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Availability and Need for Climate Footprint and Resilience Data from Suppliers in Automotive Supply Chains

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Abstract. This paper explores the challenges and opportunities of managing supply chain data for environmental sustainability and resilience in the automotive and vehicle manufacturing industry. It presents empirics from measuring and improving the climate footprint, based on data from interviews and workshops with original equipment manufacturers (OEMs) and suppliers, and compares concepts of resilience of supply chains. The paper focuses on the early phases of supply chain interaction, such as supplier selection and request for quota, when specific product data is often unavailable or estimated. It discusses the trade-offs and conflicts between the needs and availability of climate footprint and related supplier data, such as localization, energy supply, material supply and transportation. It also highlights the importance of data regarding recycled contents, materials, and energy in the supply chain. The paper is connected to projects funded by the EU and Vinnova that aim to enhance the competitive sustainability and resilience of the industry.

Keywords. Climate footprint, Automotive supply chain, Resilient supply chain

1. Introduction

The manufacturing industries, contributing to over 400 million tons of CO_{2eq} in the European Union (as per the manufacturing & construction industry data from EEA [1]), are currently under transformational pressure to become more environmentally sustainable and resilient to supply chain disturbances. As use phase emissions are being designed out in the automotive and vehicle manufacturing industry, the focus on supply chain emission control is intensifying [2]. This necessitates the management of a large set of environmentally related supply chain data. For efficient emission control, accurate data from diverse sources is required [3]. The supply chain data needed for climate footprint calculations, which include materials, locations, transportation etc., are also essential for certain aspects of developing more resilient supply chain systems [4].

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Supply chain data is required in various business phases such as supplier qualification, request for quotation (RFQ) (or request for proposal, RFP), industrialization, and performance evaluation of currently supplied products [5]. This research commences in the early phases of supply chain interaction when a product has not yet been supplied, and the agreement between the prospective supplier and the customer OEM is not finalized. Within a supply chain research framework, it presents concepts and frameworks currently being developed in industrial practice for climate footprint and resilience data. It aims to discuss and elaborate on the sometimes-conflicting needs of, availability of, and willingness to distribute climate footprint and related supplier data through the following research questions (RQs):

RQ1a: What environmental data that is needed for a climate footprint at the component level in the quotation phase?

RQ1b: What are the challenges of getting access to this data?

RQ2: With regards to development of supply chain resilience what data could be useful and possible to collect simultaneously with the environmental data?

2. Literature background

To disseminate the RQs, explanations of climate footprint and how it is calculated in different supplier-customer relational phases and resilience factors were summarized from literature.

2.1. Climate footprint

One of the most prevalent methods to evaluate the environmental performance of a product or organization is through Life Cycle Assessment (LCA). An LCA analyzes a product or part in a holistic approach with a life cycle perspective, encompassing different life cycle phases such as material extraction, manufacturing, distribution, use, and disposal [6]. The LCA can be utilized to assess various environmental aspects, with the recommendation to assess multiple aspects. The most assessed aspect is the effect on climate change, measured in CO2 equivalents, carbon footprint, or as here climate footprint. For fossil-fueled vehicles, the user phase generates most of the climate footprint, necessitating design changes by OEMs. With fossil-free drivelines, the focus shifts to the footprint from resource extraction and production.

In detailed studies, LCA is recommended for in-depth analysis of how to improve environmental performance [6]. The necessary LCA data is typically fed back to design when working with existing products and markets [7]. The data collected involves details and amounts of material and energy use as well as all types of waste and emissions generated in each operational step including transport and storage [8]. Administrative operations also need to be included. In early stages, new design or green field applications, some of this operational information is not known or available and must be estimated or simplified [9].

Environmental Inventory data is needed for modelling of the climate footprint. In LCA in accordance with the ISO 14040 or 14044 standards there are four major stages of the method: scope, inventory, environmental impact assessment and interpretation [10]. In the scope, a delimitation of the life cycle stages is common. When deploying e.g., LCA for manufacturing a “cradle to gate” delimitation of the life cycle phases is often used. The Life Cycle Inventory (LCI) phase requires high-quality data collection of input and output. The inputs should include energy and water use, raw materials, and process materials & services. Transports and distribution are often recorded as a separate service. The outputs should include products, waste, and emissions. The most important data for climate footprint of a manufacturing supply chain involves amount and type of energy used at each supplier and sub-supplier, type of and origin of materials used in each product and transportation data e.g., localization and transport mode for each product and customer [8]. To improve the environmental and climate footprint performance, increase of circular origin of material and selection of fossil-free energy for operations are the most important actions [11]. Thus, use of renewable, reused, and recycled components, materials and energy use need to be documented in the inventory phase. In upcoming product passport regulations these data are expected to be separately reported in addition to the climate footprint.

2.2. Climate data in different supply chain business stages

Proactive procurement involves different stages of business relation between customer and supplier. The customer first identifies a need, then initiates a relation with a supplier (here referred to as supplier qualification, SQ), then it obtains lowest total cost assessment (including e.g. environmental reputation) for a certain product (here referred to as request for quota stage, RFQ) and finally ensures material and services will have a secure supply (here referred to as industrialization phase) [12].
Different business phases necessitate different environmental output data in each phase. Typically, in supplier qualification there may be requirements of environmental management certification, and company-level greenhouse-gas (GHG) report. In the RFQ-stage adherence to hazardous substance lists and chemical material composition reported in accordance with IMDS (international material data system) is often required if available, and recently also preliminary climate footprint [13]. The industrialization stage often details the supply chain data and sub suppliers and transports may need to be reported with detailed climate footprint prediction. Sub-suppliers are here suppliers' upstream suppliers or tier 'n' suppliers [14]. When a product is in full production often actual environmental reporting of climate footprint in accordance with GHG for the company and sometimes EPD (environmental product declaration) or similar data may be required, including actual climate footprint for a produced part [15]. Similarly, in these business phases we may want to get some resilience measures on a company level, preliminary and detailed resilience prediction (or risk analysis) of a product.

Company general data can be applied in early contact phases such as supplier qualification and request for quotas. In these phases, however, specific reliable product related LCA data are often unavailable and must be estimated from already supplied products performance, manufacturing performance data estimations and estimated material compositions [15]. In addition, general information around upstream sub-suppliers and their locations is less visible and less known in the RFQ phase [14].

2.3. Supplier data for improving supply chain management resilience

Resilience of a supply chain can be said to consist of different processes to overcome disturbances or breaks in the system and achieve supply security. Mainly resilience concerns the disturbances that are unexpected or unplanned for. Supply security can be increased by multiple sourcing or through closer supplier relations, but it also depends on which type of supplier and where it is located [5].

Survival and recovery of disruptions is essential for organizations [16,17]. Resilience does not necessarily mean to bring a disrupted state back to normal (as it was before the disruption), but it may also be to transform it to a new state [17]. Assessing supply chain resilience may concern assessing various themes, *supply chain; health, risk, recovery,* and *adaptability/transformability* to changing and new states [18]. Supplier health can be assessed with financial metrics such as Altman Z-score, with data taken from suppliers' financial statements (often publicly available). Supply chain risk and recovery may also be assessed using process metrics, such as the established SCOR model's value at risk metrics [18]. These, however, require access to, or estimation of, supplier specific quantitative process data which are seldom accessible. When it comes to long term supply security, the access to data about material content and supply chain visibility of critical and conflict materials may be important [19]. In addition to these quantitative metrics, it may be valuable to assess different supplier capabilities, strategies or characteristics which can affect supply chain resilience. These strategies can be supply network focused, which includes mapping the ability of the wider supply network or be supplier-focused which means assessing the capability of specific suppliers.

One group of strategy methods aim to increase information and knowledge about what, when and where external events may happen, and what effects they will have. This enables risk preparedness and alerts on events may enable early detection and response. Geopolitical risks can also be related to specific geographical locations of suppliers. By such knowledge, events are moved from being unexpected into being expected and be planned for [20]. Another group of strategies are concerned with how to prepare for, handle and reduce negative impact from events that cannot be expected or planned for.

Known strategies for reducing impact of disturbance is to keep redundancies in a supply chain, keep safety stocks, enable transport re-routing. Here supply market intelligence [21] including knowledge of the total amount of sub-suppliers for each type of raw material, the location of active and potential sub-suppliers and the transport routing data can be important to improve supply assurance.

As the critical importance of the materials sourced from second-tier supplier to the OEM increases, the specificity and criticality of the sourced materials also increases [22]. Knowledge about sub-supplier network, locations and volumes is often seen as business-critical information and suppliers usually do not want to state their sub-supplier data to their customer in order to not get circumvented [14].

3. Method and data collection

This paper's empirics is grounded in workshops and data collection trials with suppliers supplemented by interviews and a workshop with automotive and manufacturing original equipment manufacturers (OEMs).

3.1. Workshops and data collection trials with suppliers

During eight months in 2023, workshops led by environmental/LCA-expert coaches and data collection trials, performed by company representatives, were conducted with small and medium sized enterprises (SME) suppliers, focusing on the collection of data necessary for calculating climate footprints. All companies were SMEs and automotive industry suppliers and participated based on engagement in sustainable development. This data, which included supplied materials (type and qualities), transportation (frequency, mode, and distance), and energy (type and supplier), could be estimated for future products. These supplier workshops were part of a climate footprint project coordinated by The Scandinavian Association for Suppliers to the Automotive Industry.

The results presented in this paper concentrate on the precision, availability, and timeframe within which this data can be acquired. Life Cycle Assessment (LCA) consultants utilized the inventory to construct a simplified cradle-to-gate LCA-model in Sima Pro (https://simapro.com/) or LCA for Experts (https://sphera.com/life-cycle-assessment-lca-software/). This LCA-model, which employs a simple cut-off for waste, used either certified climate data from sub-suppliers or, more commonly, general Ecoinvent data for materials and energy. Subsequently, a climate footprint calculation model was developed that could simulate the climate footprint to produce a new product in the factory based on the production volume and mix for the previous year. Twenty-four companies underwent a brief introductory course on data collection. They then attempted to collect data independently using their respective Enterprise Resource Planning (ERP) systems and other internal sources. The inventory dataset adhered to a full company inventory in accordance with an initial environmental review [23]. However, some data from the full inventory was omitted; permits, accidents, and employee travel were excluded while all material inflow and outflow (amount, type, supplier distance, and transportation mode) for productive materials, chemicals, process consumables as well as products, waste, and recycled materials were collected. Additionally, suppliers and volumes of all energy input (electricity and fuels) and externally purchased transportation services were gathered. Equipment and buildings that are not typically included in an initial environmental review were not included.

Three of the companies withdrew due to internal organizational reasons (e.g., contact persons going on parental leave or changing roles or jobs). Three companies did not manage to complete the full inventory on time, while eighteen companies managed to collect sufficient data to calculate the simplified climate footprint.

3.2. Interviews

Interviews were conducted with personnel from three different Swedish automotive and vehicle Original Equipment Manufacturers (OEMs), focusing on the OEMs' needs and preferences for data pertaining to climate footprint. The three largest automotive OEMs producing in Sweden were asked to participate. The analysis of these interviews involved a comparison of responses with regulatory demands and industry standards as presented in literature, regulatory reports, and conference presentations and workshops.

Of the four OEM interviewees focusing on environmental data, two had roles in supply chain and purchasing, while the other two were environmental and life cycle analysts. The interviews commenced with a series of open-ended questions, although the interviewees were free to discuss other related issues. Detailed notes were taken during the interviews, but an exact transcription was not made. Subsequently, an analysis was conducted based on the responses to the following initial open-ended questions: 1. What climate-related information do you need from component manufacturers today? 2. What information will you need in the future (e.g., in 5 years)? 3. What drives you to ask for this data? What do you use it for? 4. What data is easy and difficult to get from suppliers? 5. Do you see that it could be a competitive advantage for your suppliers to have climate footprint data sheets for their products? 6. What sustainability-related frameworks/protocols or similar do you report on today? In the future? 7. What are your thoughts on a simpler type of climate declaration for components (does it need third party verification)? Do you have any thoughts on how it would need to be designed to work well? 8. Is there any other information that would help you more? 9. Are you interested in information on something other than climate? 10. Are you requesting any data related to social sustainability in the supply chain? 11. Are you aware of other similar initiatives?

The responses were analyzed based on how different roles answered to: A. Rationale for collecting climate-related information from suppliers. B. Current importance of climate-related information from suppliers. C. Additional information of interest. D. Importance of verification E. Competitive advantage and benefits of climate data sheets.

To collect additional data about resilience measurement we conducted interviews and a workshop with four supply chain management (SCM) personnel of large OEMs. The overall question was: “What data is the most important to retrieve in order to improve resilience of SCM?”.

4. Results

4.1. Time span for answering RFQ

In workshops with suppliers, when queried about the most common time frame suppliers must respond to a quota, the responses varied between two days and four weeks, with a median response time being about two weeks. This implies that most data used in the quota phase need to be collected and prepared in advance. Upon receipt of a request for quota, a conceptual design must be created with a proposed Bill of Materials (BOM) and Bill of Processes (BOP) for the offered product. Within this time frame, the preliminary climate footprint must also be delivered, along with any other responses concerning supply risks and vulnerability. Due to time constraints, all inventory life cycle data needed for climate footprint had to be prepared based on the previous year’s summary. The climate footprint for the new product was then simulated using the new product’s BOM and BOP but with footprint base data from the previous year.

4.2. Data Availability and Challenges in Data Acquisition

Data was collected on all supplies of raw materials, energy, water, chemicals, and process materials (consumables and maintenance materials). Reports and invoices from energy companies provided information on energy amount and type. Waste volumes and waste transport data were obtained from reports and invoices from waste management suppliers. Inventory data on type and weight of raw materials, place of sub-supplier origin, and sub-supplier transport mode of existing material were readily available in most cases.

Eighteen companies managed to collect all the data required. Several of the eighteen struggled with some of the actual inventory data for the current production mix. There was also a problem acquiring an input-output balance where logged output in some cases was higher than logged input. A few had to do simplification of small amount of process materials and material categorization of waste, etc. However, one company that entered late, managed to extract data from its systems within one month, which shows that stable and digitally mature companies can gather data quite fast. The reported challenges that one or several of the companies encountered are summarized in Table 1. Worth mentioning is, regarding the chemicals and process fluids, the safety data sheets (SDS) only must contain information regarding hazardous substances. That might be a relatively small amount of the chemical (in some cases <0,5%). For some chemicals, the

SDSs were not a way forward due to too little usable information in SDS. Instead, personal contact with engineers with knowledge of the actual use case and function were used to figure out if it was an organic or inorganic chemical etc.

In addition to specific problems mentioned in Table 1, there were also issues around digital maturity at a smaller fraction of the companies. The ability to collect data from several sources and summarize them in the ERP was mentioned as a development need. Transport fuel and sub-supplier factory footprint or even sub-supplier energy type and use have not been available in most cases. These data may be available upon request but take longer to obtain. The same applies to recycled content in raw materials.

Table 1. Input data unavailability in one or several of the case companies

Input data wanted	Problem encountered	Proposed solution/comment
Chemicals type	Chemical content not known only brand name	Look into each chemical SDS, which helps sometimes.
Raw material type	Material content not known only brand name	First look for technical data sheets, then in practice, google the brand name to find them, or ask supplier
Raw material recycled %	No data for recycling available	Calculate conservative 0% recycled content and ask for supplier spec until next year
Spill %	The material balance does not fit due to unknown content of waste and variation in stock balance	Check stock, investigate waste material content, find lost material flows
Subcomponent weight	Unknown weight of subcomponents	Weigh all subcomponents or ask for supplier spec until next year
Sub-supplier location	Several suppliers can be used selection is not ready in quota phase	Use regular last year supplier or do several scenarios in calculation
Transport mode	Several transport types are used between sub-supplier and supplier	Model as mixed transport mode
Waste material content	Unknown material mix in waste fraction	Estimate or do a waste sampling analysis
Input – output balance	Logged input lower than logged output	Check real weight of outgoing products and scrap, recheck input inventory including packaging
Weight of outgoing products	Total weight of outgoing products often not easily extracted from systems.	Weigh single components

4.3. Description of environmental conversion data problems

The climate footprint calculation model developed uses EPD-data from sub-suppliers when available. This was seldom the case. Many companies had one or a couple (out of hundreds) of inputs where sub suppliers could give EPD, full LCA or equivalent data on their material/energy. When EPD is not available a secondary general dataset for climate footprint of that type of material/energy. In the first trials the companies' representatives (industrial practitioners) tried to find open data on conversion factors. This was assessed in the development phase and large errors could be found when using different open sources of climate footprint factors for materials, components, and processes. It was found that competence in judging data-quality and judging data-applicability was not enough among the industrial practitioners to find conversion factors with high quality enough to pass validity demands and customers data quality expectations. Although not good enough for the RFQ purpose, the open data were useful to educate industrial practitioners and good enough for internal hot spot analysis and prioritize improvements.

To reach a higher data model quality, professional databases for LCA data were used, for the needed secondary data. Professional LCA consultants extracted the conversion model out of commercially licensed databases (Ecoinvent). Conservative secondary data were chosen when e.g., recycled content or electricity mix were not known. Using consultants was considered time efficient without compromising the understanding of environmental impact for the industrial practitioner. Using licensed databases however meant that a non-transparency in the model were introduced not to leak any of the original datasets. In order to validate the models, the licensed datasets were shown to the validating agency not to the industrial practitioners. There were still some data issues in finding the conversion factors which are summarized in table 2.

Table 2. Challenges in obtaining conversion factors.

CO2eq conversion factor	Problem encountered	Proposed solution/comment
Chemicals type conversion factor	Difficulties to find appropriate ecoinvent data	For significant ones look into chemical datasheet. Simplified approach to divide chemicals that could not be found in larger groups such as detergents, lubricating oil, inorganic and organic chemicals then look up base chemical
Electricity mix	Mix said to be “green” but certificate of origin/production mix is not specified	Ask supplier for EPD, certificate of origin including specific mix or use conservative Ecoinvent data (residual country mix)
Recycled plastics	Lack of representative data for many types of recycled plastics	Use proxies for other similar plastic types (e.g. recycled polyethylene as proxy for recycled polypropylene)
Electronics components	Difficult to know if database data are representative. Many datasets are old.	Old database data is a problem for emergent technologies, need to be cautious of this problem.
Electronic components	Database data is missing for several electronic components	Check if the actual component is active or passive and use generic dataset for active or passive electronic components.

4.4. OEM interviews demands on data

A. Rationale for collecting climate-related information from suppliers

Both purchasing and supply chain personnel, as well as environmental and LCA experts, concur that the primary motivation for collecting climate-related information from suppliers is rooted in the company’s sustainability values, strategies, and goals. Environmental and LCA specialists also cite external agreements such as the Science Based Target Initiative (SBTi) (based on the GHG protocol [24]) and forthcoming EU legislation, e.g., on product passport data.

B. Current importance of climate-related information from suppliers

Most interviewees indicate that the volume and type of material and energy, particularly the rate of renewable/recycled content, are important, although obtaining this information remains challenging despite its mandatory nature under the automotive ELV directive. The rate of recycled content appears to be more important than the climate footprint. Material efficiency or yield in the supply chain is another desired input. One interviewee notes the absence of standardized alloy names in the IMDS data. Some companies have initiated trials to incorporate a climate footprint for certain components, while others estimate their own climate footprint based on IMDS material data, particularly for aluminum, steel, and cast-iron components plus electronics and batteries. They identify issues with availability and standardization in component-level climate footprints. One interviewee mentions that IMDS data is only available for products in full production, not in the quotation phase.

C. Additional information of interest

All interviewees mention recycled content, which is climate-related information. Other than direct climate-related information mentioned is CSR related, social and ethical issues like conflict minerals and good working conditions at all sub-suppliers. Localization of sub-suppliers and risk assessments for unexpected disturbances are mentioned by supply chain and purchasing roles. Some interviewees mention the difficulty in obtaining this information from Tier 2 or higher sub-suppliers since they only have a business relationship with the Tier 1 supplier. The need to access information from further down in the supply chain is increasing.

D. Importance of verification

All interviewees prefer to receive validated/verified climate footprint data. Some mention that data quality needs to be evaluated. Some form of third-party verification and a standardized calculation format is needed if environmental and LCA responsible are to use climate footprint data. Digitalized information seems to be more important than formal verification. Own estimations are used to compare with climate footprint given by suppliers. If the difference is too large, additional questions are posed.

E. Competitive advantage and benefits of climate data sheets

Interviewees believe that to a certain extent a low climate footprint can compensate for a slightly higher price per part. Transparent continuous reporting will be an advantage but only if it is given in a standardized format, preferably in digitalized format for automatic analysis.

In short, empirics from interviews can be concluded in that environmental personnel desire better quality data than currently is available in the RFQ stage, while purchasing personnel desire data that is simple to compare, e.g., validated standardized numbers.

4.5. Resilience data needs and opportunities

In the OEM SCM specialists' interviews and workshop, the most important input data needed to improve SCM resilience was discussed. Although transport modes, number of parallel suppliers and material availability were mentioned, the most critical data needed to assess and improve SCM was considered the location of suppliers in the supply chain for each material stream or segment. However, this data was not easily accessible – not even for existing suppliers. Supplier specific capacity and financial risk data, that was motivated by the literature, was not considered as critical in early phases. Other resilience data discussed, but perceived difficult to collect in early phases, include the ability to track and trace shipments and supplier data about social and ethical aspects.

5. Analysis and discussion

5.1. What environmental data is needed for a climate footprint at the component level in quotation phase and what are the challenges of collecting it?

For stable manufacturing SMEs, most of the data needed (inbound and outbound transports for tier 1, and supplies of raw materials, energy, water, chemicals, and process materials) to do a rough estimate of the climate footprint is available, within some limitations. Some other upcoming data-need in product passport need further inquiry. In many but not all cases the rate of recycled and renewable content was known, but sometimes it was hard to know the quality of such numbers. In most cases sub-suppliers' energy types were not known, but own energy supply was known in all cases.

To be useful, all suppliers answering an RFQ need to calculate climate footprint according to the same method standard. Similarly, suppliers mention they prefer to calculate in the same way to all customer OEMs. This need for commonality is in line with similar problems found earlier with risks of diverging standards for EPDs [15].

Since production is estimated from previous years' data, the overall climate footprint of the plant, e.g., the production mix regarding operations and volumes need to be stable. To assure volume stability, economical figures of the supplier can be assessed, while mix stability may be more difficult. If the company submit yearly environmental reports for two or more years, it may give a good indication.

To get climate footprint from the first-tier supplier based on simplified LCA (which includes data from second tier supplier data) may give better input than using estimated IMDS data, especially since at least for the first-tier supplier, material losses and recycled amount are included in modelling which is missing when using IMDS [13]. On the other hand, IMDS can give improved insights on material content. It is still difficult to obtain correct IMDS in the quota stage according to the empirics.

Primary EPD data for climate footprint of materials and energy were generally not available and conservative secondary commercial database data (e.g., Ecoinvent) were used instead, this usually means that SME-suppliers need to use LCA consultants which may give longer lead times and external costs for producing a climate footprint. An alternative would be to provide the raw input data to the customer. Customer OEMs mentioned supplier reporting for the plant according to GHG, especially in the SQ-stage. In inventory according to GHG, the inputs are categorized into three scopes, one, own emissions, two purchased energy and three all other inputs and outputs, with, eight upstream and seven downstream subcategories [24]. To transparently report the raw data on inputs and outputs accordingly for each supplier and sub-supplier may be wished for by OEMs and may also be possible to achieve for follow up of ongoing contracts in full production, but in the quota phase with no signed agreements it is not advised to give out data on e.g., sub-suppliers [14]. In this study GHG categories were not used, when it comes to e.g., personnel commuting, it may give some input to vulnerability. Many of the suppliers involved were hesitant to show who their suppliers were to customers, especially before long-term customer agreements were signed.

5.2. What supply chain resilience development data could be collected simultaneously with the climate footprint data?

The collected data on climate footprint is only to a lesser extent useful for assessing and improving resilience of the supply chain directly. The actual climate footprint number does not give any support in a resilience assessment. The raw data collected on type of materials, existing suppliers, location of supplier, transport modes, energy supplies etc. could be useful to assess the vulnerability of supply. It gives qualitative and quantitative information of the tier 2 supplier, such as location, company name, volume of supply and type of supply, which could be used as input to qualitative assessment of the tier 1 supply redundancy and vulnerability. These data are, as mentioned above, not advisable to hand out to the OEM customer before business agreements are signed. Especially location of suppliers for each material stream is seen as useful, but this data is difficult to achieve for the OEM also for existing suppliers. The results show that the supplier may be supported in a vulnerability analysis by collecting the raw data needed for climate footprint, but the OEM customer will not be helped in the quota phase unless either the raw data is shown, or a standardized vulnerability figure is reported together with the climate footprint. An alternative is to pinpoint the regions of the sub-suppliers' factories, which can then be of interest for SCM resilience of the OEMs. In the industrialization phase when an agreement has been signed, often (but not always) the raw data from inventory can often be released. Here also using IMDS for extracting volumes of critical materials is suggested by de Oliviera [19]. If IMDS is used together with data on volumes and tier 1 and tier 2 suppliers' location and it may give insights to potential vulnerability.

Consequently, the data that can be collected simultaneously with climate footprint could support assessment of supply chain risk and health, while it gives less support for supply chain recovery, adaptability or transformability to changing and new states.

6. Conclusion

Calculation of climate footprint for specific products/components is challenging for SME suppliers in the quota-stage in the automotive industry. Input data on chemical composition, recycling rate and weights and material mix of outputs (products and waste) can take time to obtain. The alternative, to use IMDS may have gaps in the quota stage but can be complementary input in later stages supporting some resilience monitoring (critical materials). For suppliers with relatively stable production regarding material and process mix, a climate footprint was possible to calculate based on previous year's production data, and on existing raw material supply. OEM customers prefer third party validated numbers. Some of the raw data needed to evaluate the climate footprint seems valuable also when assessing resilience of the supply chain, especially supplier network location data, for different types of materials. However, important resilience related data is rather connected with general supplier company data collected in the economic risk evaluation done in supplier qualification stage. Further research on efficient data collection for resilience and sustainability is suggested. In the quota phase the data on sub-supplier network for the component/product may not be advisable to communicate until agreements are signed.

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