229024876
Metals	0.00000076377	0.00000173496	0.00152845311	0.00530022140	0.01945645335	0.14389094807	0.19347597550	0.00443901360	0.00954530792	0.37763887167
Manufacturing	0.00369436745	0.00020858515	0.01242200907	0.01007538097	0.00140351388	0.07539862818	0.06036580317	0.00292259545	0.04207589817	0.20856678148
Transport	0.02220713138	0.00021930735	0.04402149609	0.01234824844	0.00954243325	0.11855694635	0.09511650514	0.00756390267	0.03327171708	0.34284768775
Minerals	0.00773855200	0.00036844630	0.31324151700	0.01103190777	0.05978020564	0.18839876726	0.04275114872	0.04486791474	0.03192857062	0.70010703003
Others	0.00666592070	0.00219207416	0.00544664512	0.00424704367	0.00118626718	0.04692222549	0.06828183117	0.01127981961	0.11741346215	0.26363528926

Own calculations

Table 4 Output multipliers (million PKR)

Sector/sector	Agriculture	Land	Energy	Chemicals	Metals	Manufacturing	Transport	Minerals	Others
Agriculture	1.270941324	0.05023049	0.047349324	0.088942365	0.051475064	0.494938863	0.083736566	0.023840241	0.058305394
Land	0.000119168	1.001543689	0.000686086	0.003735356	0.000796152	0.002141173	0.000299026	0.002627992	0.000439177
Energy	0.014998709	0.034959943	1.742671914	0.078136435	0.097681053	0.069739167	0.063398049	0.086443978	0.08250709
Chemicals	0.023699688	0.040787143	0.027823742	1.068492389	0.014205754	0.020398149	0.019398624	0.006917338	0.021786012
Metals	0.00048818	0.000648343	0.002680908	0.005450182	1.023117999	0.007362966	0.008389769	0.002259566	0.001544082
Manufacturing	0.014039859	0.032462246	0.082414539	0.175272814	0.08031815	1.10587977	0.081206925	0.040405001	0.074791157
Transport	0.04900782	0.041714119	0.243461068	0.242622497	0.355833868	0.187345877	1.137411842	0.093356726	0.081146527
Minerals	0.004486698	0.00973212	0.183256687	0.036860768	0.245700105	0.040006606	0.017803529	1.05858154	0.017813786
Others	0.015032416	0.140900496	0.056066932	0.082836057	0.078295301	0.069239078	0.077027772	0.09412295	1.145348557
Total	1.392813862	1.35297859	2.386411199	1.782348863	1.947423446	1.997051649	1.488672103	1.408555333	1.48368178

Own calculations

Table 5 Direct emission coefficients per unit of output (Gg/kt of CO₂ equivalent)

Emission/ sector	Agriculture	Land	Energy	Chemicals	Metals	Manufacturing	Transport	Minerals	Others
CO ₂	0.0000000000	0.0819851458	0.0145949035	0.0055638256	0.0021353254	0.0049123650	0.0046381179	0.0153874475	0.0043750567
CH ₄	0.0133133337	0.0000000000	0.0067654054	0.0000000000	0.0000000000	0.0000082197	0.0000235767	0.0000000000	0.0002060824
N ₂ O	0.0124124314	0.0000000000	0.0005745174	0.0000000000	0.0000000000	0.0000000000	0.0000000000	0.0000000000	0.0000490672
CO	0.0001509448	0.0000000000	0.0000064865	0.0000000000	0.0000000000	0.0000087416	0.0003081184	0.0000000000	0.0003849404
NMVOCs	0.0000000000	0.0000000000	0.0000157529	0.0000000000	0.0000000000	0.0000022180	0.0001017914	0.0001822524	0.00000694855
Total	0.0258767099	0.0819851458	0.0219570656	0.0055638256	0.0021353254	0.0049315442	0.0050716044	0.0155696999	0.0050846324

Own calculations

Table 6 Total (direct and indirect) emissions per unit of output (Gg/kt of CO₂ equivalent)

Emissions/ sector	Agriculture	Land	Energy	Chemicals	Metals	Manufacturing	Transport	Minerals	Others
CO ₂	0.0007926575	0.0839694010	0.0302501084	0.0103191021	0.0099228417	0.0085425367	0.0073609696	0.0188525544	0.0073935419
CH ₄	0.0170263070	0.0009355409	0.0124382312	0.0017369760	0.0013713415	0.0070888759	0.0015870843	0.0009241519	0.0015729972
N ₂ O	0.0157848266	0.0006504812	0.0015916666	0.0011529463	0.0006988919	0.0061868584	0.0010795772	0.0003501973	0.0008273125
CO	0.0002129488	0.0000751838	0.0001157687	0.0001221078	0.0001488836	0.0001692056	0.0003938694	0.0000695091	0.0004758836
NMVOCs	0.0000071182	0.0000164331	0.0000897120	0.0000387904	0.0000881575	0.0000347240	0.0001255546	0.0002104234	0.0000925574

Own calculations

Table 7 GHGs emitted at all stages of production in various sectors (Gg/kt of CO₂ equivalent)

Emissions/ sector	Agriculture	Land	Energy	Chemicals	Metals	Manufacturing	Transport	Minerals	Others
CO ₂	1552.1968	8282.0679	34853.0065	1688.3733	1729.4804	51818.7597	38777.5481	5707.9631	34396.6041
CH ₄	33341.2330	92.2742	14330.8495	284.1976	239.0150	43000.8989	8360.7515	279.8043	7317.9759
N ₂ O	30910.1428	64.1582	1833.8568	188.6408	121.8119	37529.2892	5687.2069	106.0288	3848.8647
CO	417.0004	7.4155	133.3842	19.9788	25.9493	1026.3957	2074.9017	21.0452	2213.9292
NMVOCS	13.9391	1.6208	103.3627	6.3467	15.3652	210.6350	661.4207	63.7096	430.6001

Own calculations

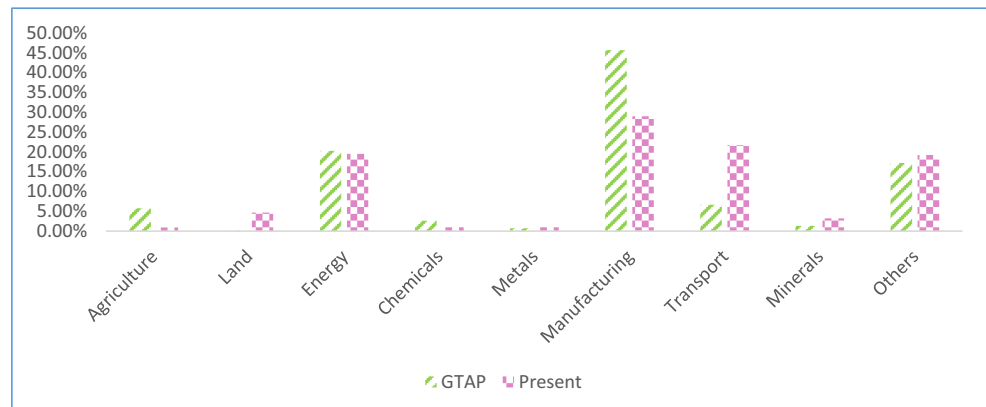
Table 5 presents the direct GHG emission coefficients. In the case of CO₂ emission coefficients, the lowest value is reported for the metals sector (0.002). Further, Table 6 reports the total emissions for the metal sector (0.009). This coefficient includes all (direct and indirect) CO₂ emissions related to the production of an additional unit (PKR million) of the output of the metal sector at all levels of production. From Table 1, it is obvious that the metal sector provides goods and services worth 174.293 billion to final demand.

The extended input-output analysis reveals that 1729 units (Gg per kt of CO₂ equivalent) of CO₂ emissions were emitted in Pakistan at all levels of production to satisfy the final demand for metal products (Table 7). The estimation results reveal that the level of CO₂ emission is the highest in the manufacturing sector. This sector is directly responsible for 37,651 units of CO₂ emissions. Further, the estimated results show that 51,819 units of CO₂ emissions was produced at all levels of production in order to produce the manufacturing output for final demand.

Comparison with GTAP database and literature

This section provides a comparison of how the different sectors contribute to the GHG emissions in Pakistan. For this

Fig. 2 Share of GHGs emitted at all stages of production (%).
Source: own calculations



Source: Own Calculations

purpose, it extracts Pakistan's social account matrix (SAM) from the Global Trade Analysis Project (GTAP) database version 9. It is important to note that the SAM in this database is an updated version of Pakistan IOT 1991, which was updated for the year 2008. Hence, the sectoral classification and the base years of the Pakistan SAM and the current EEIOT are different. Overall, the manufacturing and energy sectors contribute the most to the GHG emissions in Pakistan. These results are consistent with Shmelev (2010) and Mattila et al. (2011), who do a similar analysis for the UK and Finnish economies, respectively (Fig. 2).

Further analysis indicates that the structure of GHG emissions has changed drastically over time. The contribution of agriculture, energy, chemicals, and manufacturing in total GHG emissions is reducing in the country while the share of other sectors is increasing in GHG emissions. Further, the share of the transport sector has increased drastically in the total GHG emissions indicating the structural changes in the economy.

Conclusion and discussion

The Paris summit (2015) has become a significant achievement to attain a reliable global mitigation policy to climate change. An important aspect of the summit was the provision of emission reduction targets by each participating country worldwide.

However, the severe knowledge gap in Pakistan makes it hard to facilitate the formulation of environmental policies based on economics, which is the aim of the present study. Addressing this knowledge gap would enable policymakers to design more environmentally friendly economic policies.

The IO-LCA has become an important assessment tool to design abatement policies to fulfill the INDC targets committed by a country in the Paris summit. It provides direct and indirect amounts of GHG emissions associated with all the production activities during all the stages of production. Further, it links the final demand with GHG emissions. The present paper finds out that CO₂, CH₄, and N₂O are the top three GHG emissions produced in Pakistan. The manufacturing, transport, and energy sectors produce most of the CO₂ emissions, whereas manufacturing, agriculture, and energy sectors produce most of the CH₄ emissions. Further, manufacturing, agriculture, and the transport sector are responsible for the rising level of N₂O emissions in the country.

The sectoral production in Pakistan is skewed towards the manufacturing and energy sectors. Shifting the production from these sectors towards others (agriculture and metals) would significantly reduce the GHG emissions. However, such shifting would have some opportunity cost. Shifting production from manufacturing and energy sectors to the agriculture sector would result in lower CO₂ emissions per unit (million rupees) of output. Nonetheless, the agriculture sector has a lower output multiplier (1.39) than manufacturing (2.00) and energy (2.39) sectors. Further, given that the metal sector is among the top three sectors with stronger backward linkages, it would boost production activities in the economy particularly in the transport and mineral industries. On the other hand, shifting towards agriculture would mainly support the agriculture sector itself because it has weak backward linkages. Hence, there is a trade-off between economic growth and environmentally sustainable economic growth.

In addition, the metal sector seems a better choice for environment-friendly growth as it has the lowest total (CO₂ and CH₄) emissions per unit of output and a relatively higher output multiplier (1.95). Finally, controlling the N₂O content in the environment would require shifting production from other sectors to the minerals sectors. However, this sector has a moderate output multiplier (1.41).

Implications for theory and practice

This research work has many implications for theory and practice. For instance, it provides a detailed analysis of the changes in the composition of GHG emissions arising from a change in final demand. The IO-LCA model used in this paper encounters the many uncertainties such as the boundary of analysis and circularity effects through the double accounting principle used in the IO-LCA framework. Finally, it provides technical as well as the economic mechanisms of GHG emissions.

Future research

This research work can be extended to the multi-regional IO-LCA, which can add significantly to the literature on location quotients. Further, augmenting satellite accounts of land (irrigation land, rainfed land, and forestry) and water (blue, green, and gray) would further enrich this analysis.

Appendix

Table 8 Data aggregation scheme

No.	Sector description	Aggregation scheme
1	Crop and animal production, hunting, and related service activities	Agriculture
2	Forestry and logging	Land
3	Fishing and aquaculture	Agriculture
4	Mining and quarrying	Minerals
5	Manufacture of food products	Manufacturing
6	Manufacture of beverages	Manufacturing
7	Manufacture of tobacco products	Manufacturing
8	Manufacture of textiles	Manufacturing
9	Manufacture of wearing apparel	Manufacturing
10	Manufacture of leather and related products	Manufacturing
11	Manufacture of wood products	Manufacturing
12	Manufacture of paper and paper products	Manufacturing
13	Manufacture of printing	Manufacturing
14	Manufacture of coke and refined petroleum products	Energy
15	Manufacture of chemicals and chemical products	Chemicals
16	Manufacture of basic pharmaceutical products and pharmaceutical preparations	Manufacturing
17	Manufacture of rubber and plastics products	Manufacturing
18	Manufacture of other nonmetallic mineral products	Minerals
19	Manufacture of basic metals	Metal
20	Manufacture of fabricated metal products, except machinery and equipment	Metal
21	Manufacture of computer, electronic, and optical products	Manufacturing
22	Manufacture of electronics	Manufacturing
23	Manufacture of machinery	Manufacturing
24	Manufacture of motor vehicles	Transport
25	Manufacture of other transport equipment	Transport
26	Manufacture of furniture	Manufacturing
27	Other manufacturing	Manufacturing

Table 8 (continued)

No.	Sector description	Aggregation scheme
28	Electricity, gas, steam, and air-conditioning supply	Energy
29	Construction of buildings	Manufacturing
30	Wholesale and retail trade, and repair of motor vehicles and motorcycles	Transport
31	Land transport and transport via pipelines	Transport
32	Air transport	Transport
33	Warehousing and support activities for transportation	Transport
34	Postal and courier activities	Others
35	Accommodations	Others
36	Telecommunications	Others
37	Financial service activities, except insurance and pension funding	Others
38	Insurance, reinsurance, and pension funding, except compulsory social security	Others
39	Public administration and defense; and compulsory social security	Others
40	Education	Others
41	Human health activities	Others
42	Other personal service activities	Others

Own aggregation scheme

Balancing of the supply and use tables (SUTs) The SUTs are balanced manually as well as automatically. The manual balancing requires a researcher to detect the discrepancies in estimates. If the quality of data is poor for such estimates, it can be supported with the help of related survey reports. The SUTs used in the research paper are balanced manually firstly, and the automated RAS procedure was applied later when the SUTs diverged by 5% or less.³

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³ It is believed that the RAS method was developed by Richard Stone (1919–1991) and his colleagues.

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