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RESEARCH ARTICLE

Carbon footprint analysis of Jaguar Land Rover Slovakia s.r.o.

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Abstract – The automotive industry around the world, including Slovakia, is taking steps to decarbonize their production in accordance with the Science Based Targets initiative (SBTi). Decarbonizing the operations of automotive Original Equipment Manufacturers (OEMs) requires a holistic and systemic understanding of all environmentally relevant resource flows and the implementation of technologically and economically affordable solutions to achieve their targets for reducing the carbon footprint (CF). The CF analysis of Jaguar Land Rover Slovakia s.r.o. (JLR SK) was performed using the Greenhouse Gas Protocol (GHG Protocol). The purpose of the study was to improve the understanding of CF within the context of an OEM. The authors of this study are not aware, as of the date of publication, of any other comparable outputs from CF analyses by GHG Protocol in Slovakia, making this study the first of its kind.
The results showed that the total CF was 1,143,205 tCO2e (tonnes of carbon dioxide equivalent); of which SCOPE 1 emissions were 18,584 tCO2e (1.62%), SCOPE 2 emissions were 0.87 tCO2e (0.0001%) and SCOPE 3 emissions were 1,130,866 tCO2e (98.38%). Normalized CF values for all three SCOPES were 309.81 tCO2e per active employee; 3.08 kgCO2e per unit of turnover (EUR); and 14.95 tCO2e per vehicle produced. Current legislative standards and the active participation of OEMs can lead the automotive industry towards sustainability, including the achievement of net-zero carbon emissions despite rising consumption or production volume. With respect to some ambiguities in the initial data inventory, the presented analysis shows the first approach to identifying the CF of an automotive factory based on GHG Protocol in Slovakia.

Keywords – Automotive industry, decarbonization, carbon footprint, Greenhouse Gas Protocol, net-zero, Original Equipment Manufacturer

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1. INTRODUCTION

As the latest IPCC (2023) Sixth Assessment Report on Climate Change states, human activities, principally through emissions of greenhouse gasses (GHGs), have unequivocally caused global warming, with global surface temperature reaching 1.1°C above the average temperature between 1850 and 1900 in the last decade (2011 – 2020). The report further shows that with high confidence, global GHG emissions have continued to increase over 2010 – 2019, with unequal historical and ongoing contributions arising from unsustainable energy use, land use and land use change (LULUC), lifestyles, and patterns of consumption and production across regions, between and within countries, and between individuals (IPCC, 2023). The last decade was the warmest decade on record. Of the 20 warmest years, 19 have occurred since 2000. The majority of evidence indicates that this is due to the rise of GHGs produced by human activity (EEA, 2023a; EP, 2023).

A strengthened GHG reduction target was set under the Paris Agreement in 2021 to at least a 55% reduction by 2030 compared to 1990 levels and climate neutrality by 2050 (EP, 2023). This goal of zero net emissions is embedded in the European Green Deal (EC, 2023b). According to Eurostat (2023), the EU's share in the world's GHGs fell from 15.2% in 1990 to 7.3% in 2019. The EU ranks fourth in the world in GHG emissions generation, after China, the US and India (EP, 2023). The decrease of the EU's GHG emissions can be explained as a result of various policies, projects, and mechanisms adopted by the EU, namely the emissions trading system (ETS) launched in 2005, covering more than 12,000 installations and airlines across the EU28, Iceland, Norway and Lichtenstein. In total, the EU ETS covers around 45% of EU GHG emissions. Another policy, which has been in force since January 2013, is the European Industrial Emissions Directive (IED), which requires industrial installations to be equipped with the best available technologies (BAT) and sets new limits on emissions. Most of this decrease is attributed to a decrease in energy intensity and an increase in use of zero-carbon energy sources (Su et al., 2016).

The Integrated National Energy and Climate Plan of the Slovak Republic for 2021 – 2030 is intended to be a tool for achieving carbon neutrality by 2050 with more ambitious targets for an overall reduction of GHG emissions by at least 55% compared to 1990, which is a transposition of the European climate targets known as the Fit for 55 packages (MHSR, 2023; Council of the EU and the European Council, 2023).

The industry sector is responsible for over 22% of all GHG emissions in the EU-27 (EEA, 2023b) and automotive manufacturing is one of the most significant resource-demanding industrial segments (Wendt et al., 2023). From the revenue and resource consumption perspective, the global automotive industry is one of the world's most important economic sectors. In the past five years, the world's annual motor vehicle production, comprising both passenger cars and commercial vehicles, ranged between 78 and 96 million units (OICA, 2023). Governments and the automotive industry should take responsibility for global and whole life-cycle vehicle emissions, not just domestic emissions from tank-to-wheel (Nakamoto et al., 2023). According to Buettner et al. (2022), the decarbonization of industry is multi-layered and complex, and there are companies whose processes can only be decarbonized through significant interventions in their core processes and the way their products are manufactured. The authors further argue that a 'one-size-fits-all' approach to decarbonization is not effective and there is a need for policymakers and researchers to work more closely with industry sectors to identify and address its challenges and needs. As reported by Fais et al. (2016), ambitious emission cuts in the industry sector of up to 77% by 2050 compared to 2010 can be achieved at both UK and European levels. Some of the world's leading Original Equipment Manufacturers (OEMs) are already committing to GHG emissions reductions. For instance, General Motors' goal is to reduce absolute GHG from their operations by 31% from 2010 to 2030 coupled with a 100% renewable energy commitment by 2050 (Hildreth, 2019).

As reported by Pandey et al. (2011), common resources for GHG accounting are GHG Protocol, ISO 14064 (parts 1 and 2), Publicly Available Specifications-2050 (PAS 2050) of British Standard Institution (BSI), 2006 IPCC Guidelines for National GHG inventories, ISO 14025: a standard for carrying out Life Cycle Assessment (LCA) and ISO 14067: a standard on carbon footprinting of products, published in 2018. Many government, private, and non-profit organizations, local movements, and individuals understand that climate change is one of the most pressing sustainability issues of our generation. Therefore, they have voluntarily started to monitor their GHG emissions and have also taken steps towards adapting to a world marked by an energy and climate crisis. This development reiterates the importance and need to properly measure and reduce energy consumption and GHG emissions. One of the most widely recognized international standard for reporting the CF for the business (as well as the public) sectors is the GHG Protocol (WRI and WBCSD, 2023a). Mapping the CF of an automotive manufacturing plant according to the GHG Protocol is still a relatively new area of research. At the same time, GHG Protocol is a voluntary tool for determining CF. This will change in 2025 when the new Corporate Sustainability Reporting Directive (CSRD) will take effect in the EU for companies with more than 500 employees ("large enterprises") and the reporting of GHG emissions will be a mandatory requirement (EC, 2023a). The new obligation will directly affect around 700 large companies in Slovakia (Jenčová, 2023).

This paper provides an insight into the carbon footprint of JLR SK in 2021 and summarizes the results of the GHG analysis performed according to the GHG Protocol. Studies to date suggest (Schmidt et al., 2006; Huang et al., 2009; Lee 2011; Rüdele and Wolf 2023) that, at the OEM level, upstream and downstream activities contribute predominantly (at least 75%) to OEM CF than the manufacturing activities at the OEM site. However, CF of automotive-related manufacturing in Slovakia has not been studied in detail. Therefore, the aim of this paper is to close this research gap. Further, it proposes recommendations for decarbonization measures to reduce the company's CF.

2. Materials and Methods

JLR SK is a subsidiary of the British car company Jaguar Land Rover Ltd. (JLR UK) located in the industrial park Nitra-Sever. The maximum annual production capacity of the Nitra plant is 150 thousand vehicles and the production reached 76,481 vehicles in 2021. In the same year, JLR UK announced the new strategy called „Reimagine" about becoming carbon net zero business by 2039 by committing to ambitious Science Based Targets (SBTs). Reducing CO_2e (carbon dioxide equivalent) emissions by 46% (absolute value) from JLR's own activities and by 54% average reduction of the CO_2e intensity per vehicle from JLR's value chain by 2030 compared to levels in 2020 are the key sustainability commitments of the company.

In terms of methodological choices, the GHG Protocol's Scope 1 and Scope 2 categories were included in their entirety in the CF calculation, within Scope 3 only selected sub-categories were used, based on data availability. The selection and use of emission factors (EFs) also took into account the geo-local specificities of Slovak Republic. In the case of natural gas, the lower calorific value and the EF published by the national supplier (SPP, a.s.) on a monthly basis were used. Within the Scope 1, calorific value for diesel was used from the national diesel manufacturer and EF from the EU Implementing Regulation (2018/2066) and the IPCC database, and biomass content (FAME) from the national Renewable Energy Sources (RES) Promotion Act (309/2009). As for the mobile emission sources, the EF was based on km of travelled distance geo-locally, i.e. specifically for Slovak Republic according to The Slovak Hydrometeorological Institute (SHMU). These EFs were plotted per unit of energy. Under the Scope 2 for electricity, the EF used was determined on the basis of the energy mix of the Slovak Republic in the reporting year and the GHG offsets in the delivered electricity were calculated according to the EF of the green electricity supplier (i.e. electricity generated without the use of fossil fuels on the basis of the purchase of emission-free electricity guarantees of origin).

The GHG Protocol lists the following limitations (WRI and WBCSD, 2023a): (1) Data availability and data quality: The collection of high-quality activity data, particularly for Scope 3 emissions, is often the most significant limitation, such as reliance on estimates or data from suppliers, which may vary in quality and reliability. (2) Limitations of uncertainty estimates: Uncertainty estimates for corporate GHG inventories will, of necessity, be imperfect. Complete and robust sample data will not always be available to assess the statistical uncertainty in every parameter. To improve this limitation, the GHG Protocol corporate standard has developed a supplementary guidance document on uncertainty assessments („Guidance on uncertainty assessment in GHG inventories and calculating statistical parameter uncertainty“) along with an uncertainty calculation tool. Furthermore, a more comprehensive list of GHG Protocol limitations (Rajgopal, 2022) highlights 10 areas including the nature of the due process followed (1), organizational boundary (2), missing detailed guidance on assurance of these organizational boundaries (3), GHG from discontinued or acquired operations (4), correcting changes in principles versus changes in estimates (5), GHG segments relative to US GAAP segments (6), operating facility as per the EPA relative to US GAAP and GHG Protocol (7), what emissions number is contracted on in CEO compensation plans or in green bonds (8), need for transitional plan and net zero disclosures (9), more clarity on scope 4 emissions or avoided emissions (10) and proposed e-liability system (11).

The calculation of JLR SK CF included GHG emissions generated by the company's manufacturing operations. As a consolidation approach, we used an operational control of the data for the reporting period from January 1, 2021 to December 31, 2021. All relevant JLR SK activities and operations that resulted in the release of GHGs during the studied period were included. The calculations therefore contain direct emissions from owned and controlled sources as well as indirect emissions from sources that were not owned by the company, but which were essential to the day-to-day operation of the business. We have used calculation formulas and emission factors for GHG emissions, which are divided into three Scopes as outlined in Figure 1. Scope 1 includes direct emissions (emissions from manufacturing and non-manufacturing support processes; but emissions resulting from production or processing of various materials or chemicals typical for automotive Paint Shop operations, i.e. volatile organic compounds, were not included in the calculation as they are not subject to control under GHG Protocol); Scope 2 includes indirect emissions (consumption of purchased electricity as the only relevant energy source) and Scope 3 includes other indirect emissions (company's activities in upstream and downstream supply chains, emissions associated with externalized and outsourced production, leases or franchises that are not covered in Scope 1 or 2).

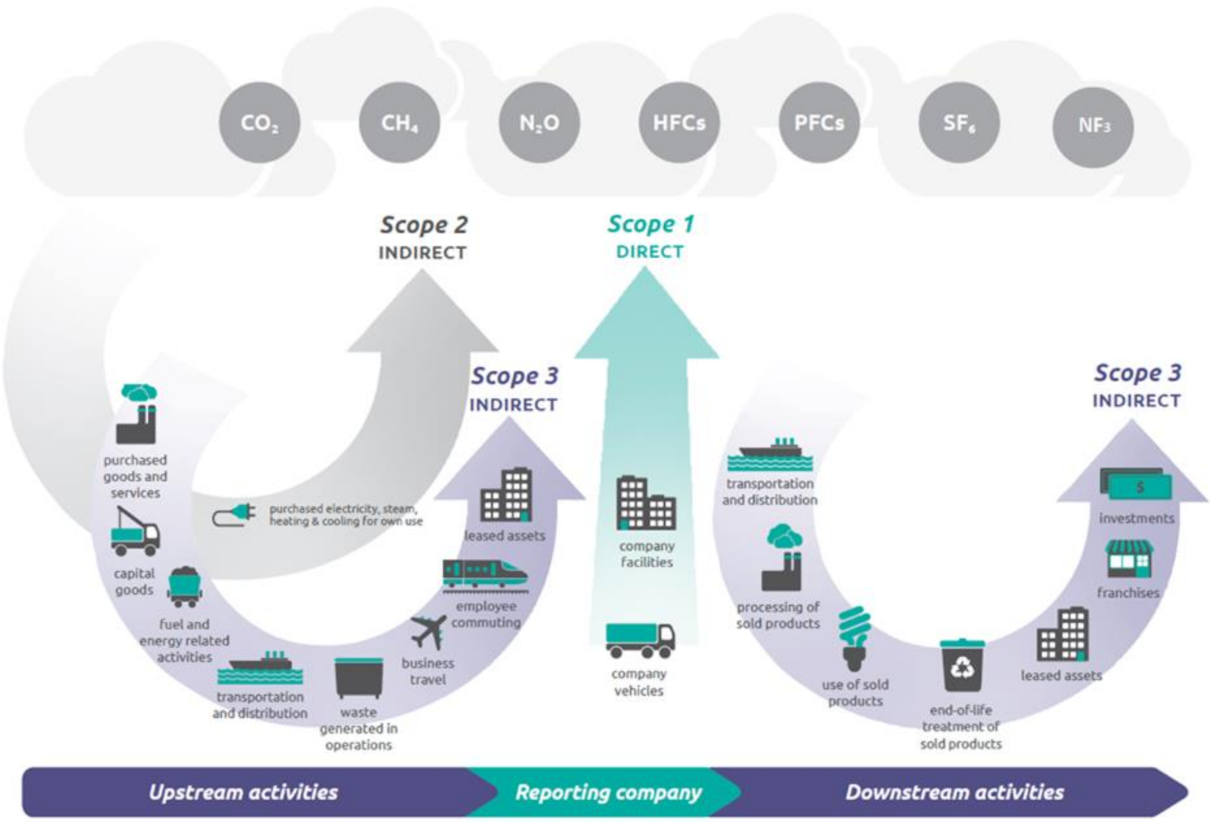

Figure 1 Overview of GHG Protocol Scopes and emissions across the value chain (WRI & WBCSD 2023b)

The GHG Protocol covers the accounting and reporting of seven GHGs covered by the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PCFs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) (WRI & WBCSD, 2023; Ecometrica, 2012). According to the GHG Protocol, all emissions of Scope 1 and 2 must be included in the CF analysis, Scope 3 is optional, however, it was included in the JLR SK CF analysis. The accuracy of the GHG calculation varies from item to item and area to area. In general, it can be stated that the precision of Scope 1 and Scope 2 is higher than that of the highly heterogeneous category of Scope 3. The normal level of accuracy of the calculation is 20%. This means that the actual CF of a company corresponds to 80 – 120% of the resulting calculated CF value. The degree of accuracy (validity) for individual input data and emission factors can be expressed using a scale as shown in Table 1.

Determination of the boundaries is a key initial step in any CF analysis. There are two principles for determining the boundaries of the analysis: (1) the control principle and (2) the equity share principle. We have used the control principle, which is a more common one for reporting 100% of GHG emissions from directly controlled operations. This applies primarily to Scope 1 emissions and partially to Scope 2 emissions. In the latter case, emissions can be influenced, for example, by switching the existing electricity supplier to a 'greener' provider or buying guarantees of origin (GoO) for fossil-free electricity.

Table 1 Accuracy of CF calculation

Degree of accuracy	Degree of accuracy
High	< 5%
Moderate	5 – 20%
Low	> 20%

The next step was to identify the emission sources. Here, we focused on obtaining the best quality data from different departments of the company (facility management, procurement, environmental management, material planning and logistics, finance, and human resources) on the consumption of individual items in the studied period.

Further, we have disaggregated emission sources and source data on consumption (or production – e.g., waste) by individual Scopes. Emissions related to direct (Scope 1) and indirect (Scope 2) energy consumption are mandatory from a GHG Protocol perspective, so we have paid the most attention to their collection and quality. Within Scope 3, we have identified the most significant and impactful emission sources and their corresponding EFs as follows:

– Category 1: Goods and services purchased or acquired; the EF was related to the volumetric unit of purchased materials; for components going into production, the EF was determined based on LCA analyses of these components provided by the parent company (since the material is sourced from the UK); for the local supplier of the workwear service, the company's specific CF was used.
– Category 2: Capital (investment) goods; the amount of finance and EF spent has been related to a unit cash cost converted by CenSA based on data from the DEFRA database, including the conversion of EF for inflation in the reporting year.
– Category 3: Fuel and energy-related activities not included in Scope 1 and Scope 2; EFs published by the EC Research Centre (JRC) per unit of energy were used.
– Category 4: Transportation and distribution (upstream); the EF was based on km of travelled distance geo-locally, i.e. specifically for Slovak Republic according to the SHMU, taking into account the load specific for JLR SK (tonne-km).
– Category 5: Wastes generated on-site (emissions from the reuse, material and/or energy recovery of the waste – avoided emissions, or emissions from the final treatment of the waste, have been accounted for); the EF was used, taking into account the treatment and disposal method specifically for the reported waste types in a reporting year from various databases (e.g. Ecoinvent, Base Carbone, BilanCarbon, DEFRA, SHMU, etc.).
– Category 7: Employee commuting; the EF was based on km of travelled distance geo-locally specific for Slovakia according to the SHMU.
– Category 8: Leased property (upstream); the EFs were based on the amount of funds and EF per unit cash cost, converted by CenSA based on DEFRA data, taking into account inflation in the reporting year.

As a general principle, we preferred geo-local EFs over generic (general data) e.g. from the Ecoinvent database. Only if Slovakia did not have a national EF for a given category, a more generic EFs were used.

Calculating GHG emissions based on verified and documented EFs is by far the most widely used method for determining a company's CF (WRI & WBSCD, 2023a). Direct measurement of emissions is practically not used for GHGs. In real use cases, many companies face a challenge due to the unavailability of adequate measurement sensorics (Alaoui et al., 2024). The sources of EFs for Scope 3 were very diverse, and it was always necessary to verify their credibility and recentness. We also used EF databases for some items. Following the GHG Protocol, the next step was to determine the appropriate EFs that express GHGs in tonnes of CO_2 or other GHGs per unit of energy or use other unit expressions (e.g., per mass or volume of product). These factors were further converted into the corresponding amount of GHGs expressed in carbon dioxide equivalent (CO_2e)

using the Global Warming Potential (GWP) of the corresponding gas. Some EFs were nationally specific (e.g., for electricity, it depends on the national energy mix, which varies from country to country and also changes over time) (Třebický, 2016). Following GWP values, based on IPCC AR5 (Assessment Report 5), were used: CH_4 = 28, N_2O = 265. Other GWPs were not relevant as other GHGs were quantified as zero or were also not relevant which is further explained in Results. The CF of an activity was calculated by multiplying the activity data (e.g., kWh of electricity consumed) by the EF for that activity (e.g., kg CO_2e per kWh of electricity). The calculation was undertaken in the first phase separately for each of the relevant GHGs. Next, these emissions were converted according to their GWP into CO_2e. This metric provided the resulting unit of the company's CF. The total CF was calculated as outlined in Equation 1:

$$CF_{ix} = AD_{ix}\ x\ EF_{ix}$$

$$CF\ CO_2e = CF_{ix}\ x\ GWP_x \qquad \text{Eq. (1)}$$

where CF_{ix} is the CF of the relevant GHG emission for item i and greenhouse gas x, AD_{ix} is activity data for item i and relevant GHG emission x, EF_{ix} is the emission factor for item i and relevant GHG emission x and GWP_x is global warming potential of relevant GHG emission x.

The following step was the normalization of the results. In this step, we normalised the total calculated CF of the company to selected key performance indicators (KPIs) of the company, namely: (a) CF per unit of turnover, (b) CF per active employee and (c) CF per vehicle produced. The normalisation of the results was also important due to the impact of JLR SK's ongoing growth or, conversely, the possible reduction of the company's production volume due to external “vis major” factors (pandemic, war conflict, disruptions in the supply chain).

3. RESULTS AND DISCUSSON

3.1 Results

As indicated in Table 2, the GHG emissions (CO_2, CH_4, N_2O) amounted to 18,583.85 tCO_2e (1.62% of total emissions in all three Scopes) in Scope 1 (direct GHG emissions from sources owned or controlled by the company) and 0.87 tCO_2e (0.0001%) in Scope 2 (purchased electricity with a guarantee of fossil-free origin) with an uncertainty level of <5%. Emissions of HFCs and PFCs have been quantified as zero while emissions of SF_6, and NF_3 were not relevant under Scope 1 and Scope 2.

The most energetically significant operation in Scope 1, was the Paint Shop technology (industrial treatment and painting of the vehicle body surface), accounting for 80% of the plant's total natural gas consumption and consequently emitted GHG emissions representing almost 7,8 million m3 of natural gas. Wendt et al. (2023) stated that painting processes contribute generally up to 73% of the total energy consumption in automotive plants. The second most demanding facility in terms of natural gas consumption was the Plant Energy Centre (operation of the central gas boiler house producing heat and hot water), with an annual gas consumption of 1,6 million m^3. The technological heating (repair cabins for painted car bodies at the Trim & Final operation) consumed 90 thousand m^3 of natural gas. In total, GHG emissions from the combustion of natural gas as a primary fossil energy source were almost 18,584 tCO_2e within Scope 1 in 2021.

Table 2 Emissions of key greenhouse gases (CO_2, CH_4, N_2O) in the Scope 1 and Scope 2 in 2021

Areas	GHG emissions tCO_2e	Degree of accuracy
SCOPE 1	18,583.85	< 5%
SCOPE 2	0.87	< 5%
TOTAL	**18,584.72**	

Initial (upstream) GHG emissions in the Scope 3 were 1,130,866.34 tCO_2e (98.38%) with an uncertainty level of 5 – 20%, as indicated in Table 3. It included categories 1, 3, 4, and 5 (goods and services purchased or acquired, fuel and energy activities not covered by Scope 1 and Scope 2, transportation and distribution, and waste generated on the premises). Categories 2 (capital goods) and 6 (business travel) were not included in the calculation due to the unavailability of accurate data. Further, an uncertainty level of >20% was achieved for categories 7 and 8 (employee commuting, leased property). Downstream GHG emissions in the following Scope 3 categories: transport and distribution, processing of the sold product, use of the sold product, disposal of the sold product at the end of its useful life, leased assets, franchises, and investments, have not been included in the CF calculation with the justification of their exclusion. In all cases, the uncertainty levels reflect the quality of the input data and the quality of the applied emission factor.

The most significant CO_2e emissions were monitored in categories 1, 4 and 2. Category 1 emitted almost 1.1 million tCO_2e (96.61%), Category 4 less than 15 thousand tCO_2e (1.38%) and Category 2 less than 6 thousand tCO_2e (0.56%).

Table 3 GHG emissions in Scope 3 in 2021

Categories	GHG emissions tCO_2e	% share of Scope 3	Avoided[2)] emissions tCO_2e	Degree of accuracy
Category 1	1,092,581.47	96.61		5 – 20%
Category 2	6,278.00	0.56		>20%
Category 3	5,519.57	0.49		5 – 20%
Category 4	15,569.32	1.38		5 – 20%
Category 5	5,634.25	0.50	-6,245.19	5 – 20%
Category 6[1)]	N/A	N/A		N/A
Category 7	5,283.51	0.47		>20%
Category 8	0.221	0.00002		>20%
Total	**1,130,866.34**	**100**		
Total (including avoided emissions)	**1,124,621.16**			

1) Business trips in the reporting year were made by company-owned vehicles, therefore, GHG emissions resulting from this activity were included in Scope 1.
2) Avoided emissions mean emissions equal to the difference between the emissions arising from the use and processing of the new raw material and the emissions arising from the use of the waste as an input in other processes

The total CF of the company was 1,149,451.1 tCO_2e, without considering the avoided emissions under Scope 3, category 5. Taking into account the avoided emissions, the CF was 1,143,205.88 tCO_2e, as outlined in Table 4. The avoided emissions in category 5 were quantified at -6,245.19 tCO_2e and these were calculated as emissions from the reuse, material and/or energy recovery of the waste, or emissions resulting from the final treatment of the waste.

The normalised overall CF results of the company per unit of turnover were 3.08 $kgCO_2$/1 Euro; 14.95 tCO_2e per vehicle produced and 309.81 tCO_2e per employee. Due to the inability to directly influence GHG emissions and the higher level of uncertainty (5 – 20% and >20%) in the Scope 3 categories, we also determined normalized CF values for Scope 1 and 2. The resulting CF value per unit of turnover was 0.16 tCO_2e/1 Euro. The CF per active employee was 5.02 tCO_2e and the CF per vehicle produced was 0.24 tCO_2e.

Table 4 Normalization of determined CF data for year 2021

Normalization	Values	Unit	Remark
CF of the company (all Scopes)	1,149,451.06	tCO_2e	Avoided emissions not taken into account
CF of the waste generated on site (Scope 3, category 5)	-6,245.19	tCO_2e	Avoided emissions
CF of the company (all Scopes)	1,143,205.88	tCO_2e	Avoided emissions taken into account
CF per unit of turnover (EUR)	3.08	$kgCO_2e$/EUR	
CF per active employee	309.81	tCO_2e/employee	
CF per manufactured vehicle	14.95	tCO_2e/vehicle	

CF (Scope 1 and 2)	18,584.72	tCO_2e
CF (Scope 1 and 2) per unit of turnover (EUR)	0.17	$kgCO_2e$/EUR
CF (Scope 1 and 2) per active employee	5.04	tCO_2e/employee
CF (Scope 1 and 2) per manufactured vehicle	0.24	tCO_2e/vehicle

3.1 Discussion

The importance of decarbonizing individual manufacturing industries has been highlighted by the scientific community for several years (Pineda et al., 2020). Gebler et al. (2020) developed a systemic understanding of an automotive factory and evaluated its carbon life cycle by applying the LCA to understand the drivers of Global Warming Potential (GWP). Hechelmann et al. (2023) linked economic and ecological considerations of measures in the context of automotive company-specific decarbonization strategies confirming energy efficiency and renewable energy sources as the most cost-effective measures. The authors further argue that for the successful development of decarbonization strategies, investment decisions should no longer consider the payback period, but rather the Greenhouse gas Abatement Costs (GAC). In the most extensive study to date, Bolay et al. (2022) established benchmarks based on corporate climate mitigation targets by assessing 2607 companies, including manufacturing, materials and power generation sectors. Results showed the importance of taking a sectoral perspective when determining or comparing target ambitions.

Lee (2011) initiated CF identification and measurement in the HMC supply chain, while Rüdele and Wolf (2023) compared the 2022 GHG emissions in tCO_2e per vehicle of eight of the ten OEMs with the highest number of sales worldwide. Based on their findings we can conclude, that the results of this paper (0.24 tCO_2e per vehicle) are comparable with „Production by OEM“ category which equals with Scope 1 and Scope 2 of GHG emissions of eight studied OEMs (results varied from 0.3 to 0.8 tCO_2e per vehicle).

As the results of the CF analysis showed, SCOPE 3 emissions were by far the most significant. These emissions also include purchased materials such as aluminium, the use of which in passenger cars is likely to quadruple by 2050, thus hugely increasing the emissions from aluminium production (Billy et al., 2023).

The fact that the company purchases electricity with the guarantees of fossil-free origin (100% hydropower), contributed significantly in decreasing of the Scope 2 emissions from 18,756 tCO_2e in 2020 to only 132 tCO_2e in 2021, which is drop of 99.3%. From an economic point of view, the annual cost of the fossil free electricity is about 350K Euro (as green premium cost) in addition to the standard electricity cost.

Following framework measures (technical, organizational) for reducing the CF of the company were identified but their further elaboration would require additional research. As supporting measures to further reduce the company's CF, we propose to electrify most of the processes, especially the Paint Shop technology. The natural gas combustion equipment (drying ovens, regenerative thermal oxidizers) should be replaced with electrical equipment. A key measure to significantly reduce emissions in Scope 3 will be the electrification of individual car models. However, as noted by Richert et al. (2023), protecting the environment by switching to electro-motorization makes sense only when cars are charged with fossil-free electricity and also the production of batteries for these cars and other components should have a zero-CF. The waste heat in individual processes should be recovered and transferred to electricity using for instance a thermoelectric generator as proposed by Liu et al. (2015). Another suggestion is to explore the use of renewable energy sources. The companies should consider the installation of photovoltaics to compensate for the baseload consumption of non-production electricity demand. Furthermore, available options to decarbonize electricity procurement should be considered and/or a switch from natural gas to biomethane which, as confirmed by Hechelmann et al. (2023), have the highest GHG abatement potential in Scope 1 and 2.

5. CONCLUSIONS

Reporting GHG emissions is a very important part of a modern company or organisation's environmental policy. It is crucial to keep track of what types of GHGs a company emits, in what quantities and over what time period. Regardless of the choice and combination of decarbonization measures selected, the resulting combination of measures will be specific and "tailor-made" for the analysed company, based on individual priorities, objectives, financial means and realities. The article outlined the carbon footprint analysis of Jaguar Land Rover Slovakia s.r.o. in 2021 based on GHG Protocol methodology. The inventory of GHGs (both direct and indirect) was categorised into three Scopes. The resulting data were normalized per unit of turnover per active employee and vehicle. The results of the analysis confirmed the premise of a majority share of Scope 3 indirect emissions (almost 98%) from the total carbon footprint of the company. The direct emissions within Scope 1 and 2 represent only up to 2% of total emissions. Reporting GHG emissions according to the international standard GHG Protocol is a good way to set up this process in a systematic way.

Understanding the emission sources and their distribution within each GHG Protocol Scopes has enabled the prioritisation of company targets for decarbonization. However, the main challenge is the decarbonization of core manufacturing processes, namely natural-gas powered Paint Shop technology. A corporate decarbonization strategy should be seen as a continuous process of adaptation, which is also confirmed by (Buettner, 2022).

Some research limitations also should be addressed. First, the main limitation of this analysis lies in the timeframe, which is one calendar year (2021). Due to the change in the legislative framework and the CF reporting obligation for the company from 2025 under the CSRD (data reporting for 2024), the quality and methodology of internal data collection for carbon footprinting will need to be further improved.

Disclaimer

The corresponding author is directly employed at Jaguar Land Rover Slovakia s.r.o. and has worked as an environmental manager in the carbon footprint analysis project of the presented case.

Second, improvements in the quality of input data under Scope 3 will be needed in Category 1 (in particular for other purchased services such as cleaning and housekeeping, catering services, and technical building management services), Category 4 (transport and distribution), Category 6 (staff travel) and Category 7 (staff commuting), but this would with a high level of probability confirm the dominance of the overall CF share in this area. Third, the design of this study used only JLR SK, which might potentially have created grounds for bias. Any potential bias introduced by limited number of cases cannot be explicitly ruled out. Further OEM's carbon footprint analyses are also likely to benefit from studies that are conducted in different countries and industries to gain research validity. Finally, this study relies heavily on self-reported activity level data provided by internal stakeholders, further studies could offer additional evidence that can be placed on the results reported here by employing a multi-case study approach for research reliability and validity.

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