Technical efficiency of car manufacturers under environmental and sustainability pressures

Citation for published version:
Stefanoni, S & Voltes-Dorta, A 2021, 'Technical efficiency of car manufacturers under environmental and sustainability pressures: A Data Envelopment Analysis approach', *Journal of Cleaner Production*, vol. 311, 127589. https://doi.org/10.1016/j.jclepro.2021.127589

Digital Object Identifier (DOI):
10.1016/j.jclepro.2021.127589

Published In:
Journal of Cleaner Production

TECHNICAL EFFICIENCY OF CAR MANUFACTURERS UNDER ENVIRONMENTAL AND SUSTAINABILITY PRESSURES: A DATA ENVELOPMENT ANALYSIS APPROACH

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ABSTRACT

Managers in the competitive automotive sector face growing pressures in terms of sustainability and environmental performance. While most efficiency studies focus on traditional financial and operating indicators, this study broadens the scope of analysis to include Environmental, Social, and Governance (ESG) activities. The well-known Data Envelopment Analysis (DEA) method is employed to estimate the technical efficiency of 33 global automakers from 2014 to 2017, including their ESG scores as outputs in the model. Our findings show that ESG-adjusted efficiencies tend to be higher than the traditional ones, with the Governance-adjusted model achieving the highest efficiency scores, followed by the Environmental and the Social models. The results of a second-stage bootstrapped truncated regression reveal the significant impact of the automakers' size, degree of innovation and geographical region on the ESG-adjusted efficiencies. Finally, this study has implications for managers in the industry, as well as investors interested in creating sustainable portfolios.

Keywords: Automotive Industry; Technical Efficiency; Sustainability; Data Envelopment Analysis.

1. INTRODUCTION

The automobile industry is a key sector in the global economy given its capital intensity and the relationships to the energy, steel, and technological sectors. The global recession that started in 2008 translated into a sharp decline in sales and profits, with General Motors and Chrysler having to the bailed out by the US Government (Anginer and Warburton, 2014). Further to the traditional financial and operational pressures, governments, customers, and investors are also increasingly demanding automotive manufacturers to take care of Corporate Social Responsibility (CSR) matters. First, many regulations have been introduced all over the world in a continuous attempt to reduce the sector's environmental footprint. Second, there is an open debate on gender diversity on corporate boards and workplace in a sector that has been traditionally dominated by men (Horak and Cui, 2017). Third, we can also mention the recent governance-related controversies that ultimately led to major emissions scandals, within automakers striving to regain the confidence of customers (Muoio, 2017). Besides improving CSR performance, this Environmental, Social, and Governance (ESG) framework can also constitute a tool through which managers can improve financial performance. Access to Socially Responsible Investment funds (SRI), as well as to the broader capital market through credit ratings based on ESG considerations, represents an important pool of financial resources for automakers.

Traditionally, the efficiency of car manufacturers has been assessed in relation to operating and financial measures only, and employing multi-output methodologies, either parametric (i.e. Stochastic Frontier Analysis) or non-parametric (i.e. Data Envelopment Analysis - DEA). Few articles evaluate the performance of automakers incorporating environmental metrics, and no existing contribution addresses the efficiency of automakers under other CSR dimensions. In order to bridge this gap, we aim to analyse the evolution of the technical efficiency of 33 global car manufacturers between 2014 and 2017, to determine whether the efficient automakers under a baseline model differ from the efficient ones under increased sustainability pressures. To this end, our DEA models include both financial and operational measures combined with the ESG ratings supplied by Sustainalytics. Additionally, we carried out a bootstrapped truncated regression in a second-stage analysis to determine the drivers of the ESG-adjusted efficiencies, considering factors such as the automakers' size, degree of innovation, brand status (i.e. luxury vs non-luxury brands), diversification, and geographical region. The results from our study can have implications for managers in the sector (i.e. to improve firm efficiency and ESG performance) and for investors (i.e. to assist in the evaluation of companies under SRI criteria).

The remainder of this paper is structured as follows: Section 2 reviews the application of DEA to the automobile sector, with and without environmental targets. The broader literature on the effects of CSR practices on automakers' performance is also covered in order to further support our contribution. Section 3 provides insights on the sample data and the ESG scores. The specification of the DEA models and second-stage regressions are also covered in this part. Section 4 presents and discusses the results and draws a few managerial implications. Finally, Section 5 summarises the main findings and concludes with the limitations and directions for future research.

2. LITERATURE REVIEW

2.1 DEA studies in the automotive sector

The existing literature provides only a few examples of articles that evaluate the efficiency of automobile manufacturers, for which DEA is the most popular approach. The studies, summarised in Table 1, exhibit differences in terms of purpose and research interests because they were carried out in different contexts. Indeed, the increasing financial, technological and sustainability pressures, continuously shape the dynamics of the industry, providing the justification to revisit the topic of automakers' efficiency over time. For example, the 2008 global economic crisis became an opportunity to analyse the financial and operational consequences and reactions of firms in one of the most affected sectors (Choi et al., 2017). There is also an increasing awareness of environmental impacts that led to stricter regulations and, consequently, scandals that involved some of the most influential automakers in Europe. More recently, the rise of Socially Responsible Investment and eco-funds incentivises firms to develop and better communicate their "greener" activities in order to improve their ratings and brand image (Otani and Yamada, 2017). It is on this last context that the contribution of the present work can be placed.

Table 1. Past efficiency studies examining the efficiency of the automobile sector

Authors	*Dataset information*	*Inputs*	*Outputs*	*Environmental variables*
Shaobing and Xixian (1996)	1 Chinese automaker from 1971 to 1993	Personnel of R&D, investment in R&D and cost per unit	Sales income and ratio of profit and taxes	-
Xie and Wang (2009)	11 Chinese automakers from 1997 to 2005	Total assets and shareholders' equity	Operating revenue and net profit	-
Nandy (2011)	Indian automakers between 2007 and 2008	Raw material Expenses (%), Employee cost (%) and selling and administration Expenses (%)	Net profit margin and return on capital employed (ROCE)	-
Maritz and Shieh (2013)	6 Taiwanese automakers from 2007 to 2009	Number of employees, operating costs, gross assets	Operating income	-
Guan and Pan (2014)	26 Chinese automakers in 2012	Spending on R&D, total asset and total operating costs	Earnings per share, total revenue and net profit	-
Otani and Yamada (2017)	8 global automakers from 2008 to 2012	Operating assets and number of employees	Operating profit and sales units. Undesirable: CO2 emissions	CO2 emissions
Du et al. (2018)	3 Chinese automakers from 2005 to 2012	Number of employees, total assets and annual energy consumption	Operating revenues and auto production. Undesirable: carbon emissions	Annual energy consumption & carbon emissions
Choi et al. (2017)	16 global automakers from 2005 to 2012	Number of employees and total assets	Revenues and operating income	-
Jiang et al. (2018)	77 Chinese automakers from 2012 to 2016	Net fixed assets and intangible assets, operating expenses and number of employees	Operating income	-
Panigrahi (2019)	19 Indian automakers from 2008 to 2018	Manufacturing cost, overhead cost and maintenance cost	Gross sales	-

Source: own elaboration

Despite the different research contexts, there are many common aspects in the methodological approaches used by past papers. Regarding the outputs, operating revenues and total turnover are the ones most frequently considered. In addition, Otani and Yamada (2017) also account for the number of vehicles sold, whilst Du et al. (2018) focus on the units produced. Regarding the inputs, capital is often measured by total or fixed assets, such as plants, machinery and equipment. When accounting for the labour variable, the total number of employees is usually preferred. Many studies in the broader DEA literature employ second-stage analyses to identify the determinants of the efficiency scores. However, when looking for second-stage analyses in automotive DEA studies, we find a gap in the literature. The only example is Choi et al. (2017), who performed a Kruskal–Wallis H test in order to account for the effects of different regions of origin on the firms' efficiency. The findings identified statistically significant differences across countries, due to different technologies, labour or environmental regulations.

Furthermore, while most studies in the past deal with operational or financial performance, there are few contributions that aim to incorporate aspects of corporate social responsibility (CSR) into the analysis, and all of them focus exclusively on environmental aspects. Thus, some studies have analysed fleet efficiency of carmakers, often adding variables related to the CO_2 emissions of the car models sold (Papahristodoulou, 1997; Voltes-Dorta et al., 2013; Cantner et al., 2012; Hampf and Krüger, 2014). For example, Choi et al. (2017) evaluated the efficiency of car companies when incorporating CO_2 emissions as undesirable output. They concluded that the efficiency rankings of sample countries reversed with respect to the studies that ignore emissions. Thus, starting from 2012, European car manufacturers became the leaders after surpassing Japanese producers. Interestingly, Otani and Yamada (2017) confirmed the benefits of sharing resources related to the lower-carbon technology that led to improved eco-efficiency for Fiat and Chrysler after their merger.

In view of the above, this study differs from past contributions in terms of sample period (we employ more recent data), methodology (a more comprehensive second-stage analysis) and the geographical scope of the sample (global decision-making units – DMUs). Furthermore, while past studies control for carbon emissions as an indicator of sustainable operations, the broader literature on the CSR performance of automakers hints at the influence of other aspects, including those traditionally linked to the firms' social and governance dimensions.

2.2 CSR performance car manufacturers

Although being often associated to organisational and personal values (Isa, 2012), CSR is also connected to efficiency improvements, mainly related to cost reductions, reputation and market position (Sukitsch et al., 2015). In addition, firms investing in green technologies would be able to access funding from agents following socially responsible investment (SRI) guidelines (Ferri and Pini, 2019). These funds may allow automakers to develop advanced technologies at lower costs in anticipation of increasing competition. Thus, managers in the automotive industry are now pressured to balance multiple objectives, i.e. financial, operational, and CSR, so any comprehensive indicator of performance in the sector must also account for all areas.

A few non-DEA papers have examined the effects of different CSR aspects in the automotive sector. In regard to corporate governance, Horak and Cui (2017), with a study in the Chinese sector, concluded that a higher proportion of females on the board positively affects firm performance in terms of sales growth and reduced risk. These results should encourage automakers to voluntarily increase gender diversity especially in a historically male-dominated industry. Diabat et al. (2013) argued about the importance of working towards a greener supply chain which, in turn, is proven to have positive effects on economic performance. Similarly, Sakuramoto et al. (2019) carried out a study on the Brazilian automotive sector and discussed how sustainable outsourcing practices translate into a reduction in transaction costs that boost the firms' profitability.

CSR reporting represents the main channel to communicate potential investors and the society at large on the firms' initiatives and performance. In this context, Russo-Spena et al.

(2018) investigated the changes in the most common dimensions described in CSR reports from 2010 to 2013. They found that the contents concerning the environment, labour practices and community involvement increased over the period, alongside the depth and accuracy with which they were communicated (Russo-Spena et al., 2018). Analogously, Sukitsch et al. (2015), analysing 14 automakers operating in Europe, confirmed the relevance of environmental management systems, stakeholder integration, education, emissions reporting, and freedom of association. Indeed, most manufacturers referred to CSR as an integral element of their business models by further developing clear sustainability strategies. A reason for this trend was provided by Chen et al. (2015), who found a positive impact between CSR reporting and return on equity (ROE).

Even though improvements have been made in recent times within the automotive sector, the quality of working, safety, and health conditions still varies widely across plants and male prevalence is still present (Martinuzzi et al., 2011). Indeed, the ability of firms to adapt to the numerous recent laws regarding working conditions and organisation, especially in the European Union, may affect their long-term performance. For example, the European Commission (2012) put forward legislations concerning mandatory quotas of women on boards for all listed companies (Horak and Cui, 2017). Thus, companies need to anticipate and rapidly react to the upcoming regulatory changes. Indeed, the forthcoming “Europe 2020 strategy” tackles social inclusion, climate change, innovation and education, which will ultimately produce effects for firms operating in the EU through different channels.

The CSR literature indicates that both social and governance factors can have an impact on the performance of automakers and hence its inclusion in DEA models is warranted and becomes the main contribution of this work. All the factors ranging from board composition, green procurement, sustainability reporting, or board diversity are incorporated in this analysis in order to account for a larger scope of CSR performance.

3. DATA AND METHODOLOGY

3.1. Case study and datasets

The panel dataset used for this study is shown in Table 2. It includes 33 automakers observed from 2014 to 2017. They come from 13 different countries (China, France, Germany, Hong Kong, India, Indonesia, Italy, Japan, Malaysia, South Korea, Taiwan, Turkey and USA), that can be grouped into four regions (Asia-Pacific, Middle East, Europe and North America). The firms considered in this study refer to the respective holding companies that manage different brands[1] and often diversify into disparate businesses[2]. Yet, in order to ensure comparability, we only include firms with the largest share of assets and turnover is related to vehicle manufacturing and sales.

Table 2. Sample firms (2017)

Automaker	Country	Region	Luxury status (2017)	Multiple vehicles production (2017)	Employees (2017)
Ford Otomotiv Sanayi AS	Turkey	Africa/Middle East	No	No	11,501
TOFAS Turk Otomobil Fabrikasi A.S.	Turkey	Africa/Middle East	No	No	9,712
Toyota Motor Corporation	Japan	Asia/Pacific	No	Yes	364,445
Honda Motor Co., Ltd.	Japan	Asia/Pacific	No	No	211,915
BYD Company Ltd.	China	Asia/Pacific	No	Yes	201,000
Dongfeng Motor Group Company Limited	China	Asia/Pacific	No	Yes	146,843
Nissan Motor Co. Ltd.	Japan	Asia/Pacific	No	Yes	137,250
Hyundai Motor Co.	South Korea	Asia/Pacific	No	Yes	122,217
Guangzhou Automobile Group Co., Ltd.	China	Asia/Pacific	No	Yes	84,290
Tata Motors Ltd.	India	Asia/Pacific	No	Yes	81,090
Great Wall Motor Company Ltd.	China	Asia/Pacific	No	No	68,505
Suzuki Motor Corp.	Japan	Asia/Pacific	No	No	62,992
Kia Motors Corp.	South Korea	Asia/Pacific	No	Yes	51,789
Mazda Motor Corporation	Japan	Asia/Pacific	No	No	48,849
Geely Automobile Holdings Ltd.	China	Asia/Pacific	Yes	Yes	41,600
Mahindra & Mahindra Ltd.	India	Asia/Pacific	No	Yes	40,188
Chongqing Changan Automobile Co. Ltd.	China	Asia/Pacific	No	No	39,138
Maruti Suzuki India Ltd.	India	Asia/Pacific	No	No	34,515
Isuzu Motors Ltd.	Japan	Asia/Pacific	No	Yes	33,631
Fuji Heavy Industries Ltd.	Japan	Asia/Pacific	No	Yes	32,599
Mitsubishi Motors Corp.	Japan	Asia/Pacific	No	Yes	29,604
Yulon Motor Co. Ltd.	Taiwan	Asia/Pacific	Yes	No	11,116
UMW Holdings Bhd	Malaysia	Asia/Pacific	No	No	9,169
Brilliance China Automotive Holdings Ltd.	Hong Kong	Asia/Pacific	No	No	6,280
BMW Group	Germany	Europe	Yes	Yes	129,932
Volkswagen AG	Germany	Europe	Yes	Yes	642,300
Daimler AG	Germany	Europe	Yes	Yes	289,321
Fiat Chrysler Automobiles (FCA)	UK	Europe	No	Yes	235,915
Peugeot S.A.	France	Europe	No	No	182,157
Renault Société Anonym	France	Europe	No	No	181,344

[1] Volkswagen AG, for example, also owns Audi, Bentley, Bugatti, Lamborghini, Porsche, SEAT, and Škoda for passenger cars, MAN and Scania for commercial vehicles, trucks, and buses, as well as Ducati for motorcycles.
[2] For example, UMW Holdings also operates in the oil sector, while BYD is involved in the rechargeable batteries. Similarly, Fuji Heavy Industries is active in both terrestrial and aerospace transportation.

Ford Motor Co.	USA	North America	No	Yes	202,000
General Motors Company	USA	North America	No	Yes	180,000
Tesla Motors, Inc.	USA	North America	Yes	No	37,543

Source: Bureau van Dijk, Annual Reports, own elaboration,

Our datasets include financial, operational, and sustainability indicators. The financial data were collected from Bureau van Dijk (Bureau van Dijk, n.d.) while the ESG scores were supplied by Sustainalytics (Sustainalytics, n.d.). These scores (Environmental, Social, Governance, and total ESG, which combines the three dimensions) range between 0 and 100 and indicate the proportion of the company's exposure to ESG risks that has been managed. To be considered in the analysis, a particular ESG risk must have "a potentially substantial impact on the economic value of a company" (Sustainalytics, n.d.). The overall scores are calculated from detailed raw scores on industry-specific items for each ESG sub-dimension. Each item is then assigned a weight that, when multiplied by their scores, yield the subtotals of the sub-dimensions (Environmental, Social and Governance). These subtotals add up to a final "total" score (tot.ESG). An illustrative example for Peugeot (2017) is provided in *Appendix A*, showing the ESG weightings that are implicit in the final score, which can differ across sectors. Figure 1 shows the differences across the sample regions according to ESG performance. Notably, European automakers favour the social dimension, while Asian manufacturers concentrate on governance aspects. Europe outperforms the other regions in terms of environmental and social performance, while Africa/Middle East achieves the highest governance score.

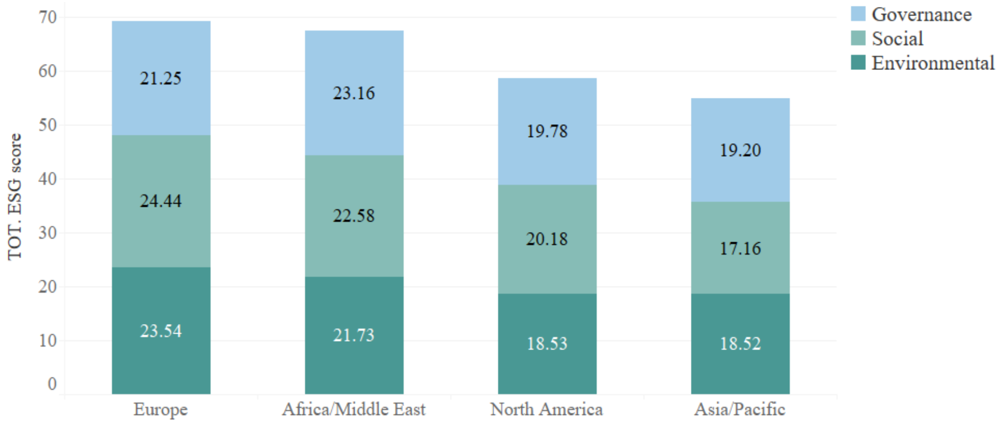

Figure 1. Total ESG composition across the sample regions
Source: own elaboration, Sustainalytics.

3.2 DEA model

The efficiency of a given automaker is evaluated by comparing its performance against a technological frontier obtained using DEA (Charnes et al., 1978). By means of linear programming, it is possible to locate the upper boundary of a production possibility set *P(x)* that indicates the maximum output levels (*y*) that can be obtained from a given set of inputs (*x*). Thus, the behaviour of automakers will be assumed to be output maximizing, as the ESG scores represent the main variables of interest which managers aim to increase. A linear optimization program runs for each individual automaker *i* in time period *t* and carries out a search for a reference firm (or set of firms) located in the technological frontier. By assuming Variable Returns to Scale (VRS), the reference set of automakers remains similar in size to the firm under evaluation. Past studies tend to assume VRS (e.g. Guan and Pan, 2014; Otani and Yamada, 2017; Choi et al., 2017; Panigrahi, 2019), which is consistent with the well-established view that the automotive industry benefits from economies of scale (Husan, 1997). In particular, the presence of high fixed costs related to plants and machinery, economies of specialisation and R&D, or high bargaining power against suppliers all make productivity in car manufacturing vary with firm size.

The linear program is shown in Equation 1:

(Eq. 1)

$$max\theta_{it} = \theta_y$$

$$s.t.\ \theta_y y_{it} \leq Y_t\lambda,$$

$$x_{it} \geq X_t\lambda,$$

$$\lambda \geq 0, \Sigma\lambda = 1, \theta_{it} \geq 0, \theta_y \geq 0$$

Where X and Y denote the input and output matrices, respectively, obtained from the data. θ_{it} indicates the coefficient, specific to the *i*th-DMU, to be maximised in order to assure the largest expansion of the firm's output (*y*) to reach a performance benchmark that depends on the input and output matrices observed during time period *t*. λ is a vector of peer weights used to obtain a linear combination of decision-making units (DMUs) that works as the benchmark for the firm under evaluation. Technical efficiency under VRS (VRSTE) is obtained as the inverse of θ (which is bounded between 1 and $+\infty$) in order to keep the efficiency score between 0 and 1. The linear program is solved using the Data Envelopment Analysis Computer Program – DEAP 2.1 published by Coelli (1996).

This paper estimates five DEA models for each of the four sample years (2014-2017). The baseline model (no ESG) only includes total assets and number of employees as inputs, and revenues and vehicle production[3] as outputs. The subsequent models retain the same variables as the baseline model, but each adds one of the sustainability scores: Environmental, Social, Governance and overall ESG score (tot.ESG), respectively. Table 3 provides descriptive statistics for the first-stage variables. The governance score has the highest average, followed by the environmental one. The highest total ESG score was achieved in 2014 by BMW (82) and the lowest belongs to Hyundai (42.99) in 2017.

Table 3. Descriptive statistics of the first and second-stage variables

First-stage variables	*Role*	*Unit*	*Obs.*	*Mean*	*Standard deviation*	*Minimum*	*Maximum*
Total ESG	Output	%	132	59.88	10.23	42.99	82
Environment Score	Output	%	132	59.53	13.24	33	86
Social Score	Output	%	132	58.15	13.61	33.9	88
Governance Score	Output	%	132	62.64	9.68	37.9	86

[3] This is proxied by the amount of finished goods in order to include all models and car parts manufactured.

Finished Goods	Output	Million PPP $	132	5,729.46	7,505.88	100.74	39,110
Total revenues	Output	Million PPP $	132	71,795.26	74,283.99	1,389.39	288,352.5
Total assets	Input	Million PPP $	132	102,724.57	124,282.75	2,884.49	527,741.25
Employees	Input	-	132	115,499.15	127,419.34	6,280	642,300

Source: Bureau van Dijk, Sustainalytics, own elaboration

3.3 Second-stage regression

For the second-stage analysis, we employ a bootstrapped truncated regression to regress the impact of selected factors on the estimated DEA efficiencies. As per Simar and Wilson (2007), the commonly employed censored-Tobit regression is not suitable for second-stage inference on DEA scores. This is due to the latter not being independent observations since they are calculated from the same sample of data, which causes serial correlation problems.

Equation 2 illustrates the specification of the five regressions that will be run.

(Eq. 2)

$$VRSTE_{ijt} = \beta_0 + \beta_1 * Firmsize_{ijt} + \beta_2 * Innovation_{ijt} + \beta_3 * Luxurycarbrands_{ijt} + \beta_4 * Multiplevehicletypes_{ijt} + \sum_{j=1}^{J-1} \beta_j * Region_j + \sum_{t=1}^{T-1} \beta_t * Year_t + \varepsilon_{ijt}$$

VRSTE$_{ijt}$ denotes the estimated VRS-technical efficiency for firm *i*, in region *j* (out of *J* sample regions) and year *t* (out of *T* sample years). The five different efficiency values that were previously calculated in the first-stage DEA analysis are used, alternatively, as dependent variables. β denotes the coefficients to be estimated and ε denotes the statistical error.

Regarding the independent variables, *Firmsize* is measured as the assets of the automakers in purchasing power parity (PPP) dollars, and also serves as a proxy for the market share of the firm that, in turn, may have an effect of profitability and efficiency (Mazumder and Adhikary, 2010). On the other hand, a larger size also increases the expectations of the stakeholders on CSR investments, as larger firms are supposed to allocate more resources on it (Ruggiero and Cupertino, 2018). Hence, the expectations about the sign of this variable are mixed.

$Innovation$ is measured as the percentage of Research & Development (R&D) expenses over revenues (Ruggiero and Cupertino, 2018). This can be expected to positively impact both financial and non-financial efficiency. Innovation helps firms to increase productivity and enhance profitability (Martinuzzi et al., 2011). Regarding the non-financial efficiency, Martinez-Conesa at al. (2017) found innovation to be a moderating factor between firm performance and CSR, whilst Martinuzzi et al., (2011) observed how innovation allows for greater levels of flexibility to deal with fast-paced developments in terms of ESG concerns. Therefore, we predict a positive relation between the firms' degree of innovation and all types of efficiency.

$Luxurycarbrands$ is a dummy variable that takes the value one if the firm sells "luxury" car brands. Car brands were labelled as "luxury" if they are referred to as such in industry publications.[4] Higher margins from high-end car models may stimulate firms to increase R&D investment. Thus, we expect the coefficient to be positive. $Multiplevehicletypes$ is another dummy variable that takes the value one if the company does not specialise on a limited number of models. Automakers following this strategy might save on costs (such as on spare parts or staff training). On the other hand, this practice could also mean that the firms will not benefit from economies of scope (Jonnalagedda and Saranga, 2019). Information on vehicle models was gathered from the firms' websites and annual reports. The $Region$ dummies control for the different regulatory conditions and customer preferences. Finally, the specification is completed with the $Year$ dummies to capture any time trends over the sample period analysed. The additional second-stage variables are summarized in

[4] Brilliance China and Yulon Motor were labelled as luxury automakers as their highest share of revenues comes from the sale of BMW and Nissan, Infiniti and Dongfeng vehicles respectively. Similarly, Volkswagen was also considered luxury as it incorporates brands such as Audi, Bentley, Bugatti, Lamborghini and Porsche.

Table 4. Note how the degree of innovation remarkably varies across firms, with UMW spending the least share of sales on R&D and Tesla Motors investing the most.

Table 4. Descriptive statistics of the second-stage variables

Second-stage variables	*Role*	*Unit*	*Observations*	*Mean*	*Standard deviation*	*Minimum*	*Maximum*
Firm size (tot. assets)	-	Million PPP $	132	102,724.57	124,282.75	2,884.49	527,741.25
Innovation (R&D as % of revenues)	-	%	132	3.245	2.632	0.005	17.743

Source: Bureau van Dijk, own elaboration

4. RESULTS AND DISCUSSION

4.1 First-stage analysis results

Table 5 shows the DEA efficiencies for 2017 in the five models. The number of efficient automakers increases as the sustainability measures are incorporated into the analysis. Among the firms that become efficient when considering ESG performance, we can mention most of the European automakers, such as BMW, Daimler, and Peugeot. In fact, as noted in Figure 2, European manufacturers beat their Asian and American competitors, with the performance gap increasing in the ESG-adjusted models. These regional effects would be further explored in the second-stage regression analysis.

Table 5. VRSTE and peer count across the five models for 2017

VRSTE (2017)	***No ESG***	***Tot. ESG***	***Env***	***Social***	***Gov***
BMW Group	0.798	1	1	1	0.983
Brilliance China Automotive Holdings Ltd.	1	1	1	1	1
BYD Company Ltd.	0.455	0.835	0.87	0.795	0.761
Chongqing Changan Automobile Co. Ltd.	1	1	1	1	1
Daimler AG	1	1	1	1	1
Dongfeng Motor Group Company Limited	0.471	0.594	0.557	0.508	0.722
Fiat-Chrysler Automobiles (FCA)	1	1	1	1	1
Ford Motor Co.	0.813	0.892	0.813	1	0.884
Ford Otomotiv Sanayi AS	1	1	1	1	1
Fuji Heavy Industries Ltd.	0.881	0.885	0.912	0.881	0.881
Geely Automobile Holdings Ltd.	0.75	0.766	0.751	0.75	0.847
General Motors Company	0.823	0.919	0.85	0.93	0.953
Great Wall Motor Company Ltd.	0.577	0.699	0.604	0.64	0.813
Guangzhou Automobile Group Co., Ltd.	0.414	0.612	0.578	0.573	0.666
Honda Motor Co., Ltd.	0.814	0.905	0.913	0.85	0.853
Hyundai Motor Co.	0.653	0.687	0.669	0.693	0.695
Isuzu Motors Ltd.	0.806	0.837	0.887	0.847	0.806
Kia Motors Corp.	1	1	1	1	1
Mahindra & Mahindra Ltd.	0.393	1	1	1	1
Maruti Suzuki India Ltd.	1	1	1	1	1
Mazda Motor Corporation	0.988	0.988	1	0.988	0.988
Mitsubishi Motors Corp.	0.827	0.827	0.914	0.827	0.827
Nissan Motor Co. Ltd.	0.713	0.863	0.908	0.81	0.801
Peugeot S.A.	0.982	1	1	1	1
Renault Société Anonym	0.484	0.961	0.997	0.89	0.912
Suzuki Motor Corp.	0.786	0.786	0.792	0.786	0.786
Tata Motors Ltd.	1	1	1	1	1

Tesla Motors, Inc.	0.325	0.751	0.887	0.575	0.621
TOFAS Turk Otomobil Fabrikasi A.S.	1	1	1	1	1
Toyota Motor Corporation	1	1	1	1	1
UMW Holdings Bhd	1	1	1	1	1
Volkswagen AG	1	1	1	1	1
Yulon Motor Co. Ltd.	0.543	0.84	0.744	0.821	0.98
Average	0.797	0.898	0.898	0.884	0.902

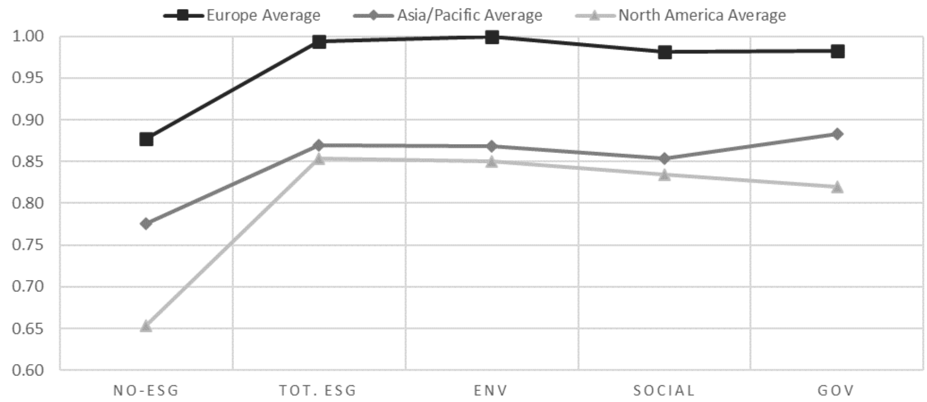

Figure 2. Region-specific average efficiencies across the five models (2017)
Note: African average excluded since all firms are fully efficient. Source: own elaboration.

Table 6 shows the evolution of VRSTE over time for the no-ESG and tot.ESG models. As shown in Figure 3, the average efficiencies have not changed significantly during the sample period, but there is still heterogeneity in performance across the firms. In the baseline model, KIA, FCA, Toyota, Maruti, Tata, Ford Otomotiv and UMW have the highest efficiency scores. KIA was among the first automakers that established their plants in emerging markets such as China, Latin America and India (Choi et al., 2017). Similarly, Fiat-Chrysler Automobiles (FCA), after the merger formalised in 2014, moved its market focus to the US where, thanks to the plants and distribution facilities owned by Chrysler and renewal of the Jeep brand, the company benefited from economies of scale (EOS), as well as increasing market shares and margins (Galvagni and Mangano, 2019). Toyota's bet on the hybrid vehicles started paying off in 2014 when, together with the emissions scandal that penalised its major competitor Volkswagen, Toyota experienced significant sales growth in Europe as the region moved away from the diesel technology (Trudell and Behrmann, 2016). Tata is the second largest Indian player and achieves higher margins from its luxury brands (Jaguar Land

Rover), while manufacturing in a country with relatively cheaper raw materials and labour costs. Thus, our findings contradict Nandy (2011) and Panigrahi (2019), that identified Tata as inefficient. We link these discrepancies to the fact that Nandy (2011) employed data prior to the acquisition of Jaguar Land Rover (2007-2008), while Panigrahi (2019) focused only on local sales. Therefore, the first conclusion that can be drawn in terms of carmakers' baseline efficiency refers to the benefits of foreign acquisitions.

There are efficient automakers with atypical business models. For example, Ford Otomotiv and UMW manufacture commercial vehicles under the Ford and Toyota brands, respectively. In this way, they can reduce costs by focusing on importing and exporting, and savings on R&D expenses as no investments in car design are required. Therefore, the second conclusion is that, in the automotive industry, licencing or manufacturing on behalf of "mother companies" generally leads to financial efficiency due to the know-how acquired from the licensors. However, these benefits are limited if the licensees sign contracts with multiple licensors, as they may refrain from investing and transferring know-how to manufacturers if it might indirectly benefit competitors that also employ the same licensees (i.e. horizontal service externalities). For example, the majority of Chinese manufacturers have partnerships with multiple Western and Japanese automakers. Examples include Dongfeng Motor Group and Guangzhou Automobile Group, that were found financially inefficient despite their manufacturing agreements with several automakers such as Renault-Nissan, Peugeot, Kia and Honda, and Fiat, Honda, Toyota and Mitsubishi, respectively.

Tesla is also very inefficient in terms of sustainability performance. Chasan (2018) pointed out some social and governance-related controversies, such as the inexpert and non-independent executives and the firm's inability to provide CSR reports that prevent the American carmaker to access SRI investments. Consequently, although Tesla improved its efficiency under the total ESG model, it still experienced low scores in the social and governance dimensions that hampered its overall ESG performance.

Table 6. Evolution of the firms' VRSTE for the baseline (No-ESG) and tot.ESG models over the sample years

	No-ESG model				*Tot.ESG model*			
VRSTE	***2014***	***2015***	***2016***	***2017***	***2014***	***2015***	***2016***	***2017***
BMW Group	0.832	0.767	0.766	0.798	1	1	1	1
Brilliance China Automotive Holdings Ltd.	0.393	1	1	1	0.759	1	1	1
BYD Company Ltd.	0.46	0.532	0.56	0.455	0.748	0.786	0.758	0.835
Chongqing Changan Automobile Co. Ltd.	1	1	1	1	1	1	1	1
Daimler AG	1	1	1	1	1	1	1	1
Dongfeng Motor Group Company Limited	0.472	0.627	0.548	0.471	0.588	0.652	0.552	0.594
Fiat-Chrysler Automobiles	1	1	1	1	1	1	1	1
Ford Motor Co.	0.845	0.812	0.795	0.813	0.95	0.94	0.901	0.892
Ford Otomotiv Sanayi AS	1	1	1	1	1	1	1	1
Fuji Heavy Industries Ltd.	0.962	0.953	0.933	0.881	0.968	0.953	0.934	0.885
Geely Automobile Holdings Ltd.	0.414	0.438	0.537	0.75	0.668	0.679	0.657	0.766
General Motors Company	0.988	0.781	0.804	0.823	0.988	0.828	0.816	0.919
Great Wall Motor Company Ltd.	0.693	0.693	0.751	0.577	0.79	0.73	0.751	0.699
Guangzhou Automobile Group Co., Ltd.	0.294	0.3	0.419	0.414	0.698	0.62	0.608	0.612
Honda Motor Co., Ltd.	0.815	0.768	0.856	0.814	0.829	0.895	0.89	0.905
Hyundai Motor Co.	0.685	0.624	0.619	0.653	0.773	0.755	0.753	0.687
Isuzu Motors Ltd.	0.839	0.753	0.788	0.806	0.853	0.776	0.789	0.837
Kia Motors Corp.	1	1	1	1	1	1	1	1
Mahindra & Mahindra Ltd.	0.734	0.724	0.452	0.393	1	1	1	1
Maruti Suzuki India Ltd.	1	1	1	1	1	1	1	1
Mazda Motor Corporation	0.954	0.942	1	0.988	0.996	0.996	1	0.988
Mitsubishi Motors Corp.	1	0.939	1	0.827	1	0.939	1	0.827
Nissan Motor Co. Ltd.	0.708	0.674	0.735	0.713	0.856	0.873	0.885	0.863
Peugeot S.A.	0.758	0.923	1	0.982	1	1	1	1
Renault Société Anonym	0.463	0.438	0.474	0.484	0.96	0.966	0.928	0.961
Suzuki Motor Corp.	0.811	0.724	0.869	0.786	0.826	0.77	0.869	0.786
Tata Motors Ltd.	1	1	1	1	1	1	1	1
Tesla Motors, Inc.	0.8	0.524	0.474	0.325	0.974	0.874	0.879	0.751
TOFAS Turk Otomobil Fabrikasi A.S.	1	1	1	1	1	1	1	1
Toyota Motor Corporation	1	1	1	1	1	1	1	1
UMW Holdings Bhd	1	1	1	1	1	1	1	1
Volkswagen AG	1	1	1	1	1	1	1	1
Yulon Motor Co. Ltd.	0.523	0.477	0.468	0.543	0.883	0.881	0.905	0.84
Average	***0.801***	***0.800***	***0.814***	***0.797***	***0.912***	***0.906***	***0.905***	***0.898***

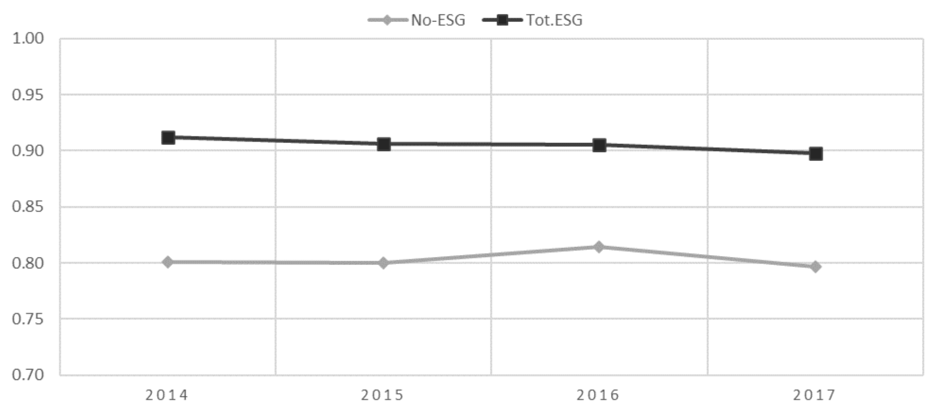

Figure 3. Evolution of average efficiencies for the no-ESG and tot.ESG models 2014-2017
Source: own elaboration.

Similarly to Otani and Yamada (2019), most European carmakers managed to reach the reference frontier in the sustainability-adjusted models. Firms such as Daimler, BMW and Peugeot outperformed Asian companies in many ESG raw scores. From an environmental perspective, it is clear than the Chinese sector is facing many challenges (Liu et al., 2015), Chinese carmakers lack effective formal environmental policies and management systems and show insufficient participation in carbon disclosure and unavailability of programs to reduce greenhouse gas (GHG) emissions from own operations. Similarly, the substandard quality of the CSR reports and poor policies on bribery and corruption represent the main weaknesses in terms of governance-related performances. For example, in 2015 the board of the Chinese second-largest automaker, Dongfeng Motor Corporation, was involved in a corruption scandal (Jourdan, 2015). Finally, in terms of social commitments, Chinese companies have much room for improvement on policies on freedom of association and elimination of discrimination in the workforce. Thus, European carmakers stand out globally in terms of implementing ESG measures and, thus, can be regarded as the main reference set of best practices. Specifically, these companies obtained remarkable scores in the governance dimension, closely followed by the environmental and social ones. In addition, European automakers are also active in more subcategories than their international competitors, outperforming in terms of greener supply chain programmes, emissions from their operations and services, reporting, percentage of employees covered by collective bargaining agreements and activities in sensitive countries.

4.2 Second-stage analysis results

Table 7 shows the results of the five bootstrapped truncated regressions. Note that the number of observations varies with the number of efficient DMUs (VRSTE=1) excluded from the second-stage truncated estimation sample. The goodness-of-fit of the five models ranges between 51 and 61 per cent, as approximated by the squared correlation coefficient between the predicted and observed efficiencies (Rho-squared).

When considering the baseline performances (no ESG), firm size appears to be the most relevant contributor to the efficiency of firms. In fact, according to the past literature, larger firms tend to be more efficient than smaller ones as they presumably enjoy larger market shares and opportunities to engage in mergers and acquisitions (Mazumder and Adhikary, 2010), which allows firms to share capabilities and benefit from EOS. In addition, the brand luxury status is found to negatively impact on the operational efficiency of the automakers (but only at 10% significance level). These findings can be traced back to the remarkable difference in the revenues per employee ratio between luxury and non-luxury automakers. Indeed, as most of the luxury brands are European-based companies, they suffer from severe overcapacity and low capacity utilization. In this context, Volkswagen has recently announced the termination of up to 7,000 workers over the next four years in order to enhance flexibility and efficiency and reallocate the money in the development of new electric and eco-friendly cars (Deutsche Welle, 2019).

Table 7. Second-stage analysis results

	No-ESG				Tot.ESG				Environmental				Social				Governance			
Variable	Coeff.	S.d.	Prob.	Sig.	Coeff.	S.d.	Prob.	Sig.	Coeff.	S.d.	Prob.	Sig.	Coeff.	S.d.	Prob.	Sig.	Coeff.	S.d.	Prob.	Sig.
Firmsize	2E-06	7E-07	0.00	***	1E-06	4E-07	0.03	***	2E-06	6E-07	0.00	***	1E-06	6E-07	0.05	**	-2E-07	3E-07	0.49	
Innovation	1.20	1.13	0.29		1.30	0.89	0.14		6.30	1.46	0	***	-0.08	0.99	0.94		-1.79	0.56	0.00	***
Luxurycarb	-0.11	0.06	0.09	*	0.00	0.05	1.00		0.13	0.07	0.08	*	0.00	0.07	0.96		-0.01	0.04	0.81	
Multipleve	-0.05	0.06	0.41		-0.06	0.04	0.10	*	0.06	0.05	0.21		-0.07	0.05	0.15		-0.07	0.03	0.01	***
Europe	-0.08	0.09	0.33		0.29	0.21	0.16		0.60	0.36	0.09	*	0.18	0.15	0.23		0.13	0.05	0.01	***
USA	-0.09	0.12	0.46		0.03	0.08	0.72		-0.24	0.10	0.02	***	0.06	0.10	0.57		0.14	0.05	0.01	***
2015.Year	-0.02	0.07	0.81		-0.02	0.04	0.70		-0.01	0.05	0.78		0.00	0.06	0.96		-0.02	0.03	0.65	
2016.Year	-0.06	0.07	0.40		-0.05	0.05	0.24		-0.05	0.05	0.29		-0.05	0.06	0.40		0.01	0.03	0.84	
2017.Year	-0.03	0.07	0.61		-0.04	0.04	0.38		-0.05	0.05	0.30		-0.05	0.05	0.39		0.00	0.03	0.91	
Constant	0.64	0.07	0		0.80	0.06	0		0.51	0.08	0		0.82	0.08	0		0.94	0.04	0	
Sigma	0.19	0.02	0	***	0.11	0.01	0	***	0.12	0.01	0	***	0.13	0.02	0	***	0.09	0.01	0	***
Rho-sq	0.58				0.51				0.54				0.45				0.61			
No. Obs.	81				70				67				66				74			

Note:, **, *** denote significance at 10%, 5%, and 1% level, respectively.*

When examining the results of the ESG-adjusted regressions, company size emerges, once again, as the most relevant variable that affects firm performance. Size positively affects the environmental VRSTE as larger carmakers obtained, on average, higher environmental scores than their smaller competitors. Therefore, these findings support the assumptions from Waddock and Graves (1997) and Ruggiero and Cupertino (2018) on the wider availability of resources and higher stakeholders' expectations on sustainable practices of larger corporations. The governance dimension represents the only exception in that, although statistically insignificant, size negatively impacts on the VRSTE. Indeed, organization complexity at large conglomerates may penalise the efficiency when considering the governance aspects. In the environmentally-adjusted model, the degree of innovation has a positive impact on the efficiency of car manufacturers. These results are consistent with the past literature as Martinuzzi et al. (2011) identified the development of new technologies in eco-friendly vehicles as a key factor to guarantee long-term competitiveness of carmakers. Similarly, technological progress related to eco-innovations was found by Beltrán-Esteve and Picazo-Tadeo (2015) as the main driver of environmental performances in the transportation industry of several European countries. Luxury brand status is significant at 10% and, in accordance with our expectations, exhibits a positive relation with environmental efficiency. Higher margin expectations may incentivise firms to further invest in developments of new technologies to meet regulatory emission targets and satisfy increasingly demanding consumers. Indeed, customers of luxury brands may constitute a more sensitive and conscious segment of demand, willing to pay more for technologically advanced and eco-friendly solutions. Finally, as also highlighted by Ruggiero and Cupertino (2018), companies engaging in CSR practices focus more on profitability (i.e. higher margins) rather than on mass-market sales and tend to spend more on innovation to enhance their long-term value.

Regarding the geographical variables, Asia represents the reference region in all regressions since there are no inefficient African DMUs that take part of the second-stage estimation sample. The results show that Europe outperforms, and North America underperforms Asian manufacturers. In this regard, it is worth noting that European automakers face strict regulations regarding emissions reductions (Kiso, 2019), which, as argued by Triebswetter and Wackerbauer (2008), can influence the degree of innovation of European automakers, leading to improvements in productivity.

In the governance model, innovation is found to negatively affect efficiency. Analogously, the VRSTE score decreases when there are many vehicle lines manufactured. Thus, firms adopting diversification strategies tend to underperform, possibly due to the addition of complexity at the management level, which could cause difficulties in terms of cohesive reporting and oversight of ESG issues. Both Europe and North America, outperformed Asian regions in terms of governance-related efficiency. These results may have been affected by cultural and regulatory factors, such as the mandatory quotas of women on boards urged by the European Commission (2012). In addition, Horak and Cui (2017) include some Asian countries such as Japan and India among the countries with the lowest scores in terms of board gender diversity. Finally, according to Post and Byron (2015), the effect on performances of women on boards tends to be amplified in countries with higher shareholder protection and gender parity. Indeed, investors protection may encourage boards to leverage different skills and knowledge, while higher gender equality may guarantee better education and access to job opportunities (Post and Byron, 2015).

5. SUMMARY, LIMITATIONS AND FUTURE RESEARCH

This study aims to estimate the efficiency of 33 global automakers under environmental, social, and governance (ESG) objectives between 2014 and 2017. To this end, we employ a DEA approach, and then regress the first-stage efficiency values against variables such as firm’s size, region, brand status, and the degree of innovation and diversification.

Our results bridge the gap between two separate strands of literature: one relating to the efficiency analysis of car manufacturers and a second one that places focus on corporate social responsibility and ESG practices in the sector. The main finding is that the ranking of efficient automakers changes according to the indicators considered, with European firms moving up in the rankings for the ESG-adjusted models. The average technical efficiency scores vary across the models, with the governance-adjusted efficiency being the highest and the social one being the lowest.

We also found the efficiency of car manufacturers under the traditional operating and financial indicators to be significantly influenced by firm size and type of ownership, thus, there is a clear recommendation for local carmakers to boost their financial performance by entering into exclusive licensing agreements with foreign manufacturers, allowing them to benefit from the licensor's know-how. The firms' geographical region and degree of innovation represent the major drivers of the ESG-adjusted efficiencies. The obvious policy implication being in support of a potential tightening of environmental restrictions that has already been shown to foster innovation and improve ESG performance in Europe. Similarly, there is an element of market positioning from which automakers can derive improvements too: by expanding their portfolio of high-end brands, the highly environmentally conscious buyers can also incentivize them to develop innovative technologies.

As per the factors above, European carmakers appear the most efficient in the governance and environmentally-adjusted models, particularly in relation to Chinese manufacturers. From an environmental perspective, Chinese carmakers lack effective formal environmental policies and management systems. Similarly, the substandard quality of the CSR reports and poor policies on bribery and corruption represent the main weaknesses in terms of governance-related performance. Finally, in terms of social commitments, Chinese companies have much room for improvement on policies on freedom of association and elimination of discrimination in the workforce. These findings together with the best practices of efficient automakers are particularly valuable for managers willing to enhance

CSR performance and identify suitable partners for M&A strategies. Also benefiting from our findings would be socially responsible investors, and governments intending to monitor the progresses made in the industry in order to set realistic targets for technological progress.

However, this research presents few limitations that should be considered. To begin with, the sample size is relatively limited, with the majority of the automakers concentrated in Asia. Secondly, different selections of financial and sustainability metrics may be considered by future studies. Indeed, given the lack of consensus on a suitable sustainability ranking, using other ESG metrics, such as the Dow Jones Sustainability Index, would add to the robustness of our findings. Lastly, future research may want to consider the adopting more sophisticated DEA models, such as the slacks-based method (SBM), which is able to tackle both input excesses and output shortfalls to achieve more discriminatory power in the efficiency assessment (Tone, 2001).

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APPENDIX A. Peugeot Sustainalytics ESG Scores (2017)

PEUGEOT (2017)

ENVIRONMENTAL MEASURES	*RAW SCORE*	*WEIGHT*	*WEIGHTED*
Formal Environmental Policy	50	0.0077	0.3846
Environmental Management System	100	0.0154	1.5385
External Certification of EMS	100	0.0154	1.5385
Environmental Fines and Non-monetary Sanctions	100	0.0077	0.7692
Participation in Carbon Disclosure Project (Investor	100	0.0077	0.7692
Scope of Corporate Reporting on GHG Emissions	100	0.0077	0.7692
Programmes and Targets to Increase Renewable	25	0.0077	0.1923
Carbon Intensity	100	0.0077	0.7692
Carbon Intensity Trend	75	0.0154	1.1539
% Primary Energy Use from Renewables	100	0.0154	1.5385
Operations Related Controversies or Incidents	100	0.06	6
GHGReductionProgramme	100	0.0077	0.7692
Formal Policy or Programme on Green Procurement	100	0.0103	1.0256
Environmental Supply Chain Incidents	100	0.03	3
Programmes to Improve the Environmental	100	0.0205	2.0513
External Environmental Certification Suppliers	60	0.0308	1.8461
Products & Services Related Controversies or	50	0.06	3.0001
Sustainability Related Products & Services	50	0.0513	2.5641
Automobile Fleet Average CO2 Emissions	70	0.0308	2.1538
Trend Automobile Fleet Average Fleet Efficiency	75	0.041	3.077
Raw Environmental Score			***34.91***
Environmental Score (49%)			***70.88***
GOVERNANCE MEASURES	*RAW SCORE*	*WHEIGHT*	*WEIGHTED*
Policy on Bribery and Corruption	100	0.01	1
Whistleblower Programmes	100	0.02	2
Signatory to UN Global Compact	100	0.01	1
Tax Transparency	0	0.02	0
Business Ethics Related Controversies or Incidents	100	0.04	4
CSR Reporting Quality	75	0.01	0.75
External Verification of CSR Reporting	50	0.01	0.5
Oversight of ESG Issues	50	0.01	0.5
Executive Compensation Tied to ESG Performance	25	0.01	0.25
Governance Related Controversies or Incidents	99	0.0425	4.2075
Policy on Political Involvement and Contributions	75	0.0075	0.5625
Total Value of Political Contributions or Political	0	0.0075	0
Public Policy Related Controversies or Incidents	100	0.015	1.5
Raw Governance Score			***16.27***
Governance Score (19%)			***77.58***
SOCIAL MEASURES	*RAW SCORE*	*WEIGHT*	*WEIGHTED*
Policy on Freedom of Association	100	0.0173	1.73
Formal Policy on the Elimination of Discrimination	100	0.0098	0.98
Programmes to Increase Workforce Diversity	100	0.0098	0.98
Percentage of Employees Covered by Collective	100	0.0173	1.73
Employee Turnover Rate	0	0.0173	0
Employee Related Controversies or Incidents	80	0.0375	3
Trend in Lost-Time Incident Rate	100	0.0248	2.48
Scope of Social Supply Chain Standards	100	0.012	1.2
Social Supply Chain Incidents	100	0.03	3
Policy on Conflict Minerals	25	0.0123	0.3075
ConflictMineralsProgrammes	50	0.0173	0.865
SupplyChainManagement	100	0.0123	1.23
Customer Related Controversies or Incidents	80	0.0299	2.392
External QMS Certifications	100	0.0223	2.23
Activities in Sensitive Countries	100	0.0001	0.01
Society & Community Related Controversies or	100	0.03	3
Audit Committee Structure-Weighted Score	0	0.0025	0
Auditor Fees-Weighted Score	0	0.0025	0
Remuneration Committee Effectiveness-Weighted	0	0.0025	0
Remuneration Disclosure-Weighted Score	60	0.0025	0.15
Director Disclosure-Weighted Score	60	0.0025	0.15
Board Diversity-Weighted Score	80	0.01	0.8
Board Leadership-Weighted Score	70	0.005	0.35
Board Independence-Weighted Score	0	0.01	0
Raw Social Score			***26.58***
Social Score (34%)			***83.78***
TOT. ESG SCORE			***77.76***