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A Qualitative Assessment of the Deployment of Zero-Emission Heavy-Duty Trucks in Logistics—Deriving Recommendations for Action from a Socio-Technical Approach on the Regional Level

Christoph Müller

Energieinstitut at the Johannes Kepler University Linz, Altenberger Strasse 69, 4040 Linz, Austria; mueller@energieinstitut-linz.at

Abstract: Although different European and national policies have set targets for a shift from fossil fuels to zero-emission heavy-duty trucks in the transport sector, their share is still rather low and mainly on a project level. The process of changing human perception in freight transport goes beyond the often discussed technical or economical aspects and demands research activities and perspectives from different stakeholders. Therefore, this paper delivers a stakeholder analysis together with a qualitative comprehensive analysis from different perspectives. It reveals the influence and importance as well as the general attitude of identified stakeholders concerning zero-emission heavy-duty trucks in logistics on a regional level in order to identify changes and barriers and to derive recommendations for action. The carried out socio-technical approach uses and adapts existing and approved scientific approaches with the general aim of creating a holistic assessment to accompany the development and implementation of zero-emission drive-systems in the transport sector.

Keywords: zero-emission; heavy-duty trucks; stakeholder analysis; socio-technical analysis

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1. Introduction

Towards sustainable development, the transportation sector represents the greatest challenge in Europe to achieve a climate neutral continent by 2050 in line with the Paris Agreement. Transport emissions must be reduced by 90% compared to 1990 levels which corresponds to a reduction from 828 to 82.8 million tonnes of CO_2 equivalent [1,2]. As in the upcoming years transport demand is still expected to grow significantly, targeted decarbonization is of correspondingly high importance [3]. For this reason, in order to achieve a targeted reduction in GHG and CO_2 emissions, the European Union has, for the first time, set a CO_2 limit for newly sold heavy-duty trucks and the values that need to be achieved are a reduction of 15% by 2025 and 30% by 2030. The reference period will be monitoring data for the period from 1 July 2019 to 30 June 2020. In this context, CO_2 emissions from heavy-duty trucks represent about one quarter of total road transport emissions [4].

In 2021, 93.4% of all new-registered trucks in Austria were powered by diesel and only 4.3% by alternative fuels, with battery-powered powertrains accounting for 84.8% and no hydrogen fuel cell solutions were included [5]. Although there is an increasing trend in alternative drives, the actual registration figures and especially the ambitious measures in the area of heavy-duty trucks are still far behind expectations. Therefore, for the achievement of the different national and international decarbonization targets, a successful decarbonization in road-freight transportation requires a wider, holistic, and cross-disciplinary approach. Consequently, the present study analyses the transition to zero-emission trucks from a socio-technical perspective, which integrates technical aspects with social science or behavioral perspectives and is especially of great importance to the

diffusion on new, innovative technologies [6–8]. Heavy-duty trucks based on batteries and hydrogen fuel cells are the two locally emission-free opportunities in freight transportation.

Due to its strong industry, the amount of exported goods and its geographical location in the middle of Europe, Upper Austria has the optimal prerequisites for a targeted consideration of the transition [9]. The present analysis provides a scientific contribution to the transformation of the transport system at a regional level. A comprehensive picture of the intended practical use of zero-emission heavy-duty trucks in road-freight transportation emerges and aims at optimal applications within the regional system boundaries [10]. Transition studies with the intention of decarbonization are a growing field in academic research to investigate possibilities to transform large socio-technical systems. Multiple actors with different visions and expectations are involved in such structural processes [11]. Decarbonization of transport systems is one of the most important international challenges and in this context; researchers, policymakers and other stakeholders view a widespread transition as both feasible and socially desirable [12].

Several studies have been carried out on stakeholder analysis concerning the use and implementation of zero-emission drive systems. Impact assessments of stakeholders under various scenarios highlight that the transition to electric vehicles is going to be challenging especially for governments and the automobile industry. For the electricity sector, it is expected to open new business opportunities [13]. Moreover, multiple perspectives can exist within and across stakeholders in the same line of profession. This implies for policy makers that working together with a few stakeholders will not cover all the perspectives that are available and needed for a structural transition to zero-emission systems in road transportation [14]. The identification of all relevant stakeholders and the interaction among them are key factors [15]. According to the results of a case study in China, technological level, policies and regulations, consumer acceptance and expectations, price and models, market structure and competition are critical factors influencing the diffusion of electric vehicles, which should be emphasized by governments and the automobile industry [16]. In an analysis for the successful implementation of liquified natural gas as an alternative fuel in Austria, 16 stakeholders are classified and listed according to their attitudes towards introduction into the current system. These are also essential for the introduction and application of other alternative fuels. For this purpose, three categories, namely proponents, opponents and neutral stakeholders were used with the result that competitors, residents and activists, respectively, and environmentalists are classified as opponents [17]. Another study identified and evaluated in total nine stakeholder groups concerning a shift and rapid uptake of electric vehicles. As a result, petrol producers and manufacturers of conventional vehicles with combustion engines were evaluated with a negative attitude, where renewable energy producers or electricity suppliers were positive influenced [18]. For a smooth transition to zero-emission vehicles, synergies between stakeholders are key, as these changes are going to affect them in different ways [13].

In this context, scientific papers deal with the operational introduction of battery passenger cars [19], light commercial vehicles [20–22] and trucks [23], but also with battery-powered plug-ins [8] and fuel-cell trucks [24]. While electric drive systems are a promising technology from an environmental point of view, their limited range leads to various practical challenges for enterprises. Despite that there are national purchase incentives, they may not lead to significant uptake as users need to lay down considerable effort to make the vehicles work for daily operations due to the limited technological readiness. On the other hand, higher purchase costs are not the main barrier but in countries without incentives and less favourable energy costs, the diffusion of alternative drive systems will likely not start [19,20]. In addition to range concern issues, vehicle operators' perceptions and acceptance of alternative drive systems are affected by other concerns, such as queue, payload and grid anxieties [22]. In general, positive attitudes and subjective norms towards alternative vehicles, perceived familiarity and perceived operational ease play a key role for adoption [21]. Support during the introduction and the general information policy on the vehicles are also mentioned as barriers and important factors. Although many

potential users may be interested in zero-emission trucks, the first priority of the commercial vehicle user is the fulfilment of the daily operations tasks and therefore, the use of what is considered a novel technology may be avoided [8]. In addition, the consideration of hydrogen fuel cell powered vehicles is in this context only addressed by one study [24].

Specific challenges for a roll-out are, beside the high purchase price, mainly due to the cost-intensive fuel cells and hydrogen tanks, and the lack of hydrogen refuelling infrastructure. Here it is also indicated that more research is needed to understand how much infrastructure is needed to support uptake in the early market [24]. Especially in the deployment phase, when the charging infrastructure has not yet been developed, a commercial vehicle fleet is particularly favourable for electrification as there is little need for public charging stations [8]. The number of electric vehicles in a country is not necessarily in proportion to the number of available electric charging stations but it is ascertained that there is a strong correlation between the country's GDP and the number of stations [25]. Charging time is essential for adopting a battery truck, as waiting time can disrupt the supply-chain operation but also standardisation of the batteries is one of the biggest challenges for manufacturers [23]. All the mentioned studies considered qualitative methods, such as conducting expert interviews including secondary literature data.

As can be seen from the existing literature that a holistic identification and evaluation of stakeholders concerning zero-emission heavy-duty trucks on regional level is missing. In this sense, the present paper brings together the following contributions:

- On the one hand, the innovative content of the present socio-technical analysis lies in a holistic identification and evaluation of stakeholders concerning the implementation of zero-emission heavy-duty trucks in logistics on regional level for the province of Upper Austria. In addition, an 'ambivalent' attitude of the stakeholders, i.e., neither supportive nor opposing, is assessed.
- On the other hand, the applied qualitative research methodology has been designed for the assessment of emerging technologies and for this reason, it represents the appropriate model for the current analysis as it contains a multi-disciplinary approach to stakeholder analysis, with STEEP analysis, SWOT analysis and an adapted TOWS matrix. A comparable integrated framework has never been applied in transportation studies before.

The general objective of the socio-technical evaluation within the presented framework is to identify, based on stakeholder analysis, potential opportunities and barriers of zero-emission heavy-duty trucks in order to be able to derive general recommendations for action. The transition towards decarbonization in road-freight transportation is a complex process and the present analysis combines in a practical-driven way stakeholder-evaluations and semi-structured interviews.

The paper is structured as follows. Section 2 elaborates the research methodology with all its different modules and combined approved approaches including the basic literature and the research focus. In Section 3, the results of the different steps and the main recommendations and measures for the introduction of zero-emission heavy-duty trucks are discussed. Finally, Section 4 summarizes the results with relevant conclusions.

2. Materials and Methods

Through the qualitative involvement of various experts, the analysis determines respective strengths, weaknesses, opportunities, and threats of zero-emission heavy-duty trucks for the targeted derivation of strategies and measures at a regional level. The roll-out of locally emission-free technologies is currently failing in freight transport due to different criteria [26] and the model used is therefore suitable for their clear identification. The main part of the present paper is the identification, categorization and evaluation of stakeholders combined with expert interviews for the generation of a holistic result.

In the present paper, a hybrid methodology combining and adapting already existing and approved approaches with the general aim of creating a holistic assessment to accompany the development and implementation of technologies is carried out. The

socio-technical model called SAMBA (socio- and multicriteria model for reducing barrier analysis) offers a qualitative, empirically based analysis to find out more about the effects of new technologies, processes, products, or services. In order to achieve this, the used model combines stakeholder analysis, STEEP analysis, SWOT analysis and TOWS matrix. STEEP analysis, which stands for an assessment of sociological, technological, environmental, economic, and political dimensions [27,28], helps in the present analysis for the identification of a preliminary set of indicators needed in the interviews with different experts. A comparable integrated framework combining the three basic approaches is also used in other research, e.g., for the development of future sustainable scenarios of transformation [28] or a stakeholder-based approach managing conflicting values in an urban design processes [29], but never applied in transportation studies before. Furthermore, an adapted TOWS matrix helps to develop strategies based on the connection between the identified strengths, weaknesses, opportunities, and threats. SWOT analysis and TOWS matrix are combined in other research for the formulation of strategic initiatives [30,31], interventions [32], or regional recommendations for the implementation of biodiesel production [33]. The overall objective of the hybrid methodology is the identification of influencing factors concerning emerging technologies, processes, products, or services to facilitate a successful implementation.

As shown in Figure 1, the model consists of four different steps: Module 1—definition of a starting point; Module 2—stakeholder analysis; Module 3—STEEP analysis; and Module 4—comprehensive analysis. In Module 1, in addition to the description of the object of the investigation, both goal and scope of the analysis are defined including a definition of the system boundaries. Module 2 encompasses a stakeholder analysis, whereas the STEEP analysis is elaborated in Module 3. Modules 2 and 3 are linked to the comprehensive analysis in Module 4, where the analysed strengths, weaknesses, opportunities, and threats are the central inputs for deriving measures and recommendations for action.

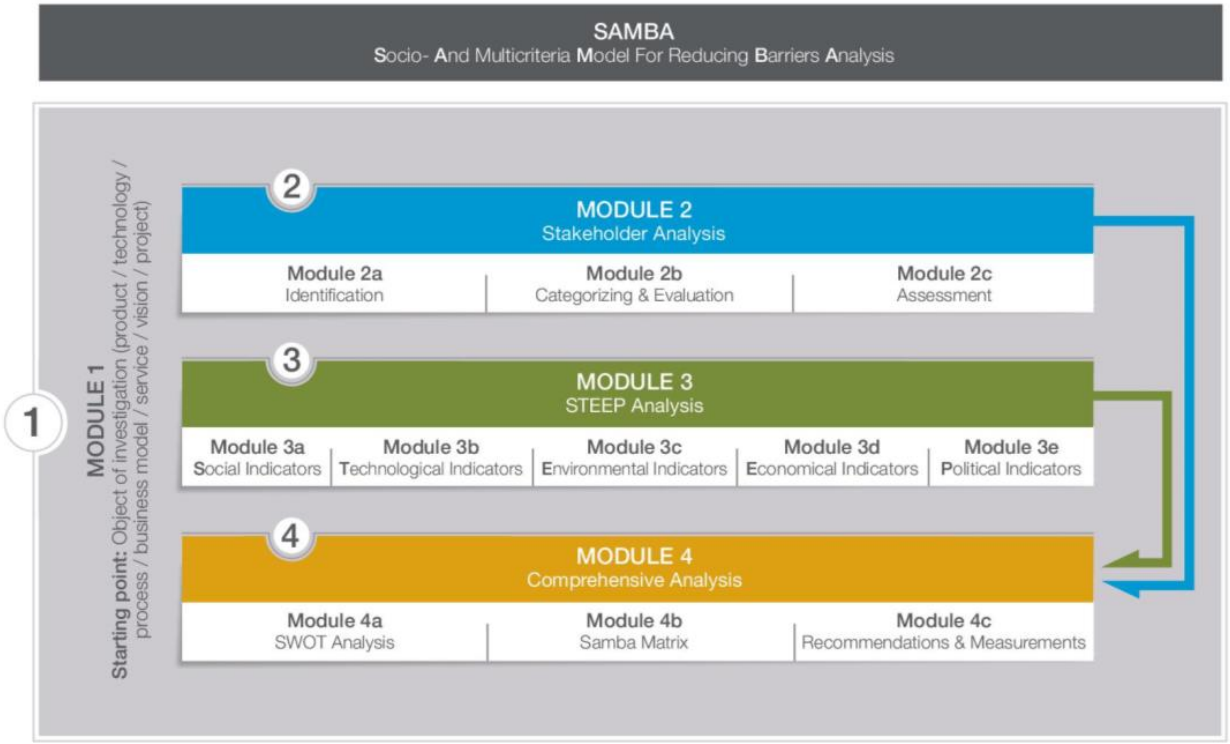

Figure 1. Socio-technical analysis with the model SAMBA.

In Module 1, the definition of the scope and boundaries used was essential as it directly affected the validity of the results and avoids misinterpretations [34–36]. A framework must have a predefined goal or vision, a benchmark for comparing the new technologies,

processes, products or services with other systems and definitions including the technical system boundary, geographical spatial boundary, and time boundary.

The stakeholder analysis in Module 2, including all its further developments, was a tool for systematically identifying and assessing stakeholders, particularly those that have a significant impact on emerging technologies, processes, products, or service. By determining the interests and influence of stakeholders, the analysis could support the achievement of strategic goals for the introduction of zero-emission heavy-duty trucks on a regional level by revealing potential conflicts and opportunities [37–39]. The stakeholder analysis in Module 2 followed in a modified form and consisted of the steps identification (2a), categorization and evaluation (2b) and assessment of stakeholders (2c) [39]. Identification was based on brainstorming and literature research and was followed by feedback loops consulting several experts in order to minimize the risk of excluding stakeholders. In the following step, the stakeholders were categorized into the 6 predefined stakeholder clusters: administration; politics; associations; business; press/media; and civil society. Based on the described role, interests, and expectations, the identified stakeholders were qualitatively assessed regarding their 'influence' as an indication of their relative power, and 'importance' as the degree of interest and the basic 'attitude' concerning the emerging technologies, processes, products, or service. As a result of the analysis, the different stakeholders were categorized regarding their position as 'supporters', 'neutral', 'ambivalent' or 'opponents' [40,41]. The stakeholder analysis identified as a result threats and opportunities from the external environment as input for the SWOT analysis in Module 4.

In Module 3, the STEEP analysis allowed the analysis of influencing factors concerning the emerging technologies, processes, products, or service. The tool has been extensively used in the field of strategy consulting to examine the impact of the external environment from different perspectives but is also suitable for assessing influencing factors [27]. For each dimension, a set of suitable indicators is developed and if necessary, further segmented into sub-indicators to include all relevant aspects [28,42,43].

This final comprehensive analysis in Module 4 merged the previous results of Modules 2 and 3 in a SWOT analysis (4a), developed the SAMBA matrix (4b) and derived measures and recommendations for action (4c) concerning the successful development and implementation of emerging technologies, processes, products, or service. SWOT stands for strengths, weaknesses, opportunities, and threats. The tool represents a popular strategic analysis in various fields to identify internal as well as external factors [44–47]. In the model, the SWOT analysis was used to collect and structure all the external opportunities and threats as well as the internal strengths and weaknesses of Modules 2 and 3. As a result the identified factors were the input to formulate different measures and recommendations. The matrix was derived from what was originally known as the TOWS matrix [48]. TOWS has been applied in different previous studies as the next step of SWOT to develop strategies on the basis of the connection between the identified strengths, weaknesses, opportunities and threats [45,49]. In the socio-technical model, the difference from the original TOWS matrix is that results of the stakeholder analysis were also taken into consideration. Therefore, besides the strengths and weaknesses, the external environment of the STEEP analysis was extended by threats and opportunities of the stakeholder analysis whereby, in general, only those factors which seemed to be important for the development of recommendations would be implemented. In the final step, the strengths and weaknesses were contextualized with the analysed opportunities and threats. Strengths are used to maximize opportunities as well as to minimize threats while weaknesses are minimized by taking advantages of opportunities and avoiding threats. This matching resulted in a list of different measures and recommendations for the successful development and implementation of emerging technologies, processes, products, or services.

3. Results of the Socio-Technical Analysis

The main objective of the present analysis was a qualitative and socio-technical assessment of the deployment of zero-emission heavy-duty trucks in transportation. As already

defined in the introduction, the aim was to identify possible changes and barriers to derive general recommendations for action. For this reason, especially both transport service providers and companies from the freight-transport sector with their own vehicle fleets were considered. From a technical point of view, the analysis was limited to zero-emission trucks based on batteries and hydrogen fuel cells. Furthermore, the analysis was purely designed for heavy-duty commercial vehicles with a total weight of more than 12 tonnes (class N3) [50]. The analysis was carried out specifically for the province of Upper Austria, which offers the optimal conditions for an investigation due to its strong industry, the amount of exported goods and its optimal geographical location as a central Austrian logistics hub. The entire study was designed in accordance with the Paris Climate Agreement and the derived global, European and national strategies with a focus on 2050 [10].

3.1. Stakeholder Analysis

A correct identification and assessment of all relevant stakeholders in Upper Austria is seen as a crucial factor for a successful implementation of zero-emission heavy-duty trucks. Data collection for the stakeholder analysis was carried out using a questionnaire with drop-downs developed in Excel in which participants were asked to assess all stakeholders identified for the analysis according to the following three criteria:

- Influence—What power does the stakeholder have to influence the introduction of zero-emission heavy-duty trucks in Upper Austria? (*1...very low*, *4...very high*);
- Importance—What interest does the stakeholder have in the introduction of zero-emission heavy-duty trucks in Upper Austria? How active or passive will the stakeholder be? (*1...very low*, *4...very high*);
- Attitude—What is the general attitude of the stakeholder towards the introduction of zero-emission heavy-duty trucks in Upper Austria? (*1...Supporter, 2...Neutral, 3...Ambivalent*, *4...Opponent*).

The process of identifying stakeholders relevant to the study resulted in a list of in total 70 different stakeholders. The stakeholders were identified through literature research, expertise from previous comparable projects and general experience. The various stakeholders were assigned to six predefined categories, with the following number identified: administration (9); politics (8); associations and NGOs (9); economic players (31); press and media (8); and civil society (5). In the subsequent stakeholder evaluation process, a total of 31 different experts from all six predefined categories of the stakeholder analysis contributed with their individual assessments to the generation of results. The sample was composed of administrative and regional experts, producers of zero-emission heavy-duty trucks and companies in the field of transport infrastructure.

For the evaluations of stakeholders, a questionnaire in tabular format with drop-down menus was prepared, where 31 experts from the predefined categories put their respective assessments on each of the 70 stakeholders related to the introduction of zero-emission heavy-duty trucks in Upper Austria. Subsequently, the received ratings were anonymized accordingly and were included in equal parts in the overall statement by forming an average value.

3.1.1. Attitude of Stakeholders

In a first step, from the three evaluation criteria, the general attitude of the stakeholders towards the introduction of zero-emission heavy-duty truck in Upper Austria ('support', 'neutral', 'ambivalent', 'opponent') was evaluated in the questionnaire by the different experts. Ambivalent stakeholders were neither supportive nor unsupportive. This yields the following results presented in Figures 2 and 3. Figure 2 shows the overall assessment, while Figure 3 shows a breakdown of attitudes by the various corresponding categories.

As shown in Figure 2, most stakeholders were assessed as having a positive or neutral attitude towards the introduction of zero-emission heavy-duty trucks in Upper Austria. About a quarter of all 70 identified and evaluated stakeholders on a regional level for the province of Upper Austria were expected to be 'ambivalent' or 'opposed'.

According to Figure 3, stakeholders expected to be 'ambivalent' or 'opposed' were mainly found in the two categories 'administration' and 'economic players'. Especially in the category of 'economic players' the evaluation of the identified stakeholders on regional level showed a potential for conflict due to the high number of 'ambivalent' or 'opposing' attitudes.

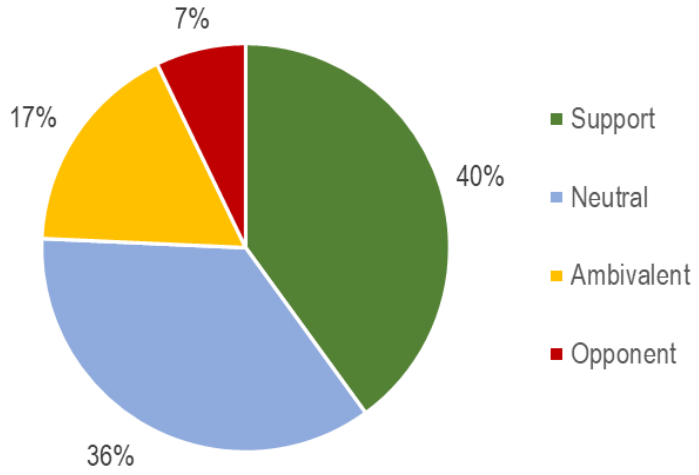

Figure 2. Attitude of stakeholders towards zero-emission heavy-duty trucks.

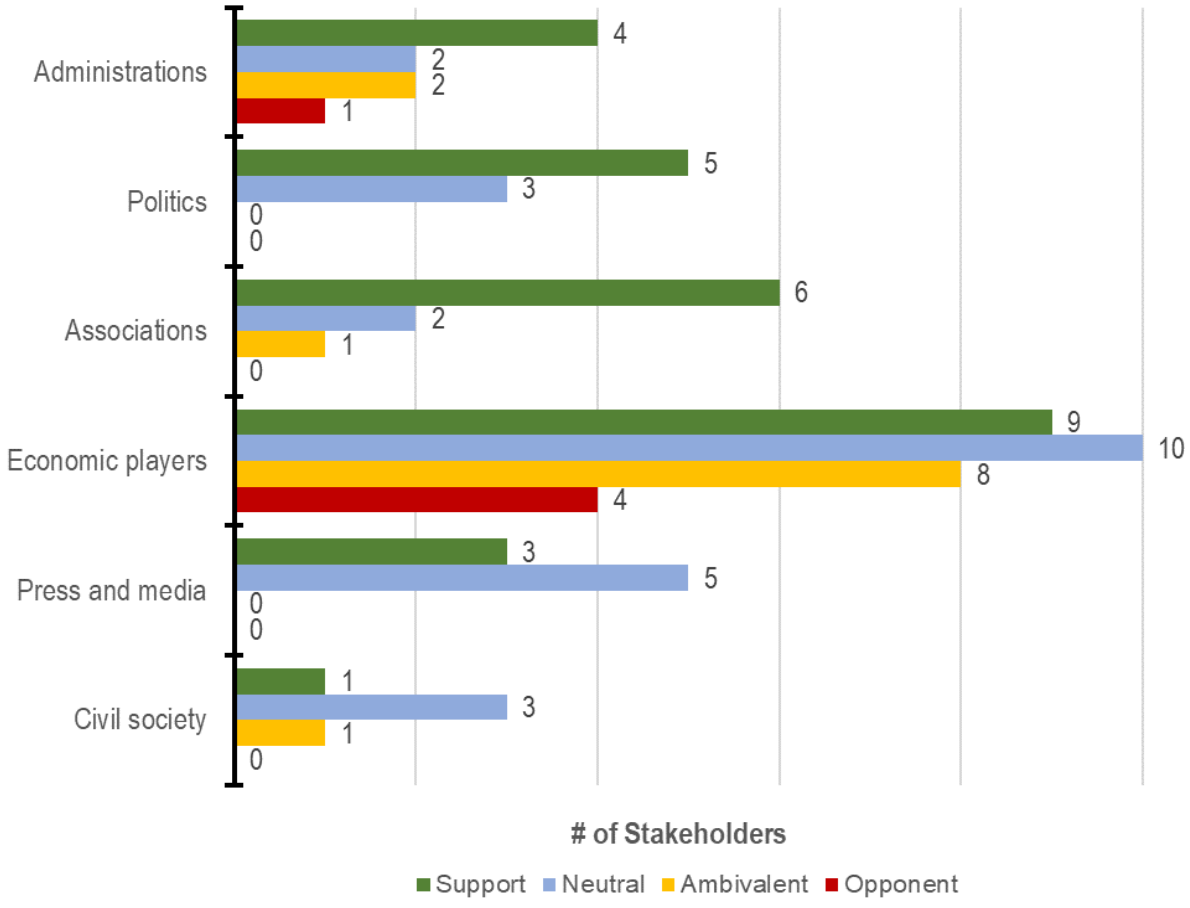

Figure 3. Attitude of stakeholders per category towards zero-emission heavy-duty trucks.

3.1.2. Influence and Importance of Stakeholders

Figure 4 shows the final assessment of all 70 identified stakeholders regarding the two criteria 'influence' (horizontal axis) and 'interest' (vertical axis) evaluated in the question-

naire by 31 experts from the predefined categories. The designation of the assessed and associated stakeholders can be found accordingly in Table 1. The diagram is divided into four different fields, where the corresponding categorization is made based on the average assessment of the respondents. The individual fields describe how the stakeholders in the respective fields should be involved, informed, and given appropriate attention. In addition, the classification of stakeholders provided important input for the design of a targeted stakeholder participation process. The following characteristics could be assigned to the four fields:

- 'Manage closely' (high influence, high importance)—stakeholders with the highest priority, requiring consideration as closely and regularly as possible;
- 'Keep them satisfied' (low influence, high importance)—stakeholders with medium priority who do not require regular attention and can be helpful in decision making;
- 'Keep them informed' (high influence, low importance)—stakeholders with medium priority who require regular information;
- 'Monitor' (low influence, low importance)—stakeholders with the lowest priority that do not require special effort, but whose possible changes in "influence" and "importance" must be considered.

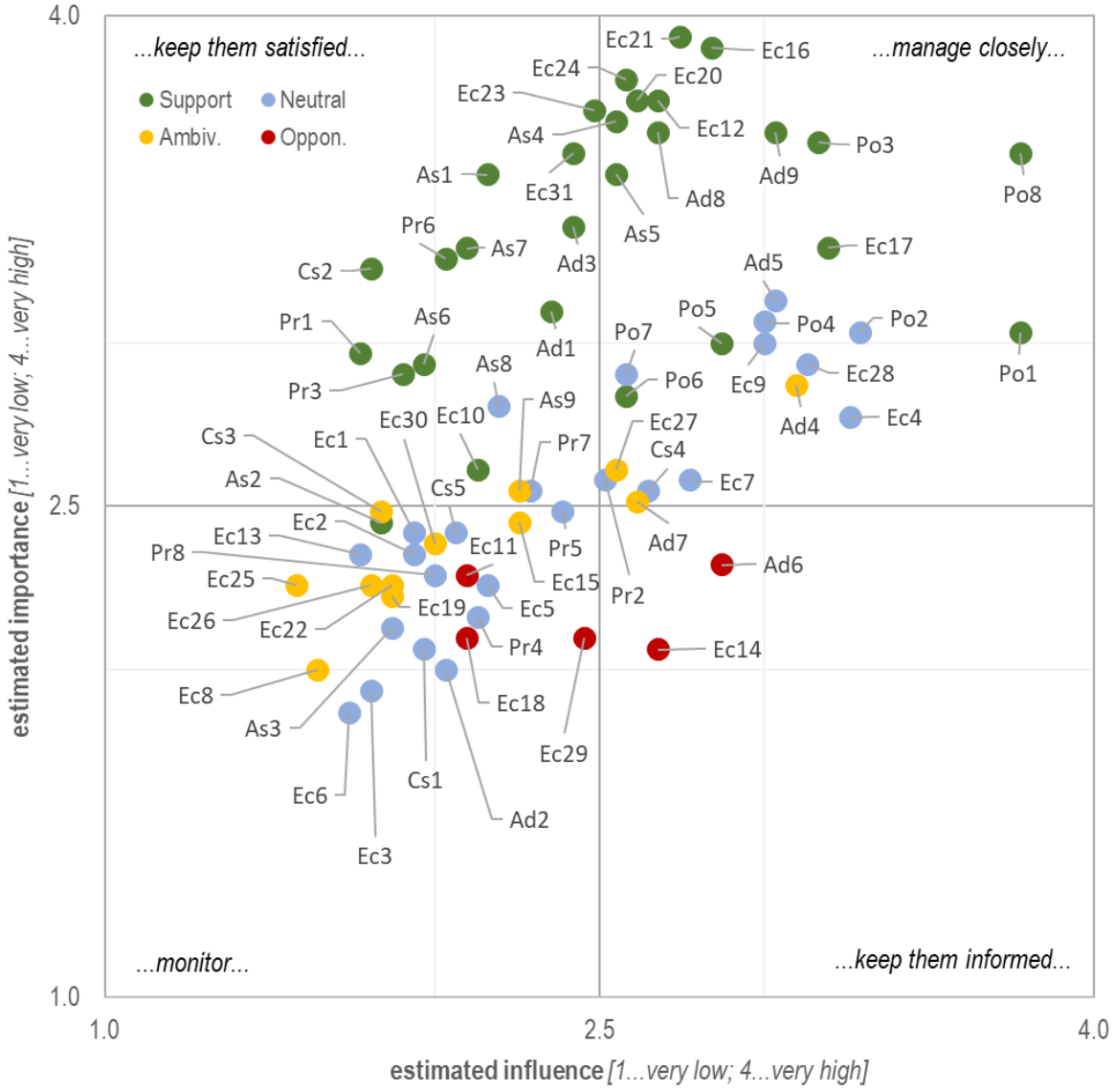

Figure 4. Influence and importance of stakeholders towards zero-emission heavy-duty trucks.

Table 1. Number and name of stakeholders per dimension towards zero-emission heavy-duty trucks.

	Administrations
Ad1	Business location agency
Ad2	Chamber of labour
Ad3	Science and education institutions
Ad4	Association of freight transport
Ad5	Association of automotive industry
Ad6	Association of petroleum industry
Ad7	Association of chemical industry
Ad8	Federal environmental agency
Ad9	Funding organization
	Politics
Po1	Regional government
Po2	Regional economic and energy department
Po3	Regional environmental department
Po4	Regional infrastructure department
Po5	Regional capital
Po6	Regional logistics location
Po7	Regional automotive location
Po8	Ministry of Austria
	Associations and NGOs
As1	Regional climate alliance
As2	Regional development associations
As3	Regional biomass association
As4	Austrian hydrogen association
As5	Association for E-Mobility
As6	Association for transport economics
As7	Mobility for future association
As8	Federal logistics association
As9	Association of freight & logistics
	Press and Media
Pr1	Scientific journals & databases
Pr2	News portals
Pr3	Newsletters
Pr4	Social networks
Pr5	Daily newspapers
Pr6	Trade journals
Pr7	Public radio & TV stations
Pr8	Private radio & TV stations

	Economic Players
Ec1	Regional port
Ec2	Regional tank port
Ec3	Freight stations
Ec4	Company for motorways & expressways
Ec5	Railway companies
Ec6	Shipping companies
Ec7	Freight forwarders
Ec8	Garages for trucks
Ec9	Original Equipment Manufacturer (OEM)
Ec10	Suppliers of drive-independent components
Ec11	Suppliers of conventional components
Ec12	Suppliers for zero-emission drive systems
Ec13	Manufacturer of vehicle superstructures
Ec14	Manufacturers of conventional fuels
Ec15	Biofuel producers
Ec16	Hydrogen producers
Ec17	Energy supply companies
Ec18	Operators of conventional refuelling stations
Ec19	Operators of natural gas refuelling stations
Ec20	Operators of fast-charging stations
Ec21	Operators of hydrogen refuelling stations
Ec22	Manufacturers of conventional refuelling stations
Ec23	Manufacturers of fast-charging stations
Ec24	Manufacturers of hydrogen refuelling stations
Ec25	Smallest transport companies
Ec26	Small transport companies
Ec27	Medium-sized transport companies
Ec28	Large transport companies
Ec29	Operators of conventional vehicle fleets
Ec30	Operators with natural gas vehicles
Ec31	Operators with zero-emission vehicles
	Civil Society
Cs1	Road users
Cs2	Residents of businesses & busy roads
Cs3	Truck drivers
Cs4	Customers of transport services
Cs5	Private customers of delivery & transport services

3.1.3. Key Results

Regarding the introduction of zero-emission heavy-duty trucks on a regional level in Upper Austria, the study shows that in addition to a predominantly supportive opinion, some stakeholders also may have an ambivalent or opposing attitude. Here, the replacement of conventional fossil-powered vehicles can endanger existing businesses and lead to reorientation. The following key results were identified in the process of the stakeholder analysis:

- Operators of exclusively conventional, diesel-powered fleets were considered to be 'opponents', since zero-emission heavy-duty trucks may require corresponding operational adjustments and investments. Medium-sized transport companies, in particular, need to be closely managed here;

- Manufacturers of conventional fuels, as well as operators of conventional refuelling stations were seen as 'opponents', as a reorientation of the core business may be necessary. Likewise, manufacturers of biofuels were evaluated by the different experts as 'ambivalent'.
- Suppliers of conventional components for road freight transport were also evaluated as 'opponents', but they were not considered to have a major influence on the topic in the assessment by the respective participants.
- The attitude of certain administrative trade associations towards the introduction of zero-emission heavy-duty trucks was assessed as 'ambivalent', as this could possibly result in economic disadvantages for the represented companies.
- Smallest (up to 9 employees as per definition) and small transport companies (up to 49 employees as per definition) were seen as 'ambivalent', but since they had both little influence and interest, no special consideration was required in strategy formation.
- Garages for trucks were also expected to be confronted with major changes and challenges as a result of the introduction of zero-emission heavy-duty trucks and therefore they were evaluated to be 'ambivalent' about the topic.
- Administrative environmental stakeholders were evaluated as supporters with a high estimated importance and influence that could be helpful for the next steps for introducing locally emission-free commercial vehicles.

3.2. STEEP Analysis

Due to the research focus of the present study, the different sociological, technological, environmental, economic, and political dimensions of the STEEP analysis [27,28] were used for the identification of an appropriate set of indicators needed in the interviews with experts. The selective reduction to certain indicators was conducted on the one hand because of the indicators' suitability for expert interviews and on the other hand because of their relevance for the analysis. After the interviews were completed, the generated transcripts were directly transferred to Module 4; the comprehensive analysis, as an overview of various strengths, weaknesses, opportunities, and threats regarding the introduction of zero-emission heavy-duty trucks was created in the SWOT analysis.

The questions in the relevant interview guide were taken from the following dimensions and dealt with indicators which on the one hand were developed specifically for the analysis and on the other hand were taken from other sources [27,44,51,52]:

- Sociological dimension—participation and communication, social and public acceptance, working conditions related to the technology;
- Technological dimension—technological limitations, integration of technology into the existing system, reliability and security of supply, potential to remove bottlenecks in the existing system;
- Ecologic dimension—environmental impact;
- Economic dimension—subsidies and other financial support;
- Political dimension—political and legal barriers and uncertainties related to the analysed technology.

In total, 10 different experts from the fields of transport, logistics, administration, research, and trade were interviewed in the area of Upper Austria in the period from May until September 2021. All of them were in a leading position as managing directors, head of departments or project managers. Half of them were in transport companies, one in mobility research, one in energy research, one in hydrogen research and one each were from administration and politics.

The interviews were conducted at the premises of the businesses or online due to the COVID-19 pandemic. The interview guide was semi-structured based on the indicators listed above including zero-emission heavy-duty trucks in general, their possible use and function in daily business, barriers and challenges and the process of vehicle selection. Semi-structured interviews are a widely used method for designing the process, where the experts are determined through targeted selection and their status. They can act as advisors

and knowledge brokers who pass on factual and experiential knowledge and thus open up good access to previously undefined areas [53].

All expert interviews were scheduled for a duration of one hour and analysed using the data analysis software MAXQDA regarding SWOT, e.g., the respective strengths, weaknesses, opportunities, and threats in connection with the introduction of zero-emission heavy-duty trucks.

3.3. Comprehensive Analysis

This final comprehensive analysis of the used hybrid methodology linked the results of Modules 2, stakeholder analysis and Module 3, and STEEP analysis, to derive strategies and measures, as well as recommendations for action to overcome existing barriers to the introduction of zero-emission heavy-duty trucks at a regional level in Upper Austria. The SWOT analysis was used to collect and structure all the external opportunities and threats as well as the internal strengths and weaknesses.

3.3.1. SWOT Analysis

The SWOT analysis identified and listed the various strengths, weaknesses, opportunities, and threats [44–47] regarding the introduction of zero-emission heavy-duty trucks in companies compared to diesel-powered trucks. Therefore, the data from the individual expert interviews were processed into a corresponding overall statement and listed in the form of bullet points.

Strengths

The strengths discuss where zero-emission heavy-duty trucks are strong and where the advantages over conventional diesel-powered vehicles are seen. Key factors for successful integration and use at the operational level are also elaborated.

- Locally emission-free technologies;
- From a company perspective, there is a positive response from the community and neighbourhood in connection with the use of zero-emission heavy-duty trucks;
- Fewer drive-dependent aggregates, such as exhaust gas recirculation, which can often lead to functional malfunctions during corporate use, are needed;
- Zero-emission heavy-duty trucks run smoothly and quietly, enabling driving in noise-sensitive areas and thus alternative route planning;
- Lower maintenance requirement compared to diesel trucks;
- There is the possibility of self-sufficient and autonomous energy generation for the driving operation, e.g., through a PV or hydrogen refuelling station;
- Zero-emission heavy-duty trucks deliver good and appealing transport and driving performance at the corporate level.

Weaknesses

The weaknesses discuss where disadvantages over diesel-powered commercial vehicles in the transport sector are seen and where perspective is missing. Moreover, the needed improvements in this technology are discussed and listed.

- Very high acquisition costs;
- Significantly lower range than comparable heavy-duty diesel trucks;
- Insufficient model and truck availability;
- Technology maturity as with diesel powered engines is probably still a long way off;
- From a company's point of view, existing test trucks are currently used almost exclusively for image purposes and less because of practical relevance or necessity for business operations;
- The greatest technological challenge is seen in the implementation of heavy 40-tonne trucks due to various deficits such as range, charging time, etc.;
- Limited flexibility of zero-emission heavy-duty trucks compared to diesel, e.g., due to a reduced range, longer charging time or changed structure of the chassis;

- Lack of infrastructure and limited refuelling station network.

Opportunities

The opportunities describe what needs are expected regarding zero-emission heavy-duty trucks. Expected technological breakthroughs and the political as well as societal trends are especially relevant in this section.

- Zero-emission heavy-duty trucks can promote the sustainable orientation of the company, which is increasingly demanded;
- From the stakeholders' point of view, heavy-duty vehicle manufacturers have already set the course for the future series production;
- Provision of targeted public purchase subsidies;
- Public programmes and policies increasingly push the use of zero-emission heavy-duty trucks;
- Support the achievement of global, international, and national climate targets;
- From a company's point of view, customers of transport companies are generally very positive about the use of zero-emission heavy-duty trucks;
- Revitalisation of the European commercial vehicle market by new, globally active companies, e.g., from the Asian or American regions.

Risks

The section of risks discusses what negative developments are to be expected regarding zero-emission heavy-duty trucks, including which negative political and social developments are emerging in this context and which trends are being followed by competing technologies.

- Due to the current lack of economic viability of zero-emission heavy trucks, incumbents are at risk of losing market share;
- The economic aspects continue to have a stronger impact on companies than the ecological aspects;
- Currently, there are no zero-emission heavy-duty trucks comparable to diesel available for various corporate applications;
- A lack of political stability is seen as a general obstacle to corresponding investments in alternative drive systems;
- The economic situation in the transport sector is becoming increasingly difficult due to low profit margins;
- The availability of sufficient energy, especially green energy (electricity, hydrogen), is seen as critical from various perspectives;
- Acquisition of zero-emission vehicles is currently driven only by legislation and not by the market via a corresponding business case.

3.3.2. Recommendations and Measures

In the present study on the deployment of zero-emission heavy-duty vehicles in logistics, the contextualization of the analysed strengths and weaknesses of the SWOT analysis with the respective opportunities and threats was not carried out. Therefore, the results of the SWOT analysis were directly transferred and clustered into various recommendations and measures for a successful implementation of zero-emission heavy-duty vehicles on a regional level.

Communication and Stakeholder Engagement

- Zero-emission heavy-duty trucks should be used by individual transport companies to promote the development of a sustainable corporate image in parallel with existing measures.
- For the targeted introduction of zero-emission heavy-duty trucks, administrative and political decision-makers should seek a targeted exchange with transport compa-

nies. So far, there has been little or no involvement from the transport companies' point of view. In this way, e.g., the lack of infrastructure could be solved in the best possible way.

Acceptance

- From the transport companies' point of view, the positive feedback from society in connection with the use of zero-emission heavy-duty trucks opens new marketing opportunities. For transport companies, these can be used specifically to generate new orders and additional business.
- The acceptance of zero-emission heavy-duty trucks on the part of both customers and the public should be used to advance the maturity of the technology through increased testing in companies. Currently, there are only a few tests in the practical environment, which has resulted in a limited database for improvement.
- Public and political strategies to demonstrate political stability, which are necessary for sustainable or long-term investments at the company level, are of great importance. On the side of original equipment manufacturers (OEMs), the course for future series production of zero-emission trucks has already been set, while pressure is coming from new, non-European players.

Further Technological Development

- Zero-emission heavy-duty trucks must be available for various applications as soon as possible. The development of a modular vehicle architecture should increase flexibility and provide a corresponding remedy for pushing alternative technologies.
- Development and increased use of zero-emission heavy-duty trucks with a total weight of 40 tonnes, since from a company's point of view the greatest technical challenges are currently seen in this weight class.
- Solving the range problem of zero-emission heavy trucks compared to conventional diesel vehicles to increase availability and flexibility for various applications accordingly.

Economics

- Illustration in specially prepared documents that, among other things, low maintenance costs of zero-emission heavy-duty trucks in conjunction with the elimination of problematic aggregates could improve long-term profitability from a company's point of view.
- The economic situation of companies can be improved by independent and autonomous energy generation for driving, e.g., by having their own PV or hydrogen refuelling station. This makes them independent of fossil fuel prices, which are expected to rise in the future.
- Design of suitable, targeted subsidy schemes or monetary support measures for the acquisition of zero-emission heavy-duty trucks that enable the transport companies to develop corresponding business cases and thus move away from models that are exclusively driven by legislation.

Targeted stakeholder involvement by administrative and political decision-makers is essential, as a lack of consideration in various strategies has been identified. Furthermore, demonstration projects with zero-emission heavy-duty trucks at the company level are also essential. In general, further technological development of trucks remains an important issue. As the economic viability of trucks is the most important decision criterion from a company's point of view, the operating and maintenance costs of zero-emission vehicles are already low, but due to the high purchase price, special financial support measures are needed.

4. Conclusions

The holistic identification of in total 70 different stakeholders on a regional level delivered a new holistic list of required regional perspectives concerning the implementation of zero-emission technologies in six different predefined categories. This holistic approach, involving all relevant stakeholders at the regional level can be seen as a key factor [15]. The evaluation showed that especially in the category of 'economic players', a potential for conflict due to the high number of 'ambivalent' or 'opposing' attitudes exists. Also on regional level, petrol producers and manufacturers of conventional, fossil-powered vehicles were evaluated with a negative attitude towards the transition to zero-emission trucks. These facts are consistent with the reviewed literature [18] but additionally also operators of conventional refuelling stations were evaluated as 'opponents', as this could result in economic disadvantages for them.

The additional setting of the attitude 'ambivalent' indicated that certain stakeholders, e.g., administrative trade associations or medium-sized transport companies, neither support nor non-support the introduction of zero-emission heavy-duty trucks. This additional setting provides an added value in terms of information compared to other evaluations that only allow 'support', 'neutral', or 'opponent' [17]. The introduction depends especially on the willingness of the transport companies to invest and replace the current truck fleet. The general societal and public acceptance of zero-emission transport solutions rises, but truck manufacturers will also have to develop appropriate solutions soon, and this is where European stakeholders are called upon to put additional effort into this issue. Ultimately, from a company's point of view, the replacement of conventional trucks depends heavily on the economic framework conditions, which is why special support programmes are essential. This fact is useful in planning future strategies for the transition to alternative drive-systems in transportation. In this case, a key recommendation for action is seen in the targeted involvement of transport companies in the development of various political and public strategies for the increased introduction of zero-emission heavy-duty trucks. This could both identify their concerns and address them with targeted measures. In addition, this mutual exchange could lead to increased practical testing and further increase acceptance. A sustainable corporate image is already of corresponding importance and could support the large-scale introduction of sustainable technologies [54].

The province of Upper Austria offers due to its strong industry, the amount of exported goods and its geographical location optimal conditions for an investigation of the introduction of zero-emission heavy-duty trucks in road -freight transportation. Therefore, the present analysis provides an effective scientific contribution to the transformation of the transport system at a regional level. The applied hybrid methodology combines stakeholder analysis, STEEP analysis, SWOT analysis and an adapted TOWS analysis with the general aim of creating a holistic assessment for new and emerging technologies. A comparable integrated framework combining the three basic approaches has been used in other research, e.g., for developing future sustainable transformation scenarios [28], but was used for the first time in zero-emission road-freight transportation.

From a technical perspective, the interviewed experts see an important point in solving the range problem. Although hydrogen powered heavy-duty fuel-cell trucks already have a higher range than comparable battery-powered trucks and some tours can already be successfully mapped in urban areas [55], this is still not satisfactory from a practical point of view compared to conventional diesel. The results of the study show, that the lack of charging and refuelling infrastructure is a bottleneck at the regional level that reduces flexibility compared to heavy-duty diesel trucks. In addition, the longer charging time is also seen as a major barrier to investment and replacement of the existing fleet. These facts are consistent with the statements in the reviewed literature [23,25]. However, the performance range has significantly improved since 2010 but is still a critical factor [23]. Furthermore, the development of zero-emission

heavy-duty trucks for various applications and with a total weight of 40 tonnes should be pushed more strongly in parallel. A key recommendation for action may also lie in the development of a modular architecture.

Another important measure is the design of suitable and targeted funding channels that enable transport companies to map out corresponding business cases for the acquisition of zero-emission heavy-duty trucks, which require considerably more investment than diesel at an early stage and independently of regulatory stipulations. According to the interviewed experts, the strategic development of the necessary series production has already been initiated by OEMs and is also being driven forward by new, non-European players. From the perspective of the interviewed companies, subsidy programs (e.g., tax breaks, purchase subsidies, subsidized research) are necessary for corresponding investments in zero-emission trucks until the broad market launch. With regard to operating costs, the focus of the transport companies is ultimately on economic efficiency of vehicle deployment and securing the long-term existence of the business [55].

The targeted preparation of information that enables an evaluation of zero-emission technologies from a company's point of view is also of corresponding importance. In addition to the costs for vehicle acquisition, this should also include ongoing operating costs. The individual transport company carries out an evaluation based on 'total cost of ownership' and only sufficient data availability can enable necessary cost comparisons. In this context, the possibility of autonomous energy generation through a dedicated PV or hydrogen refuelling station for the operation of zero-emission heavy-duty trucks should also be mentioned. According to the interviewed experts, the off-grid generation of electrical energy or hydrogen can ensure independence from fluctuating energy prices or possible supply bottlenecks.

Further research aspects can be oriented towards a detailed economic analysis based on 'total cost of ownership' and the involvement of a wider range of stakeholder interviews. This would allow a more complete picture and the design of targeted measures at a regional level. In addition, it would be interesting to know what the assessment of the various stakeholders in another region or country looks like and whether a comparable picture emerges.

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