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Systematic Opportunity Scan of Energy Recovery Technologies Applied to Trucks with Electric Refrigerated Units

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Abstract: This article presents an original research methodology that combines insights from patents and academic research, offering a unique perspective on energy recovery technologies for trucks equipped with refrigeration units. The purpose of the study is to perform a functional analysis of existing solutions and to suggest a mechanism for exposing unexplored areas and opportunities for innovation. To achieve this goal, a systematic opportunity scan is presented, investigating patents and conducting a state-of-the-art search of existing technologies. This scan classifies a diverse range of solutions, elucidating their interconnections and providing an overview of the existing technological area, covering system components and technical trends. Thus, the main functions and components are listed, as well as the system requirements. Once the functions have been surveyed, a morphological matrix is proposed, and five main functions are analyzed. This methodology makes it possible to list the majority of the possible solutions for the functions analyzed, taking into account the components observed in the literature review and patents, including new components raised by the research group. Finally, with the morphological matrix structure, it was possible to combine unexplored elements, achieving innovative solutions.

Keywords: patent analysis; functional analysis; transport refrigeration unit; energy recovery

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1. Introduction

Motor vehicles used for urban mobility and cargo transportation are a fundamental part of human society [1]. However, the current reliance on fossil fuels in road transportation contributes to over 24% of global greenhouse gas emissions [2,3], making it responsible for nearly one-quarter of global energy-related CO_2 emissions [4,5]. As a result, the transportation sector is the second-largest contributor to emissions worldwide [3]. This pollution is a significant concern, considering that road transportation plays a vital role in a country's economic and social development, supporting various aspects such as logistics, resources, and mobility [6].

Air quality improvement has emerged as a crucial sustainable goal for global authorities in the forthcoming decades [7]. In recent years, various countries worldwide have adopted global agreements, such as the Paris Agreement [8,9] and the European Green Deal [10], which propose a set of sustainable policy initiatives and aim for net-zero emissions by mid-century. The reduction of greenhouse gas emissions from the transportation sector is highlighted by the U.S. Environmental Protection Agency (EPA) as one of its most significant challenges in meeting global emission reduction agreements.

Considering the logistics sector, some countries, like Brazil, are heavily reliant on road transportation carried out by heavy-duty trucks powered by diesel engines. According to Moreira et al. [11], between 61.4% and 65% of all cargo transportation in Brazil is conducted via road. Despite the significance of road cargo transportation for the country's development, this dependence on fossil fuel-generated energy contradicts global policies aimed at reducing emissions. Mahesh et al. [12] emphasize that trucks are the most polluting vehicles, accounting for 5% of the total greenhouse gas emissions in Europe [13].

The electrification or hybridization of the vehicle fleet, compared with conventional vehicles, has positive and negative points, whether from an energy, environmental, or autonomy point of view. Electrifying heavy-duty vehicles can provide several benefits, such as reducing the amount of pollutants that are emitted, reducing energy use and noise, lowering maintenance costs, and providing higher torque values. Gao et al. [14] discussed and examined the energy use of electric vehicles (EV) and petroleum-fueled vehicles in a variety of heavy-duty applications. The authors surveyed the energy required for electricity generation and distribution to charge electric vehicles. Thus, comparing the electric vehicle with the petroleum-fueled one, the EV saves energy in all applications analyzed by the authors, with a highlight for the food delivery truck that shows a 40% reduction in energy use.

Although the gains made by electric trucks are remarkable, their development and deployment involve several challenges. Nadel and Junga [15] discuss some of these challenges, including the availability of electric truck models in the U.S. market, the upfront cost of these vehicles, their limited range, and challenges related to charging. The study analyzes the current landscape of electric trucks available in the United States of America (US) market, proving it to be relatively limited. The US Department of Energy releases a comprehensive list of alternative fuel vehicles, which includes electric vehicles. In December 2019, this list included 61 distinct models of all-electric trucks [16]. Nadel and Junga [15] then conclude that a wider range of electric truck models needs to be introduced, as, compared with the traditional truck market, the electric market is extremely short on options.

Another analysis carried out by Nadel and Junga [15] is about the initial cost of an electric truck. These vehicles, when compared with the equivalent diesel or gasoline vehicle, have a higher cost due to the high cost of the battery. According to the authors, although the additional cost related to the price of the battery can be recovered in a period of three to seven years, the initial amount still represents a difficulty with introducing these vehicles. Another challenge relates to the useful life of these batteries, especially in trucks, which cover much longer distances over their life cycle compared with light vehicles [17]. This results in a significantly higher discharge rate for truck batteries. Consequently, this high discharge rate contributes to the degradation of batteries, compromising their useful life [18,19]. Therefore, replacing this component implies a high cost, which influences the vehicle's resale values.

The range of electric trucks is also discussed [15]. Although the autonomy is relatively lower when compared with conventional vehicles, they are still sufficient for local deliveries and short transport, being a problem in cases of intercity travel. However, in periods of mandatory rest breaks of the driver, this time could be used to recharge the battery. However, we encounter another issue addressed by Nadel and Junga [15], which is the recharging infrastructure of these batteries, since they have larger capacities, resulting in a longer recharge time. Thus, the high-voltage chargers needed are currently limited, and their installation may require improvements to local power distribution systems [20–23]. In addition, fleets, which operate multiple trucks, will require multiple chargers at their depots, and truck stops must install high-capacity chargers to accommodate long-distance trucking. Meeting these needs may require reinforcing existing power grids, incurring both time and financial costs. According to Al-Hanahi et al. [24], due to the high power capacity of public charging infrastructure for commercial vehicles, monitoring should be performed to ensure that the capacity of the power grids at the infrastructure sites is sufficient to provide the charging power required to recharge the batteries of the trucks. In addition, a study should be carried out to ensure that the impact of charging infrastructure on the performance of electricity grids is within stability limits, especially during the peak period of residential loads. Recent studies rank the deficiency of robust charging infrastructure as the main bottleneck in the commercial electric vehicle industry [25,26].

In addition to all these listed challenges, Nadel and Junga [15] draw attention to another very important issue: the conservative stance of the trucking industry. This is reflected in the resistance that drivers present when it comes to transitioning to electric trucks. The justification is that they need a guarantee of cost parity with diesel options as well as reliability and durability at the same level. Furthermore, the retraining of service technicians and drivers becomes imperative, along with considerations of load weight management and temperature effects to ensure optimal battery performance. Notably, even seemingly simple and cost-effective technologies such as side skirts and low-rolling resistance tires have not achieved full adoption after over a decade in the market [27].

One important aspect of the transportation section is the food supply, which sometimes demands trucks with refrigeration units (TRUs). With the increasing demand for high-quality food products, the need for refrigerated trucks in cold chain systems has witnessed a rapid escalation in multiple countries [28]. Moreover, the refrigerated transport sector is responsible for 15% of global fossil fuel energy consumption [29]. Such refrigeration units are usually powered by an auxiliary diesel engine [30], which is separate from the main traction engine of the truck and, therefore, also contributes to emissions. Furthermore, despite the efficiency improvements in the development of the cold chain, certain components, such as the auxiliary diesel engine, do not meet all the requirements of the standards applied in the transportation sector [31]. Replacing the combustion-powered system with electrified alternatives may be a potential solution for the listed issues.

Refrigeration units in refrigerated trucks work based on the vapor compression refrigeration cycle [32]. There are two types of vehicles with these units: independent, where an independent motor drives the compressor, and non-independent, which depend on the vehicle's motor [33]. In the refrigeration system of electric refrigerated trucks, made up of auxiliary equipment such as a compressor, condenser, evaporator, expansion valve, and pumps, the compressor is the main source of energy consumption [34]. In the case of the mechanical refrigeration truck with a non-independent refrigerator, the compressor is driven directly by the vehicle's gasoline or diesel engine [34]. Both types consume a significant amount of energy to cool the inside of the trailer body, according to the demands of the products being transported. In addition to studies into how best to increase the energy efficiency of this system, there is also research into thermal efficiency, with studies on reducing the rate of heat transfer from the outside environment to the inside of the trailer. This can be achieved by integrating phase change material into the standard walls of the trailer [35].

In a comprehensive review of refrigerated transport, Maiorino et al. [29] present the current state of the art and potential innovations for enhancing the sustainability of the refrigerated transportation sector. In their conclusions, the authors emphasize the significant potential to reduce energy consumption and emissions in the refrigeration system by replacing the conventional auxiliary diesel engine with an electrical energy storage system. However, despite the use of a battery pack, it is important to note that a pure electric system may not be adequate to meet the energy demand of the cooling system.

In the work conducted by Maiorino et al. [36], a model for hybrid refrigerated vans is proposed that incorporates photovoltaic panels and electric batteries with the aim of reducing total greenhouse gas emissions from internal combustion engines. The study compares various technologies, including lithium and lead-acid batteries, as well as three different types of photovoltaic panels. The authors consider single and multiple delivery scenarios to assess the energetic, economic, and environmental benefits. As a result, they point out that implementing the proposed hybrid system can reduce CO_2 emissions by up to 20%. However, they also indicate that the payback period exceeds 20 years due to the cost of adapting the vehicle and current fuel and electricity prices.

Considering the limitations mentioned in the electrification of TRUs, it is crucial to develop technologies capable of harnessing energy from available sources during vehicle travel. Table 1 presents some alternatives for energy recovery in vehicles. This energy recovery is essential to enhance the operational range of the electric refrigeration system and eliminate the need for combustion engines [37,38]. Therefore, it is possible to efficiently minimize the emissions produced by these vehicles with a decrease in the use of combustion engines.

Table 1. State-of-the-art literature review about energy recovery in vehicles.

References	Details
Fernández-Yáñez et al. [39]	This paper summarizes the knowledge on waste energy recovery with thermoelectric generators (which convert heat into electrical energy) from a thermal management point of view and defines the main challenges and best practices in the design of such devices.
Caltabellotta and Pipitone [40]	Discusses a system to recover energy from gas not expanded by internal combustion engines. The propulsion system is composed of a spark ignition engine equipped with a turbo-generator set specifically dedicated to exhaust gas energy recovery and with a separate electric turbocharger. The system is specifically designed for hybrid propulsion architectures. As a result, the composite turbo system can improve vehicle efficiency by between 3.1% and 17.9%, depending on the power output level, with an average efficiency increment of 10.9% assessed over the entire operating range.
Al-Yafeai et al. [41]	Presents a review of the state of the art of different existing vibrational applications for vehicle suspensions using the piezoelectric energy harvesting technique. The authors concluded that the dissipated power of passenger cars at a speed of 13 m/s is around 200 W from suspension dampers, representing a relatively large amount of power to be harvested.
Hedlund et al. [42]	A review of flywheel energy storage technology was carried out. The authors compare this technology with supercapacitors, as examples of flywheels for vehicular applications had a specific power of 5.5 kW/kg and specific energy of 3.5 kW/kg. One of the case studies discussed by the authors is the implementation of this technology in London city buses, achieving fuel savings of more than 20%. In turn, in passenger vehicles, this system achieved 35% fuel savings in the driving cycle USA Federal Test Procedure.
Rakov et al. [43]	Addressed an assessment of the impact of regenerative braking on vehicle fuel consumption and pollutant emissions. The authors analyze the basic characteristics by comparing gasoline engine operating modes with and without brake energy recovery in a low-speed segment of the WLTC driving cycle. The results obtained are compared with the results of on-road tests of vehicles with the energy recovery system.

Some studies have demonstrated the application of power generation and energy regeneration systems to various industrial sectors, such as forestry and mining. In these cases, the motor generator can be coupled to the truck axle [44], with complementary systems coupled to the hydraulic motor propulsion semi-trailer [45]. Some alternative solutions, which use hydraulic motors, presented quantitative restrictions of the pressure and flow controls of the hydraulic pumps, making the use of more advanced control indispensable for the implementation of auxiliary hydraulic propulsion systems [46].

In addition to the use of hydraulic motors, other hybrid power transmission systems in trucks are also used. Xu et al. [47] present a comparative study of three architectures for the power train of a heavy-duty truck and a parallel, series-parallel, and power-split system. The authors conclude that the three architectures have advantages and disadvantages, none of which stands out from the others, making the optimal architecture depend on the desired application. However, an improvement of more than 18% in fuel economy was observed when compared with the conventional heavy-duty truck.

In turn, Wei et al. [48] compare the architecture and adaptive power management strategy for a plug-in hybrid electric logistics vehicle equipped with electric motors. The series, parallel, and series-parallel hybrid power train systems are examined using a dynamic programming algorithm. The results show that the fuel economy improvements of the series plug-in hybrid electric logistics vehicle are 7.60% and 6.53% compared with the parallel and series-parallel configuration vehicles, respectively.

The study presented by Maiorino et al. [49] discusses the benefits of using an electric kinetic energy recovery system in a light commercial refrigerated van. This system uses a $LiFePO_4$ battery to store electricity, a brushless motor-generator unit, and a hybrid inverter that can both charge the battery and power the van's refrigeration system. The results showed that the recovered electricity could cover more than 47% of the van's total electricity demand. Therefore, nearly half of the primary energy or fuel consumption can be saved by applying the energy recovery system to light commercial refrigerated vans. Additionally, the study reported a reduction in emissions ranging from 9 to 13 g of CO_2 per kilometer.

Cunanan et al. [50] discusses two alternatives for heavy-duty vehicles that use diesel as fuel. The two configurations presented are battery-electric heavy-duty vehicles and those using hydrogen fuel cells. The paper delves into the advantages and disadvantages of each of these configurations, presenting the working mechanism, performance metrics, and recent technologies developed for the traction system of these vehicles. With the analyses carried out by the authors, the following conclusion is presented: the diesel engine in these vehicles will remain a predominant technology in the short-term future due to the infrastructure already being in place and the lower cost compared with the other configurations, despite the high emission rates of this configuration. In turn, alternative configurations (electric and hydrogen fuel cells), according to the authors, will be slowly developed to eliminate existing technological barriers, including costs, infrastructure, and performance limitations, to be able to compete with the diesel system and introduce themselves in the market.

In their paper, Çabukoglu et al. [51] analyze the alternative of a hybrid traction system for heavy-duty vehicles using fuel cells. The authors explore the application of this configuration in Switzerland. An estimation of the feasibility of this configuration is presented, considering the daily operation patterns of the fleet vehicles. In the Swiss scenario discussed by the authors, if all trucks were powered by hydrogen produced exclusively by electrolysis, the total decarbonization would consume more than 18 TWh of renewable electricity, which represents 13% of the Swiss national consumption. The fuel cell-powered configuration has a longer range than configurations with purely battery-electric systems. Although the study notes that refueling can take more than half an hour, requiring a dense energy infrastructure, direct emissions are offset by indirect emissions, mainly through the reduced need to use natural gas. Thus, the use of hydrogen in a hybrid drivetrain of heavy-duty vehicles can assist in decarbonization once its production is truly renewable.

In view of the significant development of trucks with hybrid power transmission systems in several areas of engineering, some works have expanded research both in the analysis of manned trucks and unmanned trucks. Regarding manned trucks, the analysis is related to different position configurations of the motorization system on the hub of the front or rear wheels [44] and to the positioning of the battery pack in the frontal or posterior region of the vehicle chassis, with the objective of improving the comfort of the driver [52]. As for the application in unmanned trucks, the traction and energy regeneration system consists of two electric motors, one for the traction of the front axle and the other for the rear axle, with the objective of evaluating the energy consumption in relation to trucks with a system of traditional transmission and an internal combustion engine [53].

As can be seen, the literature reports various approaches to energy recovery in trucks, which can be applied to supply energy to the refrigerated unit system. However, despite an extensive literature review conducted for this study, no previous research was found that specifically addressed the analysis of techniques and methodologies to identify opportunities for developing energy recovery technologies in trucks equipped with electric refrigerated units. Consequently, this paper introduces an original and systematic opportunity scan methodology that draws upon insights from both patented technologies and academic studies. The analysis focuses on evaluating the functionality of the components employed in each solution as well as their potential application in powering refrigerated units. Additionally, the identified solutions are categorized based on their respective system requirements with the objective of identifying potential areas for innovation and uncovering any existing gaps in the truck electrification and energy recovery sector.

As a result, a thorough examination of the academic literature and current patents on energy recovery systems used in trucks is presented in this paper. The analysis focuses on works and patents related to technical engine solutions, new systems, and currently implemented solutions. Based on the systematic solutions research methodology applied, the paper aims to classify a diverse range of solutions and highlight the connections between them. Moreover, a functionality analysis of the components of the main solutions is performed, and a method to scan and highlight the possible gaps for novel solutions is presented.

For that reason, the present study makes significant contributions. Firstly, it identifies and analyzes pertinent studies and patents, allowing a comprehensive understanding of the technological system of energy regeneration in heavy-duty vehicles. This understanding includes the components of the system and technical trends, providing a well-rounded perspective. Moreover, the paper examines the dynamic landscape of the automotive sector, identifying its impact on technological dominance within the industry. The research also investigates how companies strategize and form alliances to compete in the pursuit of technological dominance. Therefore, with these analyses, it will be possible to understand the entire chain of development of ideas for the technological domain. In addition, the study on patents involving the theme will allow us to identify the possibilities of innovation within the sector.

2. Materials and Methods

2.1. State of Art

In this section, a vast literature review is conducted to survey the technologies that are under development for TRUs addressed by researchers in their work, as discussed by Taher et al. [54] in their review article.

TRUs are energy-intensive systems due to the need to keep the cold room refrigeration system fully operational. Thus, some alternatives are used to ensure energy production and storage. Some literature research addressing this development is presented below.

Rossetti et al. [55] discuss that solar-assisted refrigeration systems may represent a simple and viable solution to improve the sustainability of refrigerated transportation. This category of transportation is one of the most critical in food logistics, as it is responsible for ensuring the safety and quality of products, often under challenging transportation conditions. Therefore, the refrigeration system requires a large amount of energy for its correct operation, contributing to the overall emissions of the vehicle.

Aiming to contribute to the development of technologies and approaches that would assist in the production of energy in a sustainable way, helping to reduce emissions, the authors' research presents the elaboration of an electric refrigeration unit project integrated with photovoltaic generators installed on top of the refrigerated box of a light truck. The reference system used by the researchers is modified to include these photovoltaic generators, using the connection through a charge regulator to a set of batteries that power the refrigeration unit. The sizing of the photovoltaic generators is designed to cover the roof of the refrigerated box.

After sizing, a prototype of the system was assembled by the researchers and tested under stationary conditions. The results obtained demonstrate the ability of the solar system to significantly impact the net energy balance of the refrigeration unit. The performance of the system during a multi-drop urban delivery scenario and hot weather conditions was then evaluated using a dynamic lumped model simulation. The performance of the simulations is used to investigate the sensitivity to battery capacity size and shading conditions caused by urban canyon effects.

The final results discussed by Rossetti et al. [55] demonstrate that, in Athens' climate conditions, solar panels can provide from 65% to 112% of the energy consumed by the cooling unit, depending on the time spent by the truck in direct sunlight. One conclusion presented by the researchers is that larger batteries are only justified when the vehicle is exposed to long periods of direct light.

Calati et al. [56] present that 40% of the total amount of energy required for the transportation of refrigerated food is consumed by the refrigeration system. Therefore, the research presented by the researchers is justified based on the growth of refrigerated food transportation, requiring systems that guarantee the temperature of the food within a certain range.

To contribute to the resolution of this issue, the authors carry out the development of a new insulated wall for refrigerated vehicles involving phase change materials. The proposal is to consider a new wall composition consisting of a traditional polyurethane (PU) insulation layer surrounding a PCM layer. The thicknesses of the PCM analyzed are from 0.5 cm to 2 cm, on the inner face of the wall, in direct contact with the refrigerated chamber. Therefore, this addition of a PCM layer, with different thicknesses, to the traditional 5 cm insulated PU wall and its ability to maintain an adequate air temperature inside the chamber is analyzed. To maintain the temperature, three commercial paraffin waxes are investigated.

In the simulations carried out, the external solar irradiation was considered, where the hourly solar irradiation profile of a typical Italian summer day was used as input for the simulation by adopting the sol-air temperature model, where the variation of hourly solar radiation from 6 am to 4 am of a typical summer day in Vicenza (Italy) is considered. The refrigerated vehicle should be stationary, being the worst case scenario compared with the cases obtained at 40 and 80 km/h. The results obtained refer to a standard case where no doors were opened during the hypothetical journey, and the refrigerated chamber was considered empty of cargo.

The simulations are made considering a 2D transient numerical model of the truck's refrigerated chamber. The simulations and analysis performed by Calati et al. [56] confirm the feasibility from the point of view of thermal efficiency, since even the minimum thickness layer of the PCM considered ensured an adequate temperature inside the cell during almost the entire simulated period.

In turn, the work of Song et al. [34] elaborates the research based on the justification that refrigerated trucks have high rates of cargo damage, which is the result of the unstable temperature inside the cold room. It is presented by the research that, in recent years, electric refrigeration trucks have been designed where the all-electric refrigerated chamber is a new type of chamber featuring higher efficiency. However, this system also has a high rate of energy utilization. So, this is the research strand explored: how to reduce unnecessary energy consumption while ensuring the cooling effect and accuracy, and how to realize effective temperature control.

The refrigeration system of the electric refrigerated truck used as a reference for the research carried out by Song et al. [34] is composed of auxiliary equipment such as compressors, condensers, evaporators, expansion valves, and pumps. In the case of this vehicle, the compressor is driven directly by the high-voltage DC/AC motor. The compressor is the main source of energy consumption in the refrigeration system. According to the characteristics and specifications of the refrigeration unit, the compressor pump and other mechanical equipment are dimensioned with TRNSYS software (Thermal Energy System Specialists, Madison, WI, USA) [34].

To minimize energy consumption, a genetic algorithm (GA) is used to optimize the operating parameters of the refrigeration system. The optimization routine using GA determines the refrigerant flow rate, refrigerant transfer pump flow rate, and air supply flow rate. The results presented by Song et al. [34] show that the total energy consumption of the refrigeration system was reduced by an average of 0.5 kW, and the coefficient of performance was increased by 0.15 equally. With this, the researchers further discuss that the endurance of the refrigerated electric truck was also improved, and the cost of electricity consumption was reduced.

Venkataraman et al. [57] highlight in their research that the vapor compression system, used for refrigeration in trucks, is generally powered by the main diesel engine or an auxiliary diesel engine. The researchers explain that when the diesel engine is used, whether it is the main or auxiliary engine, it needs to run continuously at idle to power the cooling system, even when the truck is stationary. The engine cannot be switched off, as the temperature inside the refrigerated chamber will increase, compromising the quality and integrity of the food being transported. In addition, the loud noise generated by the diesel engine is discussed, and, in cases where TRUs are operated with electricity generated through the main engine, the engine must be kept idling, resulting in low-efficiency operating regions and increased emission levels.

The researchers propose to use an auxiliary power unit (APU) based on a solid oxide fuel cell (SOFC), thus harnessing the high-quality heat produced by the refrigerated truck equipped with a cooling system that is thermally driven. The technological novelty of the work in question is the utilization of thermal energy to power the refrigeration system. The concept consists coupling of a SOFC APU with a small-scale NH_3-H_2O-based vapor absorption refrigeration system (VARS) for a refrigerated truck application by using hot cathode exhaust from the SOFC stack to drive the VARS [57].

For this, the cooling load modeling and the SOFC and VARS units were developed. The results obtained by the modeling demonstrate the applicability of coupling a SOFC with a VARS on a small scale, representing cooling loads of up to 10 kW for application in TRUs. By harnessing the heat and power of the SOFC, the researchers achieve a total efficiency of up to 80% while also reducing the load on the main diesel engine. In this way, the diesel engine can operate at higher efficiencies and emit less polluting gases. However, the possibility of using the excess electrical energy from the SOFC to charge the vehicle's batteries was also discussed [57].

Wu et al. [58] base their research on greenhouse gas emissions from refrigerated trucks, as their use is increasing rapidly in developing countries. Thus, the focus of the research is the development of a comprehensive carbon footprint model for refrigerated trucks. This model aims to assess refrigerated trucks considering the life cycle impacts of their refrigeration systems, insulated bodies, and truck chassis, including all phases of production, transportation, installation, use, and repair of these elements and recycling.

The researchers' case study was conducted based on data from seven typical regions in China. The conclusion presented at the end of the research is that the carbon footprint is remarkably high in the use phase, accounting for approximately 96% of the total greenhouse gas emissions of the refrigerated truck. The critical points discussed are the fuel consumption, which is high to ensure the operation of the refrigerated chamber, in addition to the temperature difference between the exterior and the insulated interior of the truck body, reflecting the low efficiency of the chamber. Thus, the authors propose four low-carbon management strategies to mitigate the impact of TRUs on climate change, including improved energy efficiency, a clean electricity grid provision, environmentally friendly refrigerants, and alternative technologies for refrigeration.

Finally, we conclude that the works in the literature have focused on energy utilization and increasing the efficiency of TRUs, aiming at reducing energy consumption and pollutant emissions. To analyze more solutions, further supporting the research proposed here, the next section addresses the most relevant patents for TRUs.

2.2. State of Technique

To carry out this study, a search was conducted using a patent search system to consolidate and elucidate the existing technologies developed by the industries in the sector. Then, the system and search nomenclatures are explained. An analysis of the overview of patent applications over time is made. In addition, key technologies are presented and discussed.

2.2.1. Patent Search

The study of patents for the development of new products is widespread, either to be used to identify paths that can lead to different solutions or to be used as a source of inspiration for the project to be developed [59,60]. This approach helps to generate new ideas and compare them with existing solutions.

Currently, several software and search engines access databases that have registered the history of patents. As there is a large number of patents, there are different systems that can be used to classify the patents. According to da Silveira et al. [61], an important part of the patent analysis is the classification of patents. The classification facilitates the search for patents and can change the results of the analysis.

Patents can be classified under the European Classification (ECLA), the In Computer Only (ICO), or the DeKla, which is a German classification system, among others, and the best known and most usual is the International Patent Classification (IPC) [62]. The IPC consists of a complex and hierarchical classification system comprising 8 sections, 128 classes, 648 subclasses, about 7200 main groups, and approximately 72,000 subgroups [63]. It is worth mentioning that the IPC classification is carried out according to the functions of the patent, representing the functions of the developed technology and being an important characteristic for the development of the present work [64].

The IPC classification code is composed of 5 sets of alphanumerics. The first part of the code refers to the section, the second refers to the class, the third to the sub-class, and the fourth to the group followed by the sub-group. For example, in code B60H1/00, the B refers to the section which has the technological knowledge about Processing and Transportation Operations. The numeral 60 represents the class, which, in this case, is vehicles in general. Then, we have the H, which represents the sub-class, which, in this case, covers the connection of valves and their connection to inflatable elastic bodies in general. Therefore, only the term B60H refers to air conditioning for use in vehicles. To complete the code, we have groups 1 and 00, which are subgroups that are the inventions characterized only by the compositions, not having the structure of the tire as being important. Therefore, code B60H1/00 refers to heating, cooling, or ventilation devices for vehicles.

Initially, a search was carried out to identify the IPC codes related to the scope of this study, i.e., energy regeneration of truck trailer for use in transport refrigeration unit. The IPC Official Publication web application (IPCPUB v9.5) [65] was used to perform this search, and no IPC symbol exactly matched the scope. However, the IPC code B60P3/20, which is related to "Vehicles adapted to transport, to carry or to comprise special loads or objects - for transporting refrigerated goods" is very close to the scope of the work (partially meeting it) and was selected for use in the search strategy (Group 1, Table 2). To complement the strategy, a combination of keywords related to energy regeneration (Group 2, Table 2) was used with the IPC code. Combinations of keywords and classifications in patent searches are usual, as reported in [66,67].

Table 2. Groups of patent searches in Orbit™ Intelligence database.

Group	Terms	Fields
1	B60P3/20	IPC
2	regenerat + OR generat + OR recover + OR recuperat +	TI/AB/OBJ/ADB/ICLM
3	heat OR cold OR ozone	TI/AB/OBJ/ADB/ICLM

Fields: TI: Title; AB: Abstract; OBJ: Object of invention; ADB: Advantages; ICLM: Independent claims.

To conduct the patent search, Orbit™ Intelligence (FamPat) commercial software from Questel was used, which also has an analysis module. Other works that used this platform include da Silveira et al. [61], Sinigaglia et al. [68], Sinigaglia et al. [69]. This database groups patents into their families (patent applications in other countries) and allows for the combination of search fields with the use of basic Boolean operators (AND, OR, and NOT) and other specific ones, such as proximity operator W (the adjacent terms in the order specified inside the same sentence). The truncation symbol "+" replaces any number of characters. Hence, the groups of search strategy are presented in Table 2.

The final search strategy combined the previous groups as follows: 1 AND (2 NOT (3 W 2)). It also retrieved 906 patent families, with first application dates ranging from 2003 to 2023. Group #3 was added to eliminate specific results of thermal regeneration and ozone generation, identified in a previous exploratory search.

2.2.2. Overview of Patents over Time

An overview of the patents retrieved by the search was carried out with the number of applications (first application) of patent families in each year of the period. Then the countries (top 5) and main organizations were identified by the number of patent applications. The relationships between the organizations were identified in terms of patent citations and collaborations. All data were obtained through the Orbit™ Intelligence software (v2.0.0, Questel, Paris, France).

Figure 1 presents a general trend of technology development, showing a significant increase in the number of patent applications (patent families) after 2015. This increase can be related to the regulations that have been concerned with the impact of pollutant emissions in the atmosphere. These regulations govern companies that develop programs to reduce fleet emissions, being responsible for the development of technologies that control or minimize the emission rate.

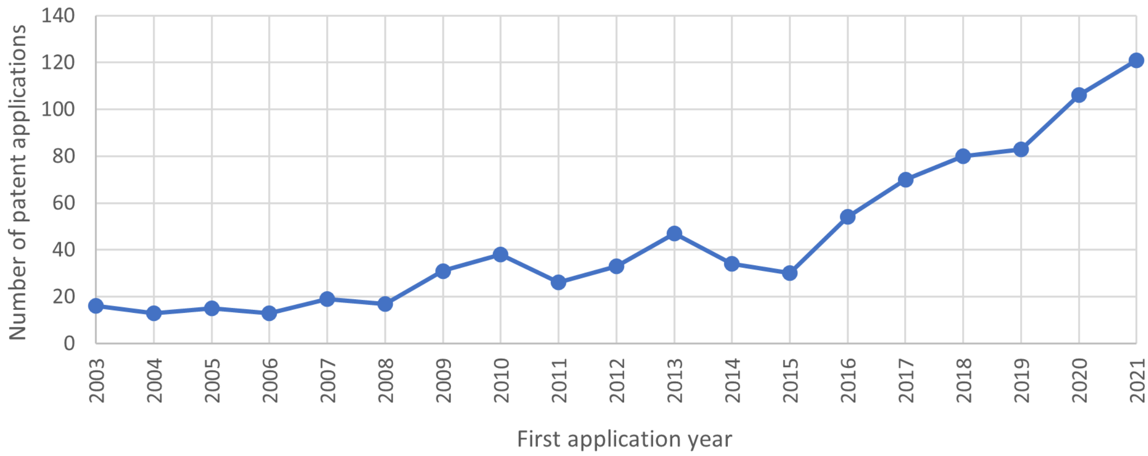

Figure 1. Number of patent applications (patent families) over time.

China has played a significant role in driving the evolution of total patent filings since 2015, as seen in Figure 2. Having become the world's largest investor in renewable energy [70], China has been directing part of its investment into systems that enable emissions reduction and energy reuse, as can be seen from the number of patents. To a much lesser extent, the US and Korea have also seen an increase in patent filings over the last period. Filings from Japan, Germany, as well as those processed by the PCT (Patent Cooperation Treaty) identified by the "WO" and the European Patent Office, have only fluctuated. Data for the years 2022 and 2023 were excluded from this analysis, mainly due to the confidentiality period of the patent applications.

Figure 3 displays the organizations that were particularly prominent during the given period. The first two are the leading companies in the refrigeration segment and have a portfolio of patents, most of which are within the period of validity or pending evaluation. Each of the following eight organizations has only a fraction of the deposits of the leaders and it is worth mentioning that among them, two universities are in the fourth and eighth position.

Regarding the relationships among the largest patent applicants, Carrier™, Thermo King™ and Daikin™ Industries have the highest number of citations among themselves, which may indicate that their developments are aimed at improving solutions in relation to their competitors.

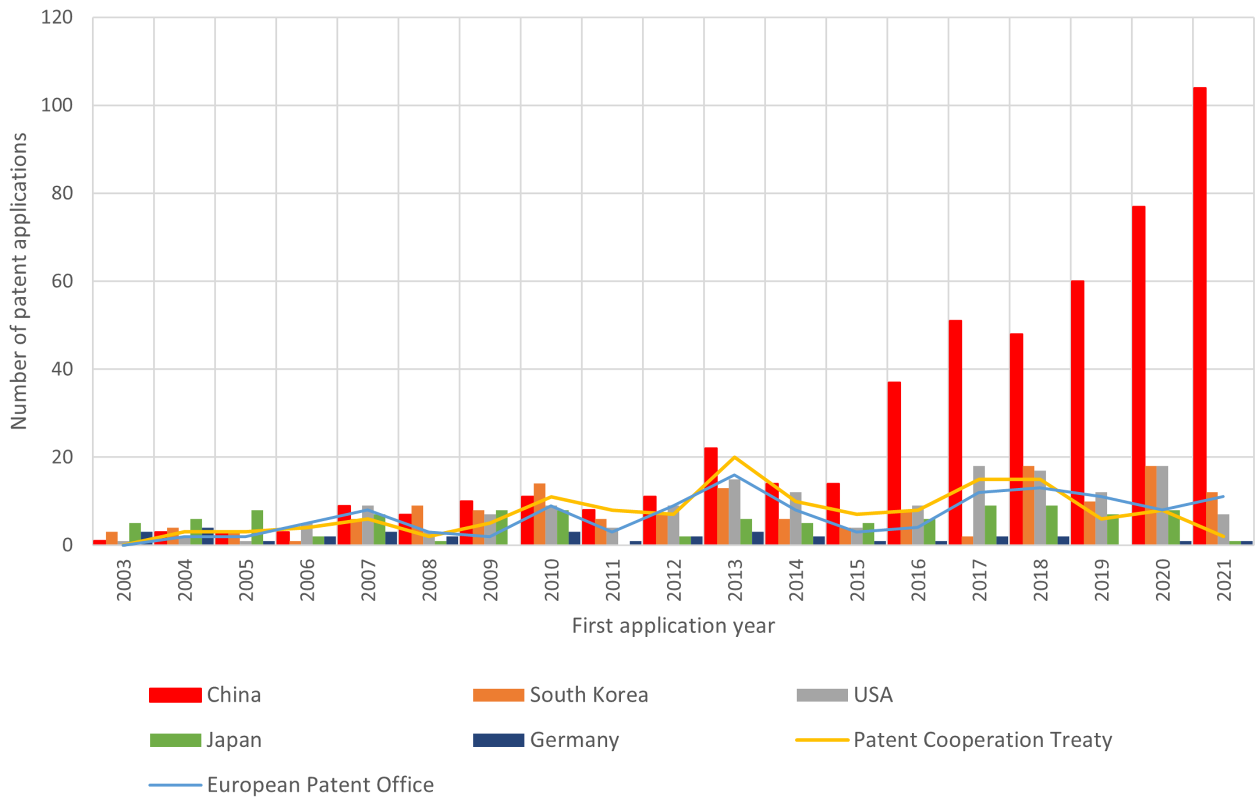

Figure 2. Publication country by first application year.

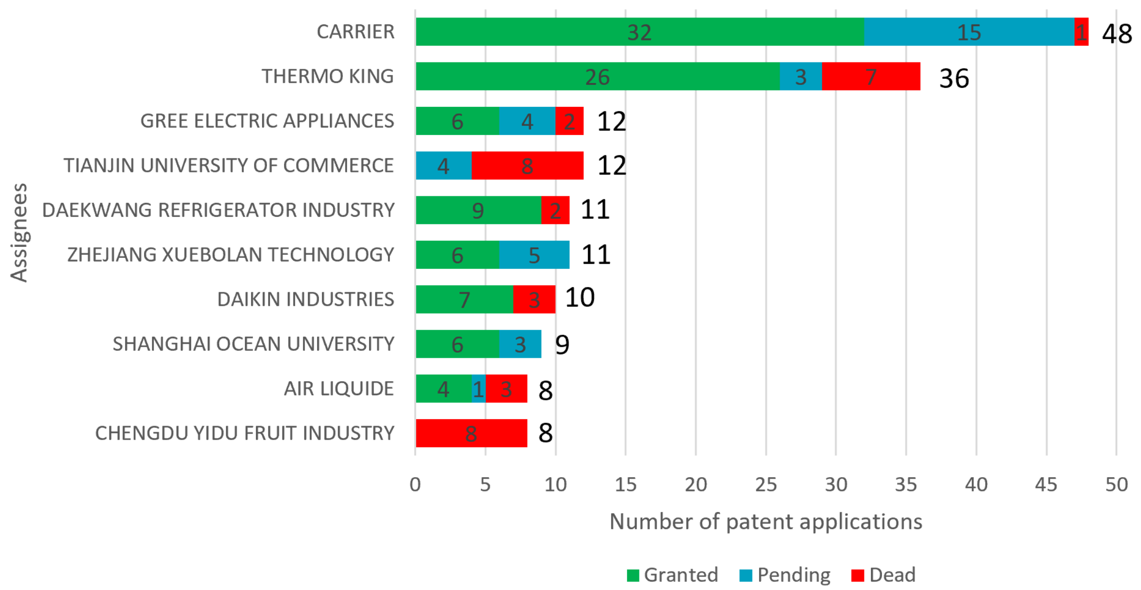

Figure 3. Main assignees by legal status of their patents.

2.2.3. Impacts of the Technologies

The patents obtained using the procedure described in Section 2.2.1 helped to identify existing technologies for regenerating energy from truck trailers for use in TRUs. This search was carried out using the terms previously described (Section 2.2.1) to obtain patents related to this specific topic.

Additionally, a further analysis of the patent portfolios of some important companies was conducted. The assignees field was used in the Orbit™ Intelligence software for this analysis. Some selected patents are presented in Table 3.

Table 3. Selected patents.

Number/Title	Year	Assignee	Object of Invention
US17452888: Transport refrigeration system energy management system and method [71]	2021	Carrier™	A transport refrigeration unit with an electric generator linked to an axle of trailer which charges an energy storage system to provide power to the refrigeration unit.
BR102021020014-6: Trailer, auxiliary axle for a trailer, device and method for controlling the coupling and/or uncoupling between a trailer axle and an auxiliary motor [72]	2021	Fras-le™	A truck trailer with a device for coupling and decoupling the auxiliary motor of an auxiliary axle. It also includes a method to manage the connection and/or disconnection between the trailer's axle and the auxiliary motor associated with it.
US9969253: Hybrid vehicle [73]	2014	Volvo Trucks™	Hybrid vehicle with an electric axle that can be driven from an energy accumulator or an external power source.
DE102013014305: Vehicle trailer [74]	2013	Man Truck and Bus™	A truck trailer with an electric motor and an accumulator for driving a cooling compressor and other accessories.
US8834314: Method and device for regenerative braking for a vehicle [75]	2012	Scania™	Compact construction regenerative brake device mounted on truck transmission.

An example of a selected patent of Carrier™, an important company in the sector identified in this search, is the document US17452888 [71]. The technologies presented in this patent refer to a transport refrigeration unit with an electric generator linked to an axle of a trailer, which charges an energy storage system to provide power to the refrigeration unit. The patent also claims an energy management system to control its generation, storage, and use. In addition, different types of electric generators are considered, such as a permanent magnet AC generator, an asynchronous generator, a synchronous AC generator, and an engine-driven DC generator.

Another example of technology is the Fras-le patent no. BR102021020014-6 [72]. In this document, a technology developed in the Brazilian market deals with a truck trailer with a device for coupling and decoupling the auxiliary motor of an auxiliary axle. It also includes a method to manage the connection and disconnection between the trailer's axle and the auxiliary motor associated with it, depending on the traction or regeneration mode and driving conditions.

To expand the view of existing technologies, patents related to energy regeneration in trucks that did not have TRU were also analyzed in the cases of large companies in the segment, such as Volvo Trucks™, Man Truck and Bus™, and Scania™. The patent deposited by Volvo Trucks™ involves operating a hybrid power system in several alternative modes of operation. The modes of operation include an autonomous power supply mode involving operating the traction motor using the energy storage system; using an external power supply in the power supply mode, involving connecting the DC/DC converter and operating one or both traction motors; using an external source of electrical power; and finally, a combination of using autonomous and external power in the power supply mode involving operating one of the traction motors using the energy storage system and the other motor using the external source of electrical power [73].

Man Truck and Bus™ claim the invention, which relates to a vehicle trailer for a traction unit. The vehicle trailer is connectable to a traction unit, which has an electric drive system for driving this traction unit so that the vehicle trailer can be towed by it. The electric drive system has at least one electrical energy storage system that can be coupled to the electric drive system of the traction unit to provide power to the drive system of the traction unit, a rechargeable accumulator, or a fuel cell [74].

For its part, the Scania™ patent proposes a regenerative braking device of compact construction, high reliability, and operational safety. The device consists of a regenerative brake for a vehicle having an internal combustion engine with an output shaft and a gearbox which is configured to connect the output shaft to the drive wheel. The system comprises an output shaft of the combustion engine, an input shaft of the gearbox, an electric machine, and a planetary gear. The method is described as follows: control the engine and the electrical machine so that a substantially torque-free state is created between the engine output shaft and the planetary gear, then disconnect the engine output shaft and the planetary gear from each other by moving a movable piston from a first position to a second position, disconnecting the engine output shaft and the planetary gear, and selectively move the piston to a third position to act on a connecting device to selectively connect the planetary gear to an element that is fixed relative to the planetary gear or disconnect them by moving the piston out of the third position [75]. A summary of the most important technologies raised from this study is presented in Table 3.

With the analysis of these patents explained and the others obtained with the search discussed in Section 2.2.1, we identified some common and basic characteristics among them, making it possible to compare the main components and functions that are described by the companies. This survey is presented in Table 4. The identification of these characteristics allows us to understand the approaches used by companies to promote the technological evolution of these systems. The description of these components and functions will assist in the elaboration of the method proposed in this article.

Table 4. Components and functions identified in the patents analyzed.

Component	**Function**
Electric motor	Convert energy
Differential with reduction	Extract energy
Battery	Store energy
Fuel cell	Convert energy
Photovoltaic panels	Convert energy
Cooling system	Provide cold air
Compressor	Compress air
Electric generator	Convert energy
Wheels	Extract energy
Gears in the wheels	Generate torque
Frequency inverter	Control speed
Electronic braking	Control braking
Control unit	Control the system
Voltage converter	Convert voltage
Cardan shaft	Conduct energy

3. Results

3.1. Proposed Method for Opportunity Technologies Gap Search

Drawing upon an extensive literature review encompassing published studies and existing patents concerning energy harvesting techniques adaptable to TRUs, the subsequent phase of this research involves delineating the core functionalities within the current products. This process facilitates the formulation of a functional framework, which in turn serves as the foundation for a morphological matrix. The integration of these sequential stages holds the potential to yield a diverse array of inventive component combinations, each tailored to distinct functions, thereby fostering the emergence of pioneering designs for energy harvesting devices applied to TRUs.

3.2. Definition of the Main Functions

According to Pahl et al. [76], one important part of the design process is the conceptual design. This process consist of identifying the problems through abstraction, turning them into functions, and connecting the working principles and the basic solutions to elaborate a principle solution [77]. Normally, the design concept generation can occur by searching to fulfill functional requirements and generating a combined concepts design [78,79].

The product design process centers around its functional analysis, given that the resulting product is a system composed of its main function and sub-functions. Consequently, a precise and comprehensive delineation and depiction of the product's functionalities is the key to solving its design challenges [80]. Therefore, the relevance of the product's functional analysis is emphasized, since it is through this process that possible enhancement opportunities can be identified and applied in the development of new products.

A fundamental aspect of engineering design is understanding the product in terms of its function [81,82]. Therefore, in this paper, the patent knowledge associated with papers' reported technologies is applied to identify the main product function and to assist the designer in the task of creating a new product concept, as presented in Figure 4. Thus, in the first part of the study, we present the state-of-the-art reading of the literature's published concepts, followed by the existing patent concepts acquired based on a systematic research methodology. Moreover, the patent research also includes an evaluation of the most relevant technologies and companies for the desired product, which, in this case, are the regenerate energy systems applied in trucks. These strategies propose broadening the possibilities of searching for solutions and the consequent expansion of alternative thinking to generate ideas in the subsequent stage of the creative process [83].

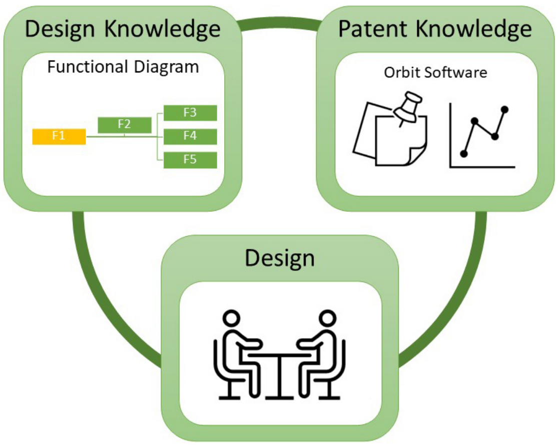

Figure 4. Schematic of proposed model.

After conducting this search, the main functions of existing technological products were identified. For the development of new ideas and the collection of additional information from other patents for new developments, the functional analysis system technique was used [84].

Realizing the functional analysis system technique, the design group can use a creative method, or concept development, to assist in the development of different and complementary solutions for the problem defined. According to Weber and Condoor [85], an effective method to execute concept generation is to divide the design problem/task into functions and then create several solutions to each function, building a solution or morphological matrix.

3.3. Functional Structure

The structure of functional analysis is presented in several representational formats, such as the Function Tree, Data Flow Diagram, Functional Diagram, or Diagram of Functional Analysis System Technique (DFAST). In any of the structures, it becomes necessary to determine a concept that represents the global function but also the search for subfunctions that demonstrate less complex interactions of the system description [86].

The Axiomatic Design provides functional meaning in product development, identifying the customer requirements and their relationship with the design parameters [87]. This theory is based on two axioms, the Axiom of Independence and the Axiom of Information [88]. The Axiom of Independence provides that the functional requirements must remain independent. The Information Axiom predicts the minimization of the information content of the project [89,90].

The Axiom of Independence is the first of the mentioned axioms, and it deals with the importance of keeping the independence between functional requirements and design parameters. Thus, the number of functional requirements will be defined as the minimum number of independent project requirements that characterize the analyzed object [89]. Therefore, this design principle should be considered over the whole product development concept and will be used in the procedures applied in this paper.

Stone and Wood [82] discuss in their work that the function is a description of a feature and can be expressed by a verb plus a substantive. In addition, the functional model provides a common design language that can be used to model the functionality of products.

The most commonly used representation of function analysis is the DFAST. This diagram should have been used to organize and visualize the function of the project [91]. The DFAST system relies on analyzing the essential functions to know which items are designed and then focuses on making improvements on those functions [92].

Normally, in the functional analysis study, it is necessary to decompose the input overall function into several detailed and concrete functional effects based on the product desired. Then, the overall function is decomposed into several small subfunctions, each of which performs a single independent sub-task with observable results and achieves one of the functional effects of the function [93]. However, in this work, we are focusing on the main functions of the product. For the survey of these functions, the patent search approach is introduced. This search aims to identify the main functions of the already developed systems that constitute the ideas of energy regeneration in heavy-duty vehicles.

The following DFAST function was obtained based on the systematic literature and patent review previously presented in this paper. Therefore, DFAST, Figure 5, starts with the root function "Access gradient". This function has the purpose of allowing state variations of the same unit (for example, low and high temperature, speed, pressure, and others). During the definition of the DFAST, it was necessary to place functions to answer the question of "how" there was passing from the higher-order functions to the lower-order functions and to answer the question of "why" there was passing from the lower-order to the higher-order function [94]. Another important function that was defined is to "Extract power from the system"; this function consists of a physical principle. Moreover, other functions were generated to complete the diagram.

Conducting an analysis at the subsystem level is an effective method of avoiding the information overload that is typical of an analysis at the product level. Furthermore, a detailed analysis of each component of the product would not be feasible due to the large number of parts [91]. Because of that, the DFAST enabled the work group to identify the major functional subsystems, the cluster modules:

- Manage Energy;
- Regeneration System;
- Traction System;
- Refrigeration System;
- Alternative Source or Complementary.

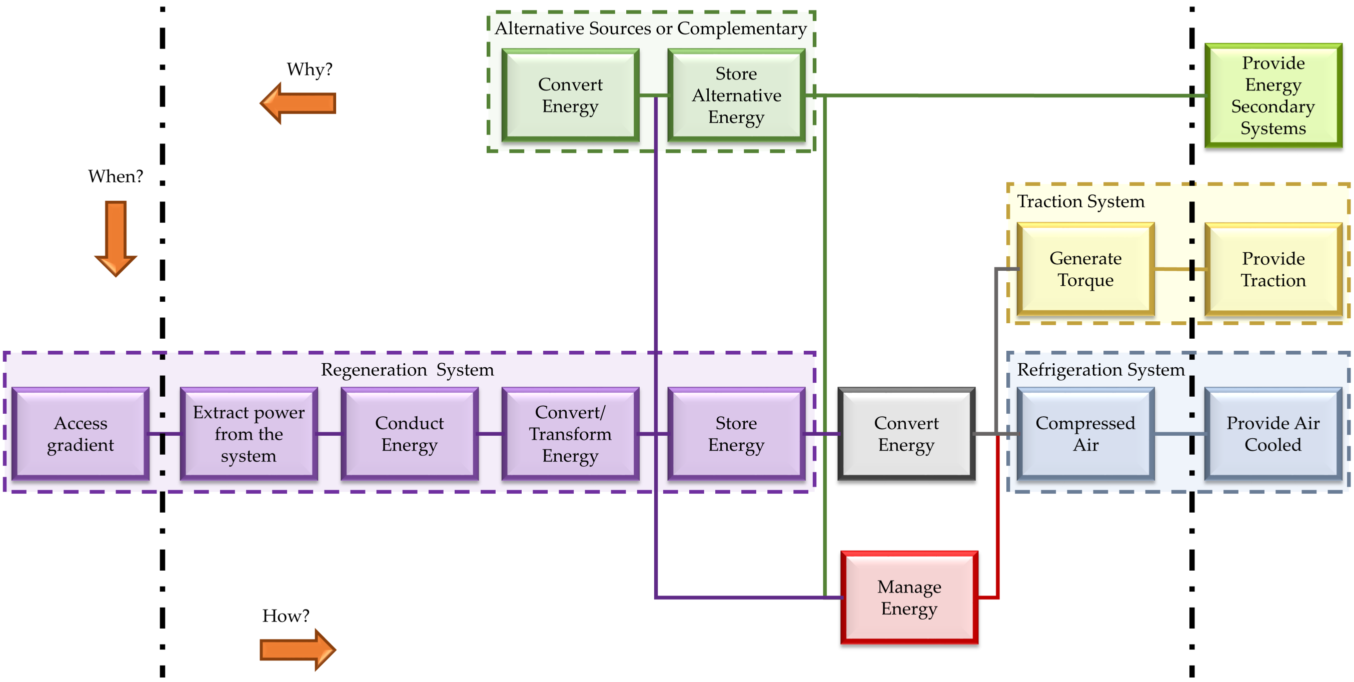

Figure 5. DFAST of the regeneration system module.

The "Manage Energy" module includes all functions related to the control and power management of batteries, engines, and other systems. "Regeneration System", in the view of this work, means possibilities to convert the truck kinetic energy into electric energy to charge the battery responsible for powering up the refrigerated unit of the TRU. The "Traction System" is considered only if the extra power applied to move the truck is used in the developed TRU concept. The "Refrigeration System" refers to the TRU system responsible for keeping the cargo at the desired temperature. Finally, the "Alternative Source or Complementary" system module aims to assist other components, generating energy by means of solar panels or even combustion generators that may be used under the condition that is not possible to obtain enough kinetic regenerated energy, which should be coming from the main power source in the developed concept. Based on the presented cluster modules, it is possible to conclude that a modular concept can be easily applied to fulfill the required functions of the system [95].

3.4. Morphological Matrix

According to Cross [96], the generation of solutions is an important aspect of the product designing. Therefore, the next presented step is to define solutions for each of the sub-functions in the DFAST presented in Figure 5. A solution reflects the physical effects and the elementary form in which it is used. In this case, the focus is on the cluster of the regeneration system and assisting in the generation of the morphological matrix used.

The morphological matrix is a method to organize alternative solutions for each function and combine them to generate many solutions [85]. As the main interest of this study is the search for novel kinetic energy harvesting concepts, which can be applied to TRUs, the presented morphological matrix is based on the "Regeneration System" block shown in Figure 5.

The solutions for the five functions of the "Regeneration System" module are compiled in the morphological matrix, as shown in Figure 6. If we take one option regarding each of the functions from the solution matrix, it will generate a product concept variant, which may lead to a potential novel solution. It is important to highlight that there is an interdependence among the solutions of the functions. Once a solution is chosen for a particular function, some solutions for the other functions become unfeasible and, consequently, should not be selected. For example, once "Temperature" is chosen as a solution for the function "Access Gradient", "Mechanical Transmission" ceases to be a viable solution for "Extract system energy" and, hence, cannot be selected when combining solutions. Once all the concept variants have been established, the designer must evaluate them in order to determine the best ones according to the defined design criteria.

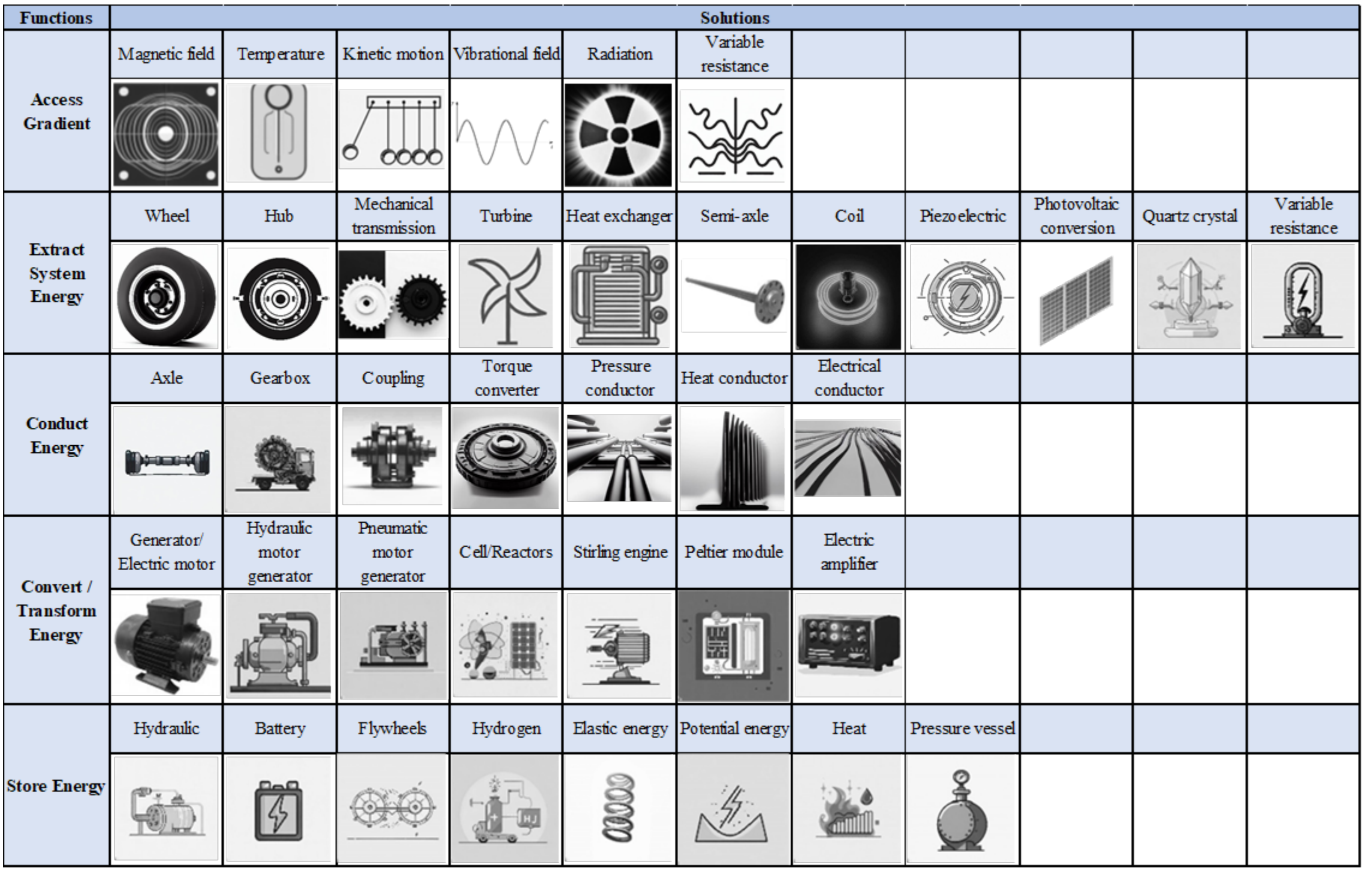

Figure 6. Morphological matrix for the regeneration system.

To build the morphological matrix, all the components that are associated with the functions identified in the state-of-the-art and state-of-the-technique stages were added. However, these pre-existing solutions do not cover all the possibilities of components that can be used to perform a given function. Therefore, brainstorming was carried out among the members of the research group to come up with new ideas for solving the problem.

The brainstorming consisted of defining a solution to the issue of regeneration systems. This method is based on the precept of the spontaneous release of the imagination without restrictions or impediments to the volume of ideas. The brainstorming aims to ensure that a group of people generate as many ideas as possible, without any initial need for them to be plausible, for the solution to a given problem. This method promotes the release of the flow of thought that stimulates new ideas, arriving at a path of logical and applicable solutions. With this process, it was possible to identify new solutions and extract from them the components for each function described in the morphological matrix.

4. Discussion

After identifying the components for each function using articles, patents, and brainstorming solutions, the research group held further discussions to identify new components that had not yet been listed. In this way, it was possible to arrive at the final morphological matrix shown in Figure 6.

To calibrate and check the components listed in the morphological matrix, four solutions were drawn up, as shown in Figure 7. The first solution obtained (A) is the result of one of the patents surveyed in the state of the art. This solution uses kinetic movement to access the gradient associated with the wheel hub to extract energy from the system, while a system of gears is used to conduct the energy, and an electric generator and a battery system are used to convert the energy and store it, respectively. This solution is the subject of patent US20190329650 A1, deposited by Emerald Technology Partners (USA) [97].

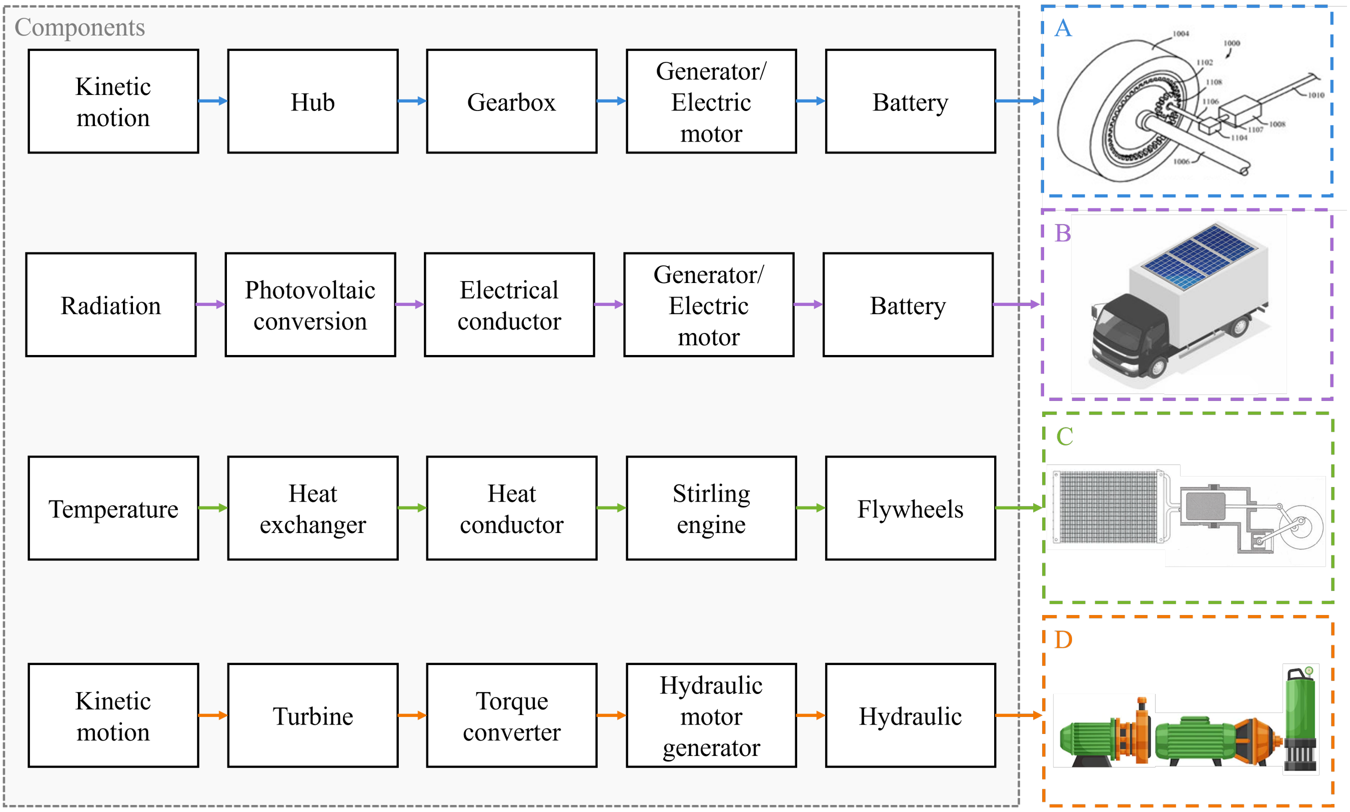

Figure 7. Four solutions obtained by morphological matrix. Solution (**A**) is based on the vehicle's wheel-mounted system. Solution (**B**) is based on photovoltaic energy conversion. Solution (**C**) uses temperature via a stirling motor. Solution (**D**) uses a turbine and a torque converter.

The second solution (B) obtained in the morphological chart represents one of the articles surveyed in the state of the art. This solution is based on the use of photovoltaic panels on the top of the TRUs, converting solar radiation energy into electrical energy and storing this energy in a battery system. With these first two solutions, it can be seen that the morphological framework obtained is well-calibrated, as it is possible to reach solutions that already exist in the literature.

To assess the ability to generate innovative solutions to the problem, two new solutions were proposed. Solution C, shown in Figure 7, describes a new approach based on using temperature to access the gradient. This possibility involves using a Stirling engine to convert thermal energy into kinetic energy, storing this converted energy in flywheels. This possibility is innovative in all the works and patents that were surveyed in this study.

Finally, solution D also presents an innovative solution principle. Although it also uses kinetic movement to access the gradient, as in solution A, this solution has a different approach. The energy conversion is carried out by a turbine which, together with a torque converter and a hydraulic motor, transforms the kinetic energy into pressure energy (flow energy). This solution explores other methods of solving the problem which, like solution C, were not observed in the papers and patents surveyed.

The morphological matrix showed that, despite the amount of work performed in the area, there is still plenty of scope for innovation in the energy regeneration system. Many of the patents surveyed, despite following different inventive principles, use the same components and approaches. The proposal to use the tools described in this paper in the area of product development has proven to be applicable, representing an interesting aspect of the process of creating new products and innovative solutions. Thus, the methodology described for scanning for opportunities to create new technologies is completely applicable and possible to use for the creation of various new products, and is applied in this work to technologies aimed at recovering energy in TRUs.

5. Conclusions

This research provides a comprehensive overview of the current trends in energy recovery technologies, with a specific focus on the applications of TRUs. The study is based on a systematic opportunity scan covering both potential advances presented in academic articles and innovations registered in patent banks. Academic research that discusses experimental and theoretical technologies and presents their respective gains was covered. In contrast, patents point out the paths that should be avoided in order to generate new solutions and serve as sources of inspiration for the development of innovative projects. In addition, patents can be used to evaluate new solutions by comparing them with established technologies and concepts. The search for patents in the area of heavy vehicles with refrigeration units returned a significant number of results, but we have highlighted five of them. This extensive search made it possible to identify the main components and functions contained in both the literature and the patents.

Through this meticulous analysis of the state of the art and existing patents, it was possible to identify the key functions that integrate the technologies in question through a critical evaluation of the solutions already available. Furthermore, by better understanding the advantages of each function in the operation of the system, it was possible to explore new possibilities for technologies that meet market demands. A functional analysis was carried out using the DFAST approach.

Based on the essential functions identified, a morphological matrix was developed that maps the components and principles available in each of the five sub-levels of the energy recovery system of a possible new product. By using this matrix as an analysis tool, it was possible to track down all the solutions cataloged in the literature review while at the same time discovering unexplored combinations of components that have the potential to give rise to innovative solutions. To demonstrate the application of the proposed methodology, one solution was obtained from the state-of-the-art review, one solution was evidenced in patents, and two completely innovative solutions were found that were not observed in the vast review that was carried out. Therefore, the broad methodological approach presented and discussed in this research makes it possible to create new technologies in the context of TRUs.

It is important to note that the solutions obtained by the morphological matrix are purely conceptual, requiring a subsequent detailed design stage to explore the constructive possibilities. This stage requires the development of simulations and analyses to validate each proposed solution, taking into account the operating conditions. Therefore, only after these evaluations can the most suitable solution be determined, based on robust data and extensive analysis.

Author Contributions: Á.C.d.C.: conceptualization; investigation; formal analysis; writing—original draft; writing—review and editing. M.H.R.M.: methodology; investigation; writing—original draft; writing—review and editing; software; formal analysis; visualization. L.C.D.A.e.S.: conceptualization; methodology; writing—original draft; writing—review and editing; formal analysis; supervision; resources. F.L.S.: writing—review and editing; visualization; investigation. R.R.K.: methodology; investigation; writing—original draft; visualization. J.J.E.: conceptualization; methodology; writing—review and editing; supervision; project administration. F.G.D.: conceptualization; methodology; supervision; project administration. All authors have read and agreed to the published version of the manuscript.

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Abbreviations

The following abbreviations are used in this manuscript:

AB	Abstract
AC	Alternating Current
ADB	Advantages
APUSOFC	Auxiliary Power Unit Solid Oxide Fuel Cell
CAPES	Coordination of Superior Level Staff Improvement
CNPq	National Council for Scientific and Technological Development
DC	Direct Current
ECLA	European Classification
EPA	Environmental Protection Agency
EV	Electric Vehicles
FamPaT	Family Patent
FAPESP	São Paulo Research Foundation
DFAST	Diagram of the Functional Analysis System Technique
FUNDEP	Research Development Foundation
GA	Genetic Algorithm
ICO	In Computer Only
ICLM	Independent Claims
IPC	International Patent Classification
LabSIn	Integrated Systems Laboratory
MDPI	Multidisciplinary Digital Publishing Institute
OBJ	Object of Invention
PCM	Phase Change Material
PCT	Patent Cooperation Treaty
PrInt	Institutional Program for Internationalization
PU	Polyurethane
TI	Title
TRUs	Trucks with Refrigeration Units
UFC	Federal University of Ceará
UNICAMP	University of Campinas
US	United States of America
VARS	Vapor Absorption Refrigeration System
WLTC	Worldwide Harmonized Light Vehicles Test Cycle

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