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Cross-country analysis of life cycle assessment–based greenhouse gas emissions for automotive parts: Evaluation of coefficient of country

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ABSTRACT

Life cycle assessments (LCAs) are time consuming and can be expensive. Sometimes a company simply needs to have a basic estimate of the environmental impacts of the country which they are conducting the operations. If a company plans to move a current established production line or set up a new production line, which countries should be considered for a full LCA? It would be useful to have a coefficient for each country which could scale an established LCA result to estimate each new country's emissions. The following study develops country coefficients which could be used to scale LCA results. After careful study of many environmental parameters, two were selected to develop the country coefficient: total primary energy supply and electricity grid mix. This coefficient was designed for fiber-reinforced composites; and as the sources of natural fiber could be very different; we also included forestry and agriculture in our study. At the end of the study, we performed LCA-based greenhouse gas emission estimates for several countries and compared the results to the estimates using the country coefficients. We were able to reach an impressive result of up to 95% accuracy in comparison to the full LCA In just simple steps.

1. Introduction

As of today, we have only a few ways to reduce the emission of the car, besides the energy management that reduce the emissions [1,2] we have the option of material change and lightweights [3,4]. Fiber-reinforced composites are among the most important materials in the automotive industry. These materials are responsible for a significant amount of lightweighting, as well as the resulting fuel savings. Although plastics have a reputation of large environmental impacts, the impacts can be greatly reduced with the advent of natural fiber–reinforced plastics and recycled carbon–reinforced plastics. In fact, they have proven to be even better for our environment than glass fiber–reinforced plastic [3–6].

One of the best-known ways to answer a question about a product's environmental impact is to perform an LCA, for which the International Organization for Standardization (ISO) has strict guidelines (ISO14044:2006). Although LCAs are extremely useful, they have their own drawbacks. For example, an LCA could be time consuming, expensive, and full of uncertainties. To address this problem, researchers have been trying to develop variations on simplified LCA. For example, a group developed an abridged version of the full LCA [7]. This simplification was used to avoid technical complexities while maintaining the scientific grounding and reliability of the results [8,9].

In many cases of simplified LCA, there is usually an assumption about the life cycle that helps eliminate a phase or flow. For example, in one case, researchers assumed a photovoltaic (PV) cell would not emit during the use phase, performing a simplified LCA for the PV system in the buildings [10]. Some researchers have assumed vehicle production and end-of-life emissions are very similar around the world; therefore, they have used simplified LCAs to see the effect of the vehicles' driving-cycle emissions [11]. Other scientists have used simplified LCA as a simpler version of a full LCA, and they were thus able to calculate the global warming potential of hybrid car body parts [12]. Some researchers have used the matrix method and combined it with the simplified LCA to evaluate a product's environmental emissions. These researchers have concluded that each of these methods contains complimentary information, therefore, depending on the application one might mix and match methods. Simplified LCA is best used on a new design or new product, but on the other hand, the matrix provides the best results for improvement of an existing product [13]. In an interesting research project using the semi quantitative method for impact

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Abbreviations:

LCA	Life Cycle Assessment
GHG	Greenhouse Gas
EGM	Electricity Grid Mix
TPES	Total Primary Energy Supply
PV	Photovoltaic
OEM	Original Equipment Manufacturer

assessment of emissions within a simplified LCA, researchers found that in cases in which emission data is not complete, their method is a robust approach to this assessment [14].

Simplified LCA also has been used to avoid uncertainties, focusing only on the recycled materials and the weight of the vehicle. Here, the researchers concluded cars are heavier now and emit more, and even though they have more efficient engines, the benefits will be seen only after 21 years [15]. Simplified LCA has also been used for streamlining data collection [16] to reduce the complexity of the system boundary [17]. There is research on comparisons of different types of simplified LCA. For example, in a very interesting research project, an environmentally responsible product assessment matrix, semi quantitative LCA, and quantitative LCA were evaluated and compared, and it was shown that the results of simplified and semi quantitative LCA could be complementary to a quantitative LCA [18]. There have also been other attempts to reduce the complexity of an LCA. For example, a group proposed SWOT analysis as a simplified life-cycle sustainability assessment. They compared most of the simplified LCA methods in their study [19]. Another research project studied well-to-wheel calculation, which focuses on greenhouse gas (GHG) emissions due to fuel consumption; by combining a simplified LCA with a production-phase LCA for GHGs, researchers were able to reduce the gap between the results of well-to-wheel and complete LCA [20].

Despite all these previously mentioned efforts, the search for a simple method is not over yet. The following research deals with the simplification of an LCA to calculate GHG emissions for automotive fiber–reinforced plastic parts between countries by means of the coefficient of the country. As mentioned previously, LCA is highly complicated, and completing different analyses for countries of interest could cost a considerable amount of resources to perform. Sometimes industries might just want to have a rough estimate for a question and consider the full LCA later. For example, suppose an Original Equipment Manufacturer (OEM) in automotive company wants to move out of Germany and go to another country. Performing a full LCA for countries around the world would be tedious and expensive; even performing a simplified LCA would be time consuming. It would be useful if this company could use a coefficient and convert the results of existing LCAs, from one country to another. This coefficient would help reduce the cost and time needed for this situation. Another potential application of this coefficient is a situation in a country to whose data we do not have access. Here, with the coefficient, we could estimate the results.

The purpose of this study is to develop a coefficient for cross-country analysis of the LCA results, focusing on the GHG emissions of fiber-reinforced composite automotive parts.

2. Materials and methods

During these calculations, we have considered only four factors to determine the best correlation possible for global warming potential.

2.1. Studied factors

The following factors have been studied and included/excluded from the calculations for the reasons mentioned.

2.1.1. Total primary energy supply (TPES)

The primary forms of energy are the ones we can find in nature, and the TPES of a country is its total energy production and energy import, minus energy export, minus the energy stored for later consumption, plus or minus energy exchange. This number shows the net production and import of energy for each country. This is the total energy a country will use in 1 year; therefore, it encapsulates a significant amount of information about the country. Because of this figure's importance, we have included it in our estimate of coefficient of country.

2.1.2. Electricity grid mix (EGM)

The EGM, which is the network of power suppliers used in a country's electricity, is an important measurement and one of the determining factors for emissions; therefore, we included it in our calculations.

2.1.3. Manufacturing Equipment, Facilities, and others

Industries are global now; even chemical companies, despite being restricted to their countries, can be found on every continent and in many countries. The difference in their emissions lies mostly with electricity or energy consumption. Because the world is more and more connected, average technology and industrial machines are sold all over the world. As a result of globalization, most of the Original Equipment Manufacturers (OEMs) in current use are very consistent. For the production of automotive parts, most North American technology is not greatly different from that found anywhere else. For example, in a country with an injection-molding machine, which is essentially the same in all countries regardless of the age of the machine, the machine's age could be a source of emissions, but data collection has shown these machines will be taken out of production lines soon, and they do not make a significant difference for one part or another. If a country does not have an injection-molding machine, it cannot produce the part, and that country is left out of the calculations.

2.1.4. Transportation

Transportation is also very similar among all the partial-producer countries; trucks for short and long haul, trains, ships, and so on will not be a source of significant difference. The only difference comes from the source of the fuel, which is already included in the TPES and was therefore excluded from the calculations.

2.1.5. Mining

Mining industries on an industrial scale use very similar technology, so the source of energy is a major source of difference. This item was excluded as well.

This study includes some other factors, as described in the following sections.

2.1.6. Forestry

A country's forestry could be a source of differences because countries use very different methods, from primitive to industrial intensive. Therefore, we included this in our study.

2.1.7. Agriculture

Countries use different agricultural methods; therefore, their emissions are quite different in this sector. This item was one of those included in our calculations.

2.2. Calculation methods

2.2.1. Calculating the coefficient of countries based on GHG and TPES

To estimate a scaling coefficient for countries' production, different countries' TPESs have been extracted from the WordBank database used to calculate the relative emissions [24]. This study covers 19 countries and seven regions, plus the world portion of energy extracted from the International Energy Agency database. The sources extracted were natural gas; crude oil; coal; nuclear; and renewables like hydropower, geothermal, solar, and biomass (Table 1). Then, the average posted emissions (Kg CO_2eq/KWh) for the source used for each type of energy carrier (Table 2) were used to estimate the weight for each type of carrier. By multiplying the portion of the carrier by the portion of the GHG emissions and then adding the weighted values, we have calculated a single weighted value for each type of carrier for each country and region. This calculated single value was then normalized, as will be discussed later.

In choosing a number representing the biomass, there was a controversy. There have been many changes in the past years, and reports range from being carbon neutral all the way to indicating biomass is worse than coal in terms of GHGs [21–23]. It was not clear what portion of the biomass burned in coal co-fired to emit more GHGs. Table 2 shows the impact index for each carrier of energy (Table 2).

2.2.2. Calculating the coefficient of countries based on GHG and the EGM

In this part, we used the International Energy Agency database [25], extracting the EGM for each country. Here, the list also shows the countries at the extremes. Then, these numbers converted to the percentage of the source for each country (Table 3). This number was then also multiplied by the portion of the CO_2eq from Table 2, and, after that this single number, was used in the normalization.

2.2.3. Using both TPES and the EGM simultaneously

One of the numbers used to predict changes in GHG emissions was the averaged index, which was an average of the EGM and TPES. We simply used the calculated normalized number and averaged the figures for each source of energy to calculate this index.

2.2.4. Calculating the coefficient of countries based on GHG, agriculture, and forestry

To calculate these coefficients, we extracted data for the same countries. Regions mentioned in Table 1 from the Food and Agriculture Organization of the United Nations database (FAOSTAT) were used [26]. We also extracted countries' GHG emissions for agriculture and forestry and total land area for agriculture and forestry. The GHG emissions were then converted from total emissions to kg CO_2eq per hectare for forestry and agriculture, and we subsequently used this data for normalization. Table 4 shows the kg CO_2eq/hectare for the countries' forestry and agriculture. This measures the emissions for the crop productions and wood production.

Table 2
Values for the calculations in the energy carrier.

	Kg CO_2eq/KWh	Portion of CO_2/KWh
Natural Gas	0.490	20.61%
Crude Oil	0.778	32.73%
Coal	0.820	34.50%
Hydropower	0.012	0.50%
Geo/Solar	0.013	0.55%
Biomass	0.034	1.43%
Nuclear	0.230	9.68%
Total	2.377	100.00%

2.3. Normalization

To standardize our calculations and scale them from 0.1 to 1.0, we used the standard feature scaling with the following formula:

$$Normalizedvalue = Low + \frac{Actualvalue - Min}{Max - Min} \times (High - Low) \qquad \text{Eq 1}$$

Min is the minimum value of the data, *Max* is the maximum value of the data, *High* is the new maximum (1.00), and *Low* is the new minimum (0.10). During this process, data from the total primary energy source, the EGM, forestry, and agriculture were separately scaled.

3. Results

3.1. TPES

TPES is one of the most important indices that will summarize the net production and import of the energy for a country. As can be seen in Table 5, among the countries around the globe, France has the lowest index because over 45% of its energy is from nuclear power, which emits fewer GHGs than others. South Africa is the worst among the countries studied because almost 70% of its energy comes from coal. The lowest index used for normalization, however, belongs not to France but Paraguay, which has a lower index in the TPES.

Table 1
Countries and regions total primary energy supply and the sources of the energy and portions (data extracted from Ref. [24]).

	World	Africa	Middle East	EU	Asia w/o China	OECD-Americas	non OECD Americas	OECD ASIA +OCEANIA	Saudi Arabia
Natural Gas	28.61%	14.06%	51.29%	21.94%	13.95%	28.56%	21.78%	34.27%	32.56%
Crude Oil	31.29%	21.34%	47.73%	32.57%	28.51%	36.48%	44.54%	5.80%	67.44%
Coal	21.18%	14.52%	0.42%	17.18%	30.92%	17.30%	4.05%	44.26%	0.00%
Hydropower	2.45%	1.37%	0.24%	2.06%	1.57%	1.31%	9.13%	1.94%	0.00%
Geo/Solar	1.32%	0.55%	0.04%	2.56%	1.78%	5.02%	0.85%	2.42%	0.00%
Biomass	10.32%	47.69%	0.12%	9.06%	22.02%	2.23%	18.80%	4.08%	0.00%
Nuclear	14.09%	0.47%	0.16%	14.62%	1.25%	9.08%	0.86%	7.23%	0.00%
	Germany	Canada	UK	US	China	India	France	Japan	Italy
Natural Gas	21.07%	30.00%	16.43%	19.52%	5.04%	5.24%	13.29%	25.53%	35.45%
Crude Oil	31.67%	38.00%	32.45%	35.39%	16.90%	22.46%	28.12%	41.20%	36.06%
Coal	26.02%	5.99%	32.85%	28.22%	65.92%	45.82%	3.83%	27.95%	9.14%
Hydropower	0.56%	11.09%	2.48%	1.01%	2.96%	1.37%	2.20%	1.59%	3.52%
Geo/Solar	2.93%	0.72%	1.68%	1.33%	1.33%	0.51%	0.96%	1.20%	6.04%
Biomass	9.66%	5.16%	4.99%	4.75%	7.12%	23.47%	6.04%	2.53%	9.79%
Nuclear	8.27%	9.00%	9.16%	7.09%	1.13%	1.14%	45.49%	0.00%	0.00%
	Korea	Brazil	Russia	Mexico	Indonesia	Iran	Australia	S. Africa	Thailand
Natural Gas	16.07%	11.84%	52.19%	32.18%	16.23%	61.39%	25.31%	2.61%	28.26%
Crude Oil	35.89%	42.17%	23.38%	51.28%	33.35%	37.01%	34.93%	14.84%	40.18%
Coal	30.44%	6.10%	14.62%	6.72%	15.99%	0.37%	33.15%	69.32%	11.86%
Hydropower	0.09%	10.60%	2.12%	1.78%	0.58%	0.50%	1.26%	0.06%	0.36%
Geo/Solar	0.22%	0.55%	0.02%	2.06%	7.65%	0.01%	1.29%	0.20%	0.11%
Biomass	2.08%	27.46%	0.99%	4.65%	26.20%	0.22%	4.06%	10.53%	19.24%
Nuclear	15.19%	1.32%	6.68%	1.34%	0.00%	0.49%	0.00%	2.44%	0.00%

Table 3
Electricity grid mix for each country (data extracted from Ref. [25]).

	(% of total) sources of electricity production					
Country Name	Coal	Natural gas	Oil	Hydroelectric	Other Renewables	Nuclear
Australia	61.16%	21.91%	2.02%	7.41%	7.50%	0.00%
China	72.63%	2.02%	0.17%	18.55%	4.06%	2.34%
Canada	9.86%	9.35%	1.22%	58.29%	4.51%	16.41%
France	2.16%	2.29%	0.32%	11.28%	5.13%	78.36%
Germany	45.81%	10.01%	0.91%	3.15%	22.98%	15.62%
India	75.08%	4.89%	1.76%	10.23%	5.18%	2.80%
Iran	0.19%	71.32%	21.66%	5.05%	0.15%	1.63%
Indonesia	52.65%	24.63%	11.28%	6.63%	4.81%	0.00%
Italy	16.73%	33.67%	5.09%	21.05%	22.34%	0.00%
Israel	49.56%	48.44%	0.49%	0.02%	1.49%	0.00%
Japan	33.69%	40.64%	11.24%	7.90%	6.13%	0.00%
Korea	42.41%	23.90%	3.19%	0.50%	1.06%	28.65%
Mexico	11.24%	57.04%	10.95%	12.90%	4.64%	3.21%
Russia	14.90%	50.22%	1.01%	16.50%	0.07%	17.02%
Saudi Arabia	0.00%	51.16%	48.84%	0.00%	0.00%	0.00%
South Africa	93.00%	0.00%	0.08%	0.39%	1.00%	5.53%
Thailand	21.64%	68.28%	0.99%	3.19%	5.89%	0.00%
UK	30.36%	29.96%	0.50%	1.75%	17.69%	18.97%
US	39.65%	26.89%	0.92%	6.05%	6.90%	19.23%
Albania	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%
Botswana	95.77%	0.00%	4.19%	0.00%	0.04%	0.00%
Brazil	4.53%	13.73%	6.00%	63.23%	9.85%	2.60%
Congo, D.R.	0.00%	0.08%	0.05%	99.88%	0.00%	0.00%
Gibraltar	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
Kosovo	96.95%	0.00%	0.28%	2.78%	0.00%	0.00%
Kuwait	0.00%	33.75%	66.25%	0.00%	0.00%	0.00%
Nepal	0.00%	0.00%	0.03%	99.79%	0.18%	0.00%
Niger	71.59%	0.00%	27.83%	0.00%	0.58%	0.00%
Paraguay	0.00%	0.00%	0.01%	99.99%	0.00%	0.00%
Qatar	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%
South Sudan	0.00%	0.00%	99.59%	0.00%	0.41%	0.00%
Tajikistan	0.00%	2.87%	0.00%	97.13%	0.00%	0.00%
Turkey	30.27%	47.85%	0.85%	16.13%	4.76%	0.00%
Turkmenistan	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%
UAE	0.00%	98.39%	1.34%	0.00%	0.27%	0.00%

Table 4
Amount of Kg CO_2eq per hectare for each country (data extracted from Refs. [26]).

	Agriculture	Forestry
Africa	701.96	−238.29
Asia	1368.73	−443.71
Australia	255.53	−1807.92
Brazil	1561.32	−659.08
Canada	863.94	87.71
China	1377.60	−1921.83
European Union	2205.36	−3193.53
France	2443.88	−3953.37
Germany	3563.22	−2312.34
India	3465.20	−1924.25
Indonesia	2740.82	6663.00
Iran	775.25	−290.12
Italy	2258.53	−3808.20
Japan	4834.31	−6054.23
Mexico	768.52	−35.36
OECD America	857.59	−706.04
Korea	7465.13	−8318.77
Russian Federation	421.75	−260.95
Saudi Arabia	30.145	0
South Africa	316.10	−90.08
non OECD America	1065.59	−391.27
Thailand	3201.97	−1089.02
United Kingdom	2534.50	−4690.33
United States of America	857.05	−1595.33
World	1036.20	−637.97
OECD Asia and Oceania	4218.22	−5277.30
Middle east	259.92	−215.66

3.2. EGM

The resulting country specific EGM indices appear in Table 6. Among the countries studied, France has the lowest index because over 78% of its electricity is sourced from nuclear power. However, here, also, Paraguay has the lowest number for the grid around the world because it is almost 100% hydroelectric. South Africa is the worst among the countries studied because 93% of its energy comes from coal; however, Botswana has the worst index because it uses over 95% coal-based electricity.

Because the TPES and EGM are comparable (Fig. 1) and both indices capture portion of the reality of energy and emissions of the country, we have made a unique index containing both numbers by averaging the normalized coefficients, and we have used this for our calculations as well.

3.3. Application of these coefficients

We also used an automotive part, namely the engine beauty cover (1 Kg), which is produced by injection molding; the results of that study have been published recently [27] and focuses on the GHG emissions from the engine beauty cover from cradle to grave (excluding the use phase of the car). Following the studies method we performed some country Scenario analysis for this auto-part, to determine GHG emissions from manufacturing it in the following countries/regions: European Union, Germany, United Kingdom, China, France, Italy, South Africa, and Paraguay. Table 7 contains the results of the LCA for different scenarios for this part.

The emissions for these scenarios were then used for checking the accuracy of the coefficients and for the calculation of the regression line

Table 5
Resulting index for total primary energy supply.

	World	Africa	Middle East	EU	Asia w/o China	OECD-Americas	non OECD Americas	OECD ASIA + OCEANIC	Saudi Arabia
Natural Gas	6.96%	3.42%	12.48%	5.34%	3.39%	6.95%	5.30%	8.34%	7.92%
Crude Oil	10.40%	7.09%	15.86%	10.82%	9.48%	12.13%	14.80%	1.93%	22.41%
Coal	8.67%	5.95%	0.17%	7.03%	12.66%	7.08%	1.66%	18.12%	0.00%
Hydropower	0.01%	0.01%	0.00%	0.01%	0.01%	0.01%	0.05%	0.01%	0.00%
Geo/Solar	0.02%	0.01%	0.00%	0.04%	0.03%	0.07%	0.01%	0.03%	0.00%
Biomass	1.00%	4.61%	0.01%	0.88%	2.13%	0.22%	1.82%	0.39%	0.00%
Nuclear	0.08%	0.00%	0.00%	0.09%	0.01%	0.05%	0.01%	0.04%	0.00%
Total	**27.15%**	**21.09%**	**28.53%**	**24.21%**	**27.70%**	**26.65%**	**23.64%**	**28.53%**	**30.34%**
	Germany	Canada	UK	US	China	India	France	Japan	Italy
Natural Gas	5.13%	7.30%	4.00%	4.75%	1.23%	1.27%	3.23%	6.21%	8.62%
Crude Oil	10.53%	12.63%	10.79%	11.76%	5.62%	7.46%	9.34%	13.69%	11.99%
Coal	10.65%	2.45%	13.45%	11.56%	26.99%	18.76%	1.57%	11.44%	3.74%
Hydropower	0.00%	0.06%	0.01%	0.01%	0.02%	0.01%	0.01%	0.01%	0.02%
Geo/Solar	0.04%	0.01%	0.02%	0.02%	0.02%	0.01%	0.01%	0.02%	0.09%
Biomass	0.93%	0.50%	0.48%	0.46%	0.69%	2.27%	0.58%	0.24%	0.95%
Nuclear	0.05%	0.05%	0.05%	0.04%	0.01%	0.01%	0.27%	0.00%	0.00%
Total	**27.34%**	**23.01%**	**28.81%**	**28.60%**	**34.57%**	**29.79%**	**15.03%**	**31.62%**	**25.41%**
	Korea	Brazil	Russia	Mexico	Indonesia	Iran	Australia	South Africa	Thailand
Natural Gas	3.91%	2.88%	12.70%	7.83%	3.95%	14.94%	6.16%	0.64%	6.88%
Crude Oil	11.93%	14.01%	7.77%	17.04%	11.08%	12.30%	11.61%	4.93%	13.35%
Coal	12.46%	2.50%	5.99%	2.75%	6.55%	0.15%	13.57%	28.38%	4.86%
Hydropower	0.00%	0.06%	0.01%	0.01%	0.00%	0.00%	0.01%	0.00%	0.00%
Geo/Solar	0.00%	0.01%	0.00%	0.03%	0.11%	0.00%	0.02%	0.00%	0.00%
Biomass	0.20%	2.66%	0.10%	0.45%	2.54%	0.02%	0.39%	1.02%	1.86%
Nuclear	0.09%	0.01%	0.04%	0.01%	0.00%	0.00%	0.00%	0.01%	0.00%
Total	**28.60%**	**22.12%**	**26.60%**	**28.12%**	**24.23%**	**27.42%**	**31.76%**	**34.99%**	**26.95%**

Table 6
The normalized coefficient (0.1–1.0) for total primary energy supply, electricity grid mix, forestry and agriculture.

	EGM	TPES	AGRI	FOREST
World	0.63	0.71	0.22	0.56
Africa	0.65	0.49	0.18	0.59
Middle East	0.70	0.76	0.13	0.59
EU	0.48	0.60	0.36	0.41
Asia w/o China	0.77	0.73	0.26	0.57
OECD-Americas	0.58	0.69	0.20	0.56
non OECD Americas	0.41	0.58	0.23	0.58
OECD ASIA + OCEANIC	0.75	0.76	0.61	0.28
Saudi Arabia	0.79	0.83	0.10	0.60
Germany	0.64	0.72	0.53	0.46
Canada	0.26	0.56	0.20	0.61
UK	0.59	0.77	0.40	0.32
US	0.63	0.77	0.20	0.50
China	0.78	0.98	0.26	0.48
India	0.83	0.81	0.52	0.48
France	0.15	0.27	0.39	0.36
Japan	0.73	0.88	0.68	0.24
Italy	0.54	0.65	0.37	0.37
S. Korea	0.64	0.77	1.00	0.10
Brazil	0.29	0.53	0.29	0.56
Russia	0.51	0.69	0.15	0.58
Mexico	0.61	0.75	0.19	0.60
Indonesia	0.82	0.61	0.43	1.00
Iran	0.67	0.72	0.19	0.58
Australia	0.81	0.88	0.13	0.49
South Africa	0.94	1.00	0.13	0.59
Thailand	0.68	0.71	0.48	0.53
Paraguay	0.10	0.10	N/A	N/A

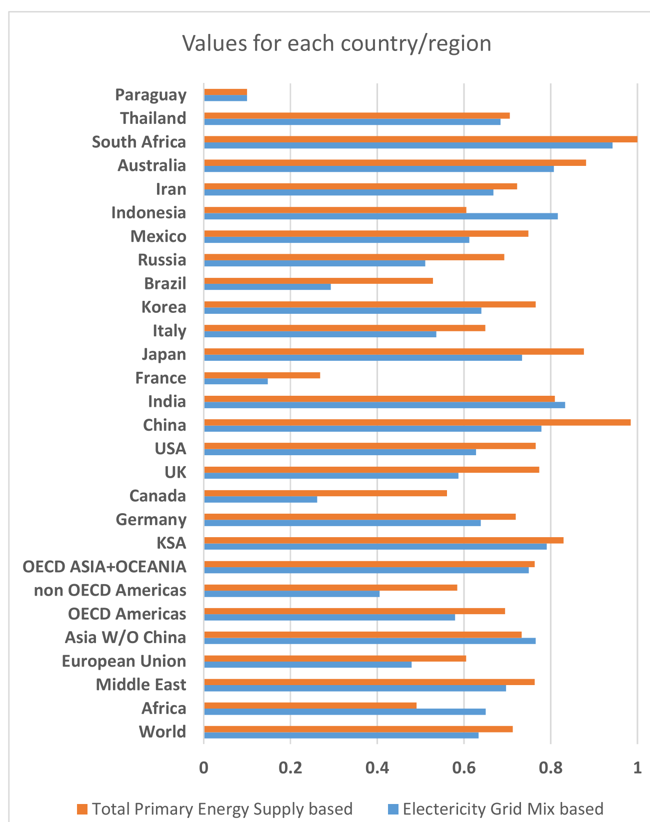

Fig. 1. Normalized coefficients for the countries.

(Fig. 2). Fig. 2 also shows the result of linear regression for the averaged coefficients and global warming potential (kg CO_2eq) for the production of a single part. As you can see the model have a very high coefficient of determination which is an indication of a good fit between the predicted numbers by the model and the actual LCA numbers.

After these results, we tried to find a relation between countries' forestry and agricultural emissions to calculate the emissions of the same parts, but this time, the only sources for natural fiber were different countries (both agriculture and forestry), which led us to the conclusion that the range is less than 1% of the total emissions and cumulative energy demand. This is ignored in most of the LCA models. For forestry, we have a correlation between the cofactors and the emissions; however, the model did not establish a correlation between the countries'

Table 7
Global warming potentials for this countries for making the engine beauty cover (1 Kg).

Country	Kg CO2eq/part
EU	9.96
Germany	10.63
UK	10.83
China	12.48
France	7.78
Italy	10.59
S. Africa	13.59
Paraguay	7.41

agricultural coefficients and emissions (Fig. 3).

One of the reason for that could be the fact that, within the weight range of the parts, the amount of fiber used is extremely low, and forestry around the globe also has less of an effect on CO_2 emissions than the grid mix. For agriculture, also, the source of fiber from the countries we studied fell under 1% of the total emissions; no direct relationship was seen between agricultural emissions and the countries' coefficients for agriculture. As can be seen, the R^2 is 0.1931, which means this model cannot predict the emissions from the coefficient. One reason for this could be that agricultural technology is still quite different among countries. Some countries still do farming by hand, and some use airplane and GPS-enabled precision farming, so obviously they are not comparable.

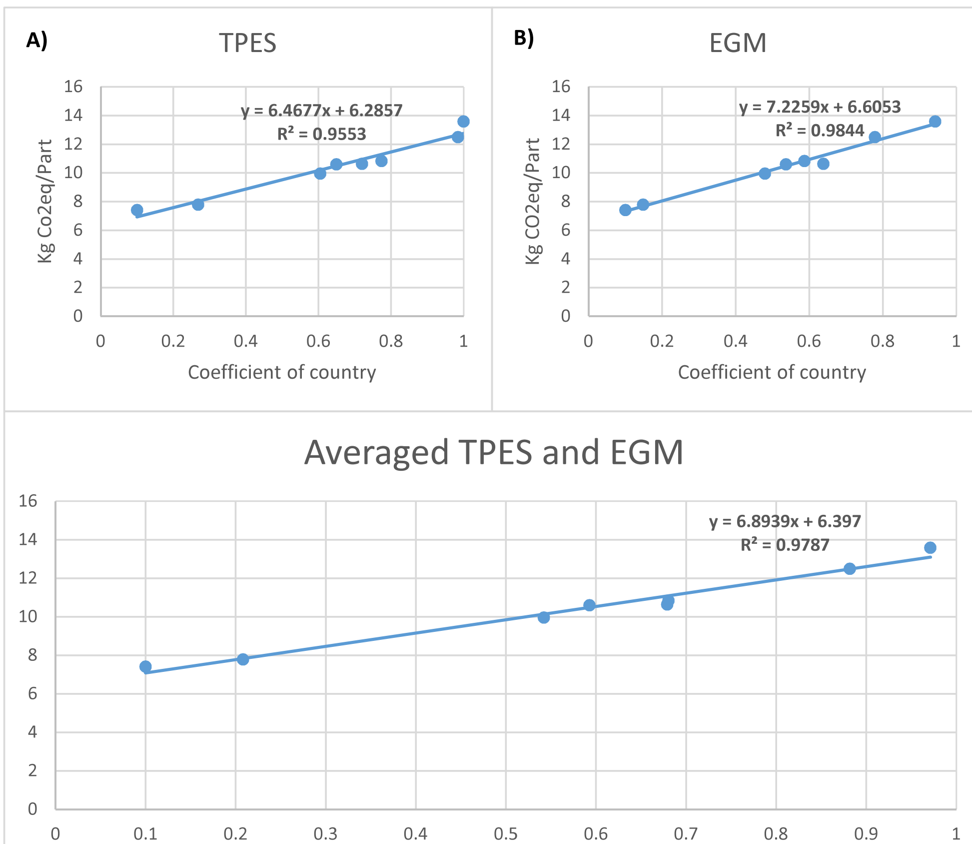

Fig. 2. A and B) shows the linear regression and R2 for the emissions and countries coefficients (EGM, TEPES). C) shows the averaged TPES and EGM for emssions based on the countries coefficients.

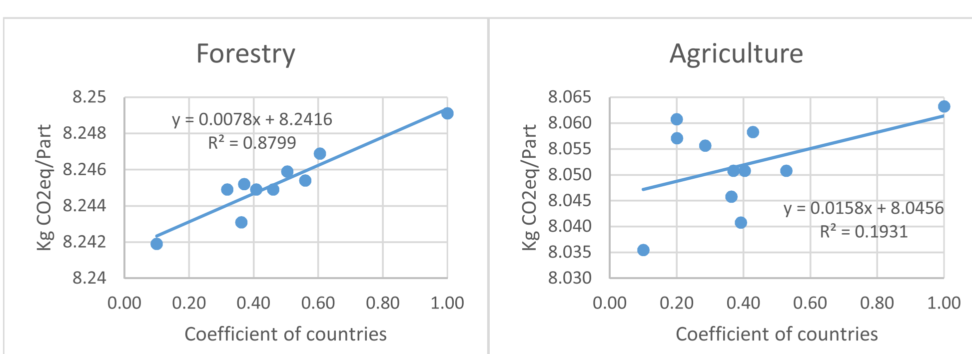

Fig. 3. Coefficient of countries vs global warming potential for an engine beauty cover for the forestry and agriculture industries.

3.4. Example cases

As calculated, the coefficient of determination is impressive; it shows these coefficients, especially the averaged coefficient for this model ($R^2 = 0.9787$), can predict the emissions over 97% of the time. The model for Canada (coefficient of 0.41) predicts the emissions of:

$$y = 6.89x + 6.4$$
$$y = 9.22KgCO_{2eq}/part(1Kg) \quad \text{Eq 2}$$

The actual reported number for this part is 8.76 kg CO_2eq/part (1 kg) [27]. This model has an error of 0.46 kg CO_2eq/part for this scenario, meaning the accuracy of this model is slightly over 95%.

The second example is about an Oilpan produced in the USA and emits 10.65 kg CO2eq/part this oil pan based on the emission from the coefficient of countries is predicted to have the emission of 6.24 Kg CO2eq/part in Canada. And the real emission of this part has been reported to be 6.27 kg CO2eq/part [28] which is over 99% accurate. On the other hand, we have a prediction that with the accuracy of 79%, which the possible reason will be discussed in the discussion and conclusion.

4. Discussion and conclusion

Simply based on the fact that different countries use different sources of energy and on the EGM, production of automotive parts could result in different emissions and cumulative energy demand. The same variation could be seen in the production of raw materials, even though our regressions model here cannot predict the variation based on the agricultural coefficient. One of the main sources of variation is the fact that natural fibers are coming from a fiber produced in an intensive or primitive farming. Even if the material comes from a forest, forestry methods are different from one country to another. Among all the studied parameters, only the electricity grid and TPES had a meaningful correlation with production of parts.

The TPES is actually related to the EGM, and it contains the transportation and all other sources of energy a part will need for its life cycle. Here, we have shown that with this simple regression model, we can actually predict the global warming potential of an individual automotive part. For the example provided, the model accuracy was 97%, which is impressive considering that one can calculate this emissions prediction for each country within a fraction of a second from a baseline LCA.

To have a better correlation, other impact categories should be studied and added to this one. Another element that may help improve this model is the electricity grid loss for each country. According to the Word bank data, Countries around the world have between 2.03% and 72.54% loss on power transmission and distribution; in the countries we studied, the loss reported was between 3% and 19% of the total output [24].

As it was shown, GHG emissions caused by a change in the manufacturing country of an automotive part are predictable. This model used only GHG emissions for the aforementioned situation and it is able to handle cross country analysis with a great precision.

CRediT authorship contribution statement

M. Akhshik: Methodology, Data curation, Writing - original draft, Formal analysis. **S. Panthapulakkal:** Writing - original draft, Resources. **J. Tjong:** Supervision. **C.V. Singh:** Conceptualization. **M. Sain:** Writing - review & editing, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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