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Capabilities of Nearly Zero Energy Building (nZEB) Electricity Generation to Charge Electric Vehicle (EV) Operating in Real Driving Conditions (RDC)

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Abstract: The growing number of electric vehicles in recent years is observable in almost all countries. The country's energy transition should accompany this rise in electromobility if it is currently generated from non-renewable sources. Only electric vehicles powered by renewable energy sources can be considered zero-emission. Therefore, it is essential to conduct interdisciplinary research on the feasibility of combining energy recovery/generation structures and testing the energy consumption of electric vehicles under real driving conditions. This work presents a comprehensive approach for evaluating the energy consumption of a modern public building–electric vehicle system within a specific location. The original methodology developed includes surveys that demonstrate the required mobility range to be provided to occupants of the building under consideration. In the next step, an energy balance was performed for a novel near-zero energy building equipped with a 199.8 kWp photovoltaic installation, the energy from which can be used to charge an electric vehicle. The analysis considered the variation in vehicle energy consumption by season (winter/summer), the actual charging profile of the vehicle, and the parking periods required to achieve the target range for the user.

Keywords: electric vehicles; energy consumption; Real Driving Conditions; renewable energy generation

1. Introduction—Motivation behind the Topic

Even though the phrase "zero-energy-building" has been used in science since 1976, the passive house idea appeared much earlier. Still, the literature review indicates a great demand for more analytical publications about constructed nZEB buildings put into use. The group of stakeholders for this concept is still limited in many countries. More and more documented and analyzed best practice will help to make nZEB more common [1]. This article combines interdisciplinary topics of the possibilities of generating energy from renewable sources and the analysis of this energy consumption by electric vehicles currently used in passenger transport. It also includes a brief history of photovoltaic roof systems and electric cars development. The history of technology helps us to see specific dependencies related to scientific and technological progress, draw conclusions, and rationally plan further activities. Therefore, when studying the future, one should also learn about the history of the technologies studied. According to the authors' systematics, the article is divided into sections to present the possibilities of connecting modern architecture with modern electromobility.

Although using solar energy has a long history dating back to ancient times (Figure 1), the basis for modern designs was the active solar energy systems of the Industrial Revolution and the first half of the 20th century [2].

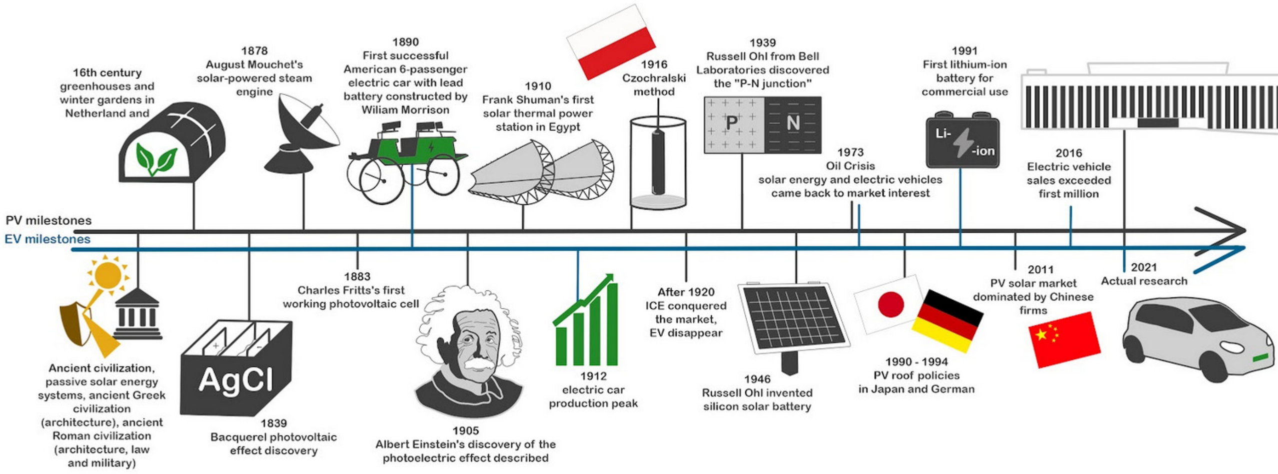


Figure 1. Timeline of analyzed aspects (own work based on [2–7]).

Today's photovoltaic roof systems are possible thanks to Russell Ohl from Bell Laboratories, who invented a "P-N junction" in 1939 and invented the silicon solar battery in 1946. Although solar technology, when compared with low prices of fossil fuels, was too expensive for everyday use, this was an excellent invention for space program needs. The Oil Crisis in the 1970s and 1980s contributed to the US government policy changes which manifested, for example, subsidies and funding systems. The solar energy industry development was also stimulated by the PV roof policies in Japan and Germany in the 1990s. In the first decade of the 21st century, Chinese companies entered the solar business, strongly supported by their government, and by 2011 they dominated the PV market [3].

The turn of the 19th and 20th centuries is also the time of significant electric vehicle development, from the dawn of electric vehicles and the first successful American 6-passenger electric car with lead battery constructed by William Morrison in 1890 to the production peak in 1912. After the 1920s, internal combustion engine cars, thanks to their significantly lower prices, conquered the market [4]. Five decades later, once again, thanks to the Arab Oil Embargo in the 1970s and environmental protection movements, the interest of the market in electric vehicles increased again [5]. The milestone moment for the electric vehicle market came in September 2015. The sales of plug-in electrified vehicles (PEVs) worldwide exceeded the first million, with 62% battery-electric cars and 38% plug-in hybrids sold [6].

Efficiency of solar cells is still growing. It is expected that, in the next three decades, solar and wind systems will play a pivotal role in the energy sector [7]. Photovoltaic systems are also considered a competitive technology for charging electric vehicles (EV) [8]. This article presents the capabilities of PV modules in nearly Zero Energy Building (nZEB) to supply electric vehicles (EV). The integration of the PV system with electric vehicles is the subject of numerous investigations [9–11].

In the previous article [12], the authors adopted data from literature [13,14]. Here, a questionnaire survey was conducted among the Faculty of Architecture (FA) and the Faculty of Engineering Management (FEM) building users. Due to limitations caused by COVID-19 prevention, countermeasure, and eradication, a short survey was requested from users of the building via email of faculty offices. The survey was prepared with the use of Google Forms and consisted of five mandatory questions and one optional question.

The survey collected information regarding the distance to work (in kilometers), the daily distance travelled by car during the working week (Monday to Friday), and the daily distance travelled by car on weekends (Saturday and Sunday). Moreover, the survey included two more questions about whether the user would be interested in using an electric vehicle if the energy to power it came from their place of work (FA and FEM building) and if the energy to power the vehicle came from their place of residence. Finally, respondents were asked if they already owned vehicles with an option of external source charging.

The survey was completed by 103 users. If the energy to power the vehicle came from their workplace, 81 respondents (79%) answered that they would be interested in using an electric car. If the vehicle's power was provided by energy from their house, only 68 respondents (66%) would still be interested in driving EVs. Only eight respondents (11%) said they owned a vehicle that can be charged from an external source (car, scooter, or bicycle). The survey also collected information about the distance to work (Figure 2).

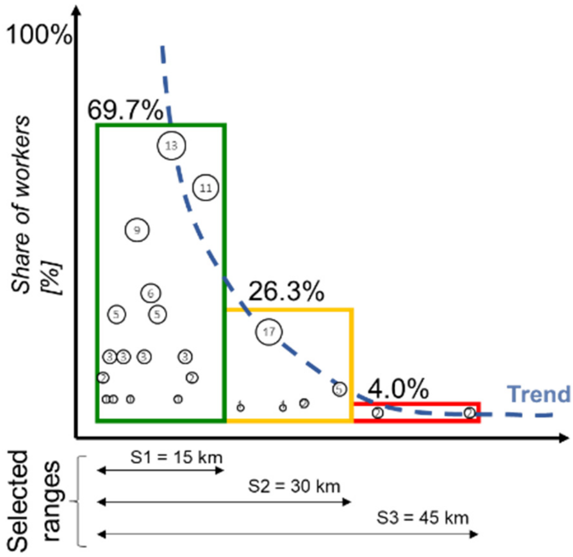


Figure 2. Average travel distance (km) questionnaire among people using the nZEB building in Poznan University of Technology complex (own survey).

As shown in the survey, most users travel small distances per day, which will result in small daily energy consumption of the electric vehicle. With respect to this, the user can decide whether to charge the vehicle daily for a short period of time to recharge the consumed energy or charge the vehicle every few days collecting more energy during working hours.

2. nZEB Form and Function versus Location Aspect of Photovoltaic Cells

The building of the Faculty of Architecture and the Faculty of Engineering Management is located in the northern part of the "Warta" campus of Poznan University of Technology (Figure 3). Its orientation is strictly determined by the permissions resulting from the Local Development Plan.

Figure 3. Location of the nZEB building (research object) on the Poznan University of Technology campus.

The form of the building, as well as additional provisions, was defined by the quarter of buildings mentioned in the document. A simple cubic building designed on a rectangular plan, with proportions inspired by the Parthenon and adopted assumptions of a nearly zero-energy building, was designed to fit the existing urban layout and ensure that spatial and landscape values remained unchanged. As a result, a four-level building was created, enhanced by rhythmic vertical stripes. Determining an appropriate height for the attic contributed to mask all technical devices located on the roof, including photovoltaic panels on the roof (Figure 4).

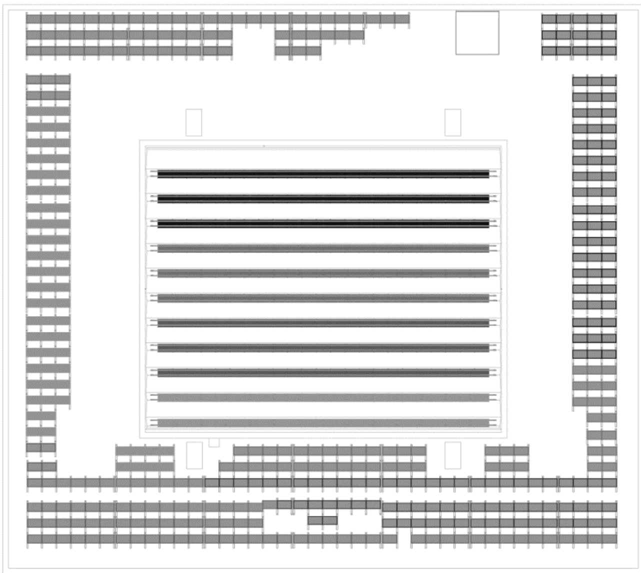


Figure 4. Arrangement of photovoltaic panels on the roof.

The function of the building was designed with reference to the functional structure of the Faculty of Architecture and the Faculty of Management Engineering, taking into account the demand for space, as well as the number of employees and students. To harmonize the functioning of both departments, the facility was divided into zones corresponding to units, with a central internal courtyard that constituted a common part. What should be noted is the building's educational character and that it serves as a basis for educating architecture students. Therefore, it was decided to carefully introduce elements that were to illustrate the overall functioning of the facility to students. That is why all elements of the structure intentionally have not been covered with plaster, and the technical equipment has been exposed and displayed. While other parts of the building have their functional justification, the courtyard covering is also a substructure for photovoltaic cells, and its shape is dictated by technological requirements of the facility with almost zero energy consumption. There will be two outdoor car parks on the site and a small car park on the lower floor of the building.

Having such a developed parking space available, a small EV charging station is planned in the indoor car park for the sake of users' safety and comfort. An essential factor, however, is a short distance to a proper switchboard, which would provide access to energy collected from photovoltaic cells.

3. Energy Consumption of Electric Vehicle in Real Driving Conditions (RDC)

At the present time, noticeable changes in the share of specific types of vehicle powertrains are caused by the implementation of new standards determining the permissible pollutant emissions to the environment and leading to the decarbonization of transport [15]. One of the effective methods is the electrification of powertrain systems [16,17]. In 2020, the sales of cars equipped with electrified powertrains increased by 39%, and forecasts indicate that electric cars will cover half of the global sales market in 2030 [18]. Following the example of Italy, in 2030, the energy consumption of BEVs is estimated at 6120 GWh per year [19].

Among others, electric vehicles can be classified into three basic categories concerning the source of driving energy. The first group consists of electric vehicles that generate their propulsion energy, including Hybrid Electric Vehicles (HEV) and Fuel Cell Electric Vehicles (FCEV). Another group includes vehicles which, in addition to generating energy, use electric energy supplied from an external source, known as a plug-in (PHEV, PFCEV) [20–22]. The last group comprises vehicles equipped with an extensive energy storage system that uses only externally supplied electricity and electricity from regenerative braking, such as BEVs [23]. The advantage of electric vehicles is the possibility of wireless charging, which is practically impossible when using fuels [24,25]. In addition, wired energy transfer enables fast charging. This allows some vehicles to be charged in 4.7 min with enough energy to cover a distance of 200 km [26,27].

LCA analyses of different types of propulsion sources indicate a significant difference between EVs and conventional vehicles equipped with an ICE [28]. Vehicles equipped with ICEs cause less environmental impact in production processes, while BEVs result in minor climate change during operation, and their benefits grow with increasing renewable energy [29,30]. In BEVs, WTT is dominant in the CO_2 emission category, while TTW is dominant in conventional vehicles [31]. Considering CO_2 emissions, electrified propulsion is preferable. Evtimov et al. indicate the relevance of the type of energy source determining CO_2 emission in LCA analysis by comparing BEVs and ICEs produced and operated in EU countries with different energy mixes [32]. The lowest CO_2 emission was achieved in Norway, where more than 98% of energy comes from renewable sources, while the highest was in Poland and Bulgaria, where the share of renewable energy does not exceed 20%.

Currently, electric vehicles report their range according to the WLTP standard (Worldwide Harmonised Light Vehicles Test Procedure), which is a dynamometer test [33,34]. Electric vehicles available in the Polish market (the market covered by the research presented in this paper) are characterized by different maximum vehicle ranges, defined according to the mentioned standard (Figure 5). However, these standards do not indicate the real conditions of vehicle operation and do not determine the real energy demand of a vehicle with respect to variable road parameters or atmospheric conditions (conditions of vehicle operation in summer or winter). Therefore, the research methodology presented in the article is extremely important to determine the actual energy consumption of the vehicle, which will determine the usefulness of the drive in specific traffic conditions.

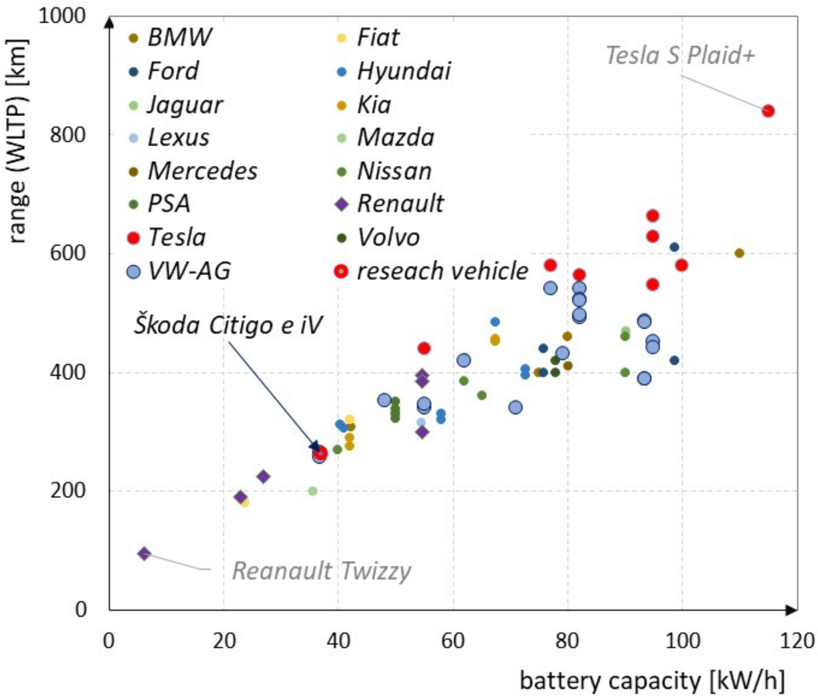


Figure 5. Range of electric vehicles in relation to battery capacity of manufacturers available in the Polish market (own draft based on [35]).

According to the presented analysis, the range of the vehicle is not only influenced by the battery capacity but also by many other parameters, such as body size, weight, and power. For a similar battery capacity, different vehicles can reach up to 50% more range in comparison to their competitors.

The summary presented above does not determine the actual performance of the propulsion system of available EVs. Therefore, the MDPI (mass drive performance index) was proposed (Figure 6), taking into account the actual range of the vehicle according to the WLTP standard, the mass of the vehicle, and the battery capacity according to the Equation (1):

$$\text{MDPI} = \frac{Battery\ capacity}{WLTP\ range \times Vehicle\ weight} \times 1000 \quad (1)$$

When analyzing charging capabilities of an EV, one should also pay attention to the time in which a given vehicle can be charged, both from the perspective of limit values (from 0% to 100% of the battery capacity) and utility values, i.e., for how much range we are able to charge the battery during 1 or 8 h of vehicle standstill. Using a ŠKODA CITIGO^{e} iV vehicle as an example, this analysis will be presented later in the article.

It is essential to plan the route in battery-powered vehicles due to longer charging time relative to liquid and gaseous fuel propulsion systems. Predicting vehicle range requires, among other things, calculation of energy consumption, which depends on many factors [36].

There was an analysis conducted to check the impact of driver's behavior on energy consumption in an electric vehicle over a distance of 17 miles [37]. Tests encompassed a group of 13 drivers of different gender, age, and education, travelling in the same vehicle on the same route in two directions (departure trip/return trip). The results showed reduced energy consumption on the return trip (less congested route) and shorter travel time. Increased traffic on the tested route resulted in increased energy consumption by 15.6% on average. However, there was no direct correlation between energy consumption of the vehicle and a particular driver. Another study [38] analyzes the effect of vehicle mass on energy consumption based on 30 electric vehicle models. High battery capacity and mass result in an 80–95% increase of energy consumption concerning low gross weight of vehicles. In a BEV, auxiliary systems that derive all their power from electricity contribute significantly to energy consumption. The greatest share of energy consumption among auxiliary systems is climate control, up to 35%, followed by power steering, braking system, and others, each up to 5% [39]. In the case of Peugeot iOn [40], the maximum power consumed by the climate control was 5 kW and decreased to 1 kW when conditions were stable. However, the determining factor for the increased power consumption is the ambient temperature. A range of 21.8–25.2 °C was identified as the optimum point at which consumption is lowest in operation [41]. Based on the model developed by Lora et al. [42], the range of BEV at 20 °C was 150 km, gradually decreasing to 85 at 0 °C and to 60 for −15 °C in FUDS, SFUDS, and NEDC tests.

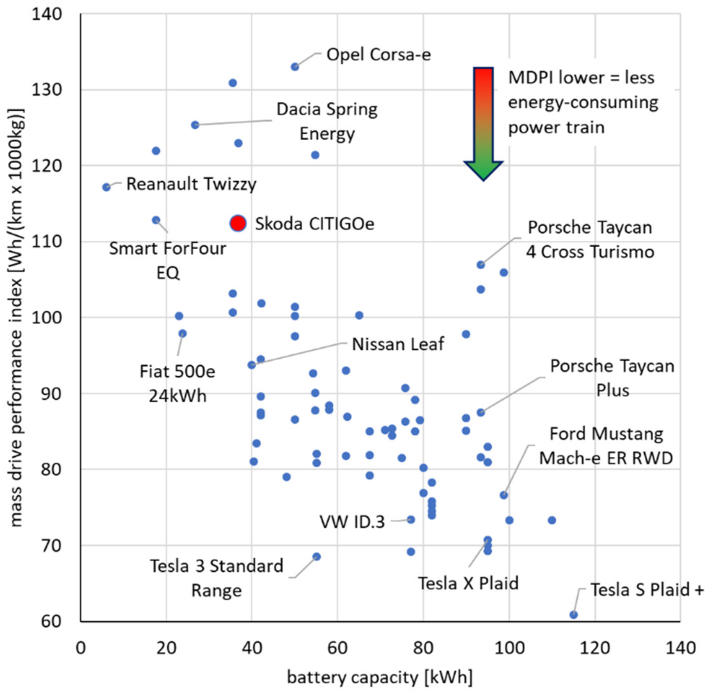


Figure 6. Mass drive performance index of EV vehicles [35].

Energy consumption of an electric vehicle is determined by measuring the powertrain operating parameters, mainly voltage, current, and vehicle speed, or using extended mathematical models [43,44]. The measurement data are obtained during tests carried out on a chassis dynamometer or during dynamic/static road tests.

Miri et al. [45] using technical vehicle data, performance characteristics of the powertrain, regenerative braking system, auxiliary systems, and driver behavior, estimated the energy consumption of the BMW i3. The accuracy of the simulation with respect to the results obtained in the NEDC (135 Wh/km) and EPA (179 Wh/km) tests was below 6%. Another modelling procedure [46], using three different electric drive system configurations in terms of NEDC and Japanese JC08 tests, allowed determination of the minimum vehicle energy consumption in the range of 81.5–97.9 Wh/km depending on the system configuration and the test performed. A small deviation from the real results (5%) was obtained [47] by optimizing the results from driving tests, road information, and geographical and weather data using a genetic algorithm. To receive the experimental results, drives were made at a distance of 6 km—city, <25 km—suburban area, and <50 km motorway.

In order to develop a model, which is the focus of another paper [48], measurements were made by carrying out 30 trips between Eindhoven and Heel (distance over 700 km) on four types of roads: motorway, city, rural, and hilly roads. A minimum energy consumption of 0.66 kWh for a distance of 5.2 km in urban conditions and 15 kWh for a distance of

114.7 km in highway driving was obtained. Many other works are also devoted to the topic of range prediction and newer and more accurate models are being developed.

4. Research Methodology

a. nZEB—technical requirements, adopted solutions and analysis method

The above-mentioned form and function factors correlated with the final location of the photovoltaic cells on the roof of the building (Figure 7). Due to the adopted quarter of buildings, the facility was tilted by 10.48 degrees from the southern axis towards the east, and the panels were set at an angle of 40 degrees in order to obtain the highest possible efficiency for the installation. In addition, due to the assumptions of nearly zero energy consumption of the facility, it was important to minimize any thermal bridges and maintain the tightness of the building, which is why it was decided to install photovoltaic cells on the roof of the building in a way that is non-invasive for the insulation layer. For this purpose, an aluminum lattice substructure was used, loaded with concrete slabs, resting freely on the insulation layer (Figures 8 and 9).

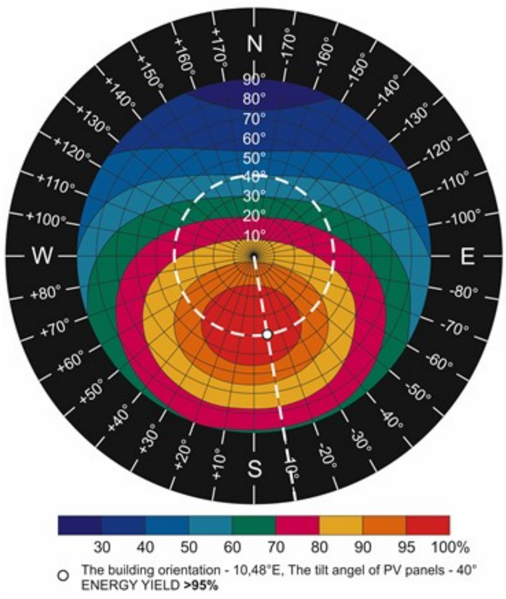


Figure 7. The effect of the building orientation and the tilt angle of PV panels on the percentage of energy yield (own work based on [49]).

Figure 8. Photo of PV cells on the roof.

Figure 9. Photo of aluminum substructure on the roof.

The shape of the photovoltaic cell substructure above the inner courtyard, resembling the shape of a shed roof, became the result of analyses carried out for the optimal selection of the inclination angles of the photovoltaic cells and the illumination of the courtyard. To achieve this goal, it was extremely important that the courtyard should not be overheated. Hence, its windows were directed to the north at an inclination of 20 degrees so that the main solar energy would not penetrate the interior of the building but instead would be reflected by the glass pane. Additionally, the parameters for selecting the radiation transmission coefficient for glass and the ratio of the glazing area to the atrium area were indispensable.

Finally, a photovoltaic cell installation was designed, consisting of 666 photovoltaic cells and generating a peak power of 199.8 kWp. These cells were connected with ten inverters located in technical rooms on level 3 of the facility (Figure 10).

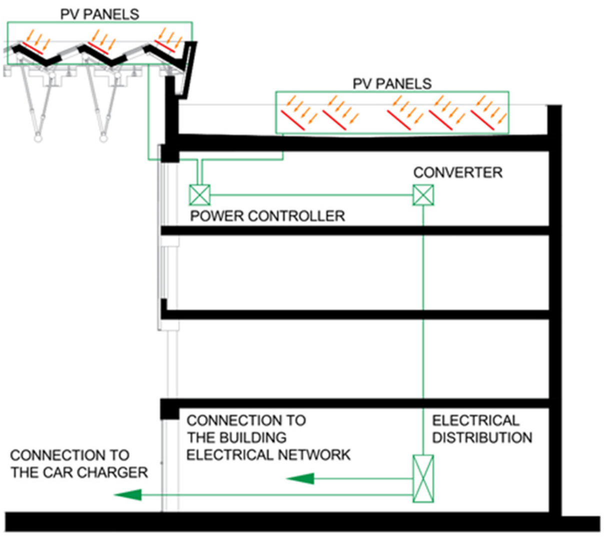


Figure 10. Photo of aluminum substructure on the roof.

b. Vehicle energy consumption analysis/RDC test requirements (based on RDE test)

The selected route (Figure 11) went through the city of Poznan and its surrounding areas. It covered urban, rural, and motorway areas. The maximum legal speed on the route is 140 km/h. Selected test requirements related to the course of the test run are presented in Table 1. As per the requirements, the duration of all test runs exceeded 90 min.

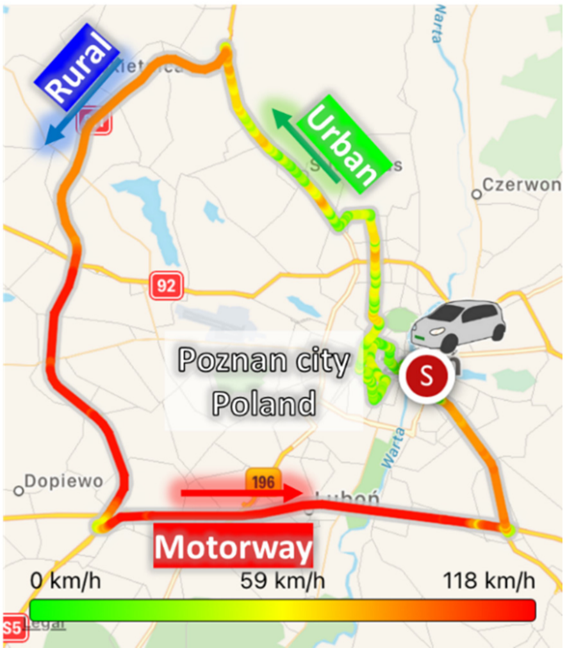


Figure 11. Route pattern followed in the research.

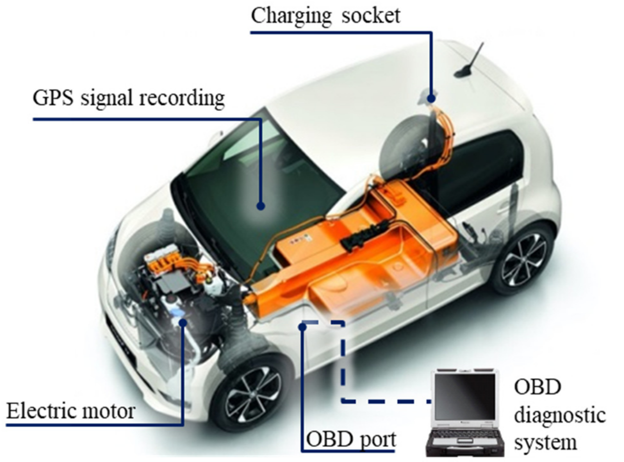
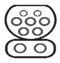
Table 1. Real Driving Conditions test requirements [50].

Selected RDE/RDC Test Requirements	Urban	Rural	Motorway
Cycle repetition (+/−10%) [%]	29 < ratio ≤ 34	33	←
Speed [km/h]	< 60	60 ≤ V ≤90	V > 90
Max. speed [km/h] (+/−15 km/h for less than 3% of driving time)	-	-	145
Average speed (stops included) [km/h]	15 ≤ V ≤ 30	-	-
Minimum travelled distance [km]	16	←	←
Altitude difference (beginning/end) [m]	100	←	←
Maximum slope [m/100 km]	1200 m/100 km	←	←

The paper presents results from tests of an electric vehicle at two different times of the day, corresponding to winter and summer driving conditions. In previous articles, the authors proved the lower energy consumption of the electric vehicle in ECO driving mode, and, in accordance with trends of reducing energy consumption as being one of the energy sources, the results for this mode only (ECO) are presented in this research.

The characteristics of the electric vehicle used in road tests are shown in Table 2. The vehicle used in the tests is a ŠKODA CITIGO^e iV, which is supplied with an electric drive allowing different driving modes and variable intensity of regenerative braking. The 61 kW ŠKODA CITIGO^e iV powertrain used a Li-ion battery of 36.8 kWh full capacity and 32.3 kWh useable capacity. A diagram based on [51] presents the location of the main components of the drive and measurement system (Table 2).

Table 2. Technical data of the analyzed powertrain fitted in ŠKODA CITIGO^e iV [51].

Powertrain		Schematic of Tested Vehicle with Data Recording Devices
Parameter	**Value**	
Vehicle		
Max. power output	61 kW	
Max. torque	212 Nm	
Max. vehicle speed	130 km/h	
Operating weight	1235 kg	
Max. voltage of electric motor	360 V	
Battery		
Type	Li-ion	
Capacity total	36.8 [kWh]	
Capacity usable	32.3 [kWh]	
Charge port type/Max. charge power 	AC—Type 2/7.2 kW DC—CCS2/40 kW	

5. Research Results

a. Annual building energy balances—electric vehicle charging potential from a renewable energy source

The annual energy balance of the nZEB in this case shows that, depending on the energy demand, more than half of the consumed energy can come from renewable energy sources (in this case from solar panels). The presented balance for the period from March 2020 to February 2021 corresponds to the performed tests of the electric vehicle during summer and winter periods. This period corresponds to the global pandemic situation, which has affected energy consumption, but basic building functions, such as lighting and technical maintenance, remain unchanged, even during the period of reduced building occupancy. In favorable conditions (i.e., weather conditions—high sun exposure), photovoltaic panels allow the production of more than 50% of the energy needed to power the building. However, this occurs only from April to June. Throughout the rest of the year, they use more energy from the grid, and renewable energy accounts for an average of 33% of the total energy demand of the building during the year (Figure 12).

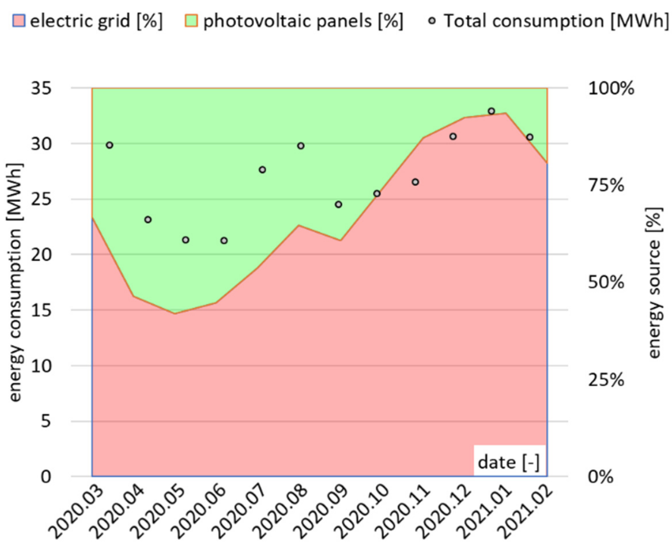


Figure 12. Share of renewable and non-renewable energy sources required to power the building.

Due to the fact that the building operates 24 h a day and renewable energy generation is only available during limited hours of the day, the energy demand of the building is divided into (Figure 13):

- Energy consumption by users;
- Energy consumption for building purposes (heating, ventilation);
- Energy consumption for illumination.

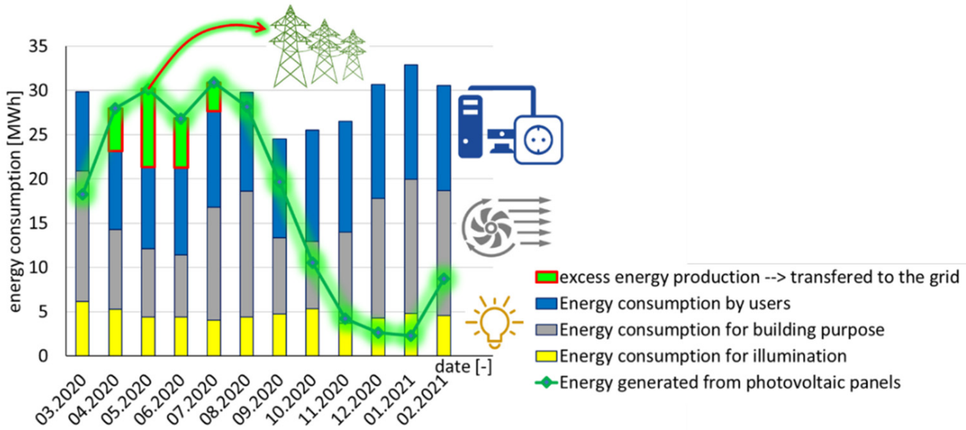


Figure 13. Distribution of the energy consumption by the building.

Direct use of the recovered energy accounts for 57% of the annual balance (only 40–45% during summer months). The remainder of the energy produced by photovoltaic panels is currently transmitted to the grid, but this energy could power electric vehicles parked on university premises during the day (Figure 14).

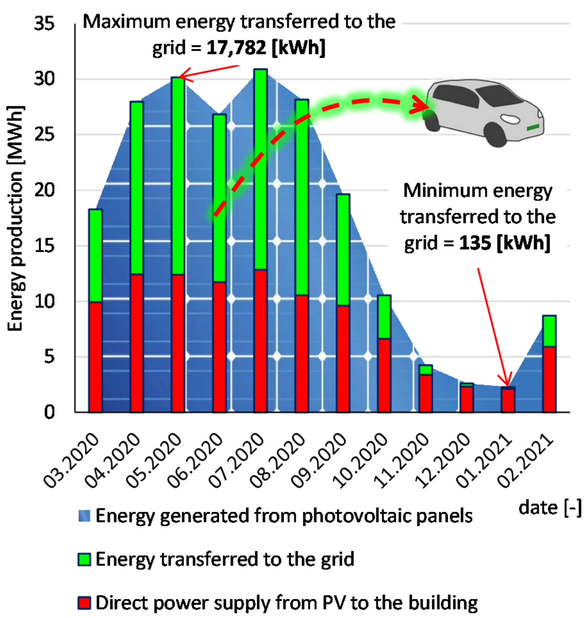


Figure 14. Opportunities for direct energy transfer for electric vehicle charging.

At the same time, it should be noted that during winter months, especially from November to January, the amount of energy transferred to the grid is extremely low, requiring future consideration whether to increase the number of photovoltaic panels.

The total energy generated from the photovoltaic panels during the year under review was 210,325 kWh, of which only 99,830 kWh was directly used by the building. The remaining 110,495 kWh of energy was fed into the grid, which, in the overall balance of the university with an energy supplier, was consumed. However, the authors of the paper see the possibility of directly using this energy to charge electric vehicles. The article's interdisciplinary summary is a compilation of an analysis of the building's energy generation, data on how electric vehicles are charged, and an analysis of their energy consumption in real driving conditions. It provides a comparison of the vehicle's charging time as a function of the distance travelled by the user depending on the type of road they travel. It should also be noted that both seasons and individual days (Figure 15) have a significant impact on energy generated by photovoltaic panels. In the presented analyses, the authors focused on the overall annual balance and signaled the problem, which will be subject to further analysis in the future.

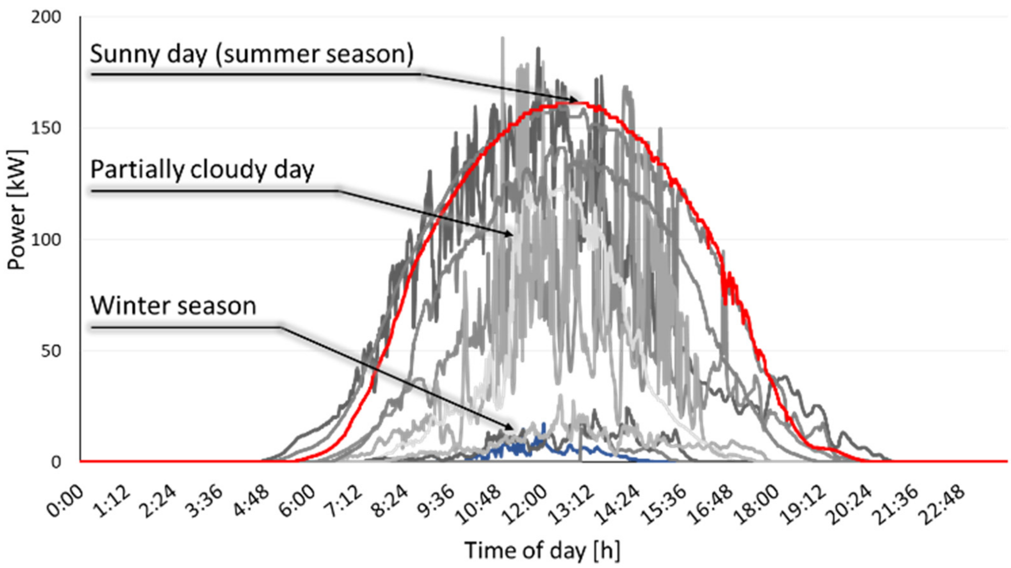


Figure 15. Daily power production profile from solar panels.

The above-presented possibilities of direct transfer of energy generated from photovoltaic panels for the purpose of charging electric vehicles by users of the university campus is the inspiration for the presented publication and presentation of an interdisciplinary analysis of cooperation between buildings and urban transport facilities using electric propulsion as zero-emission vehicles.

b. Electric vehicle charging time

Analyzing the market of electric vehicles available in Poland, it may be observed that most of the models available make it possible to charge them either with AC current within the range of 2–11 kW or with DC current within the range of 40–250 kW. In this paper, because of the initial stage of planning the electric vehicle charging station in the location of the building equipped with PV, the fast AC charging at the level of 7–11 kW was chosen for the analysis of the vehicle charging parameters. This is primarily due to the relatively low installation costs in relation to the reduced charging time of the EV [52]. Due to the fact that the location of charging points is planned in the surroundings of the place of work, it will be possible to move the vehicle to the car park after an employee has fully charged it.

The diagnostic parameters are different from the information provided by the application and indicators placed in the vehicle and read by the driver. The charging time analysis of the tested vehicle was carried out for three charging strategies (Figure 16). The information about the state of charge of the vehicle in the range of 0–100% SOC_{APP} corresponds to the real state of charge in the range of 13–96% $SOC_{DIAGNOSTIC}$.

The popularization of electric propulsion leads to the increase of the demand for chargers and market development. The price of the charger is varied, mainly influenced by the maximum available charging power. The 11kW AC chargers are considered to be the most practical choice. Such chargers are 74–95% cheaper than fast DC charging stations, the price of which sometimes exceeds half of the value of a small electric car [53]. This solution provides a favorable price with a relatively fast charging time of 100 km.

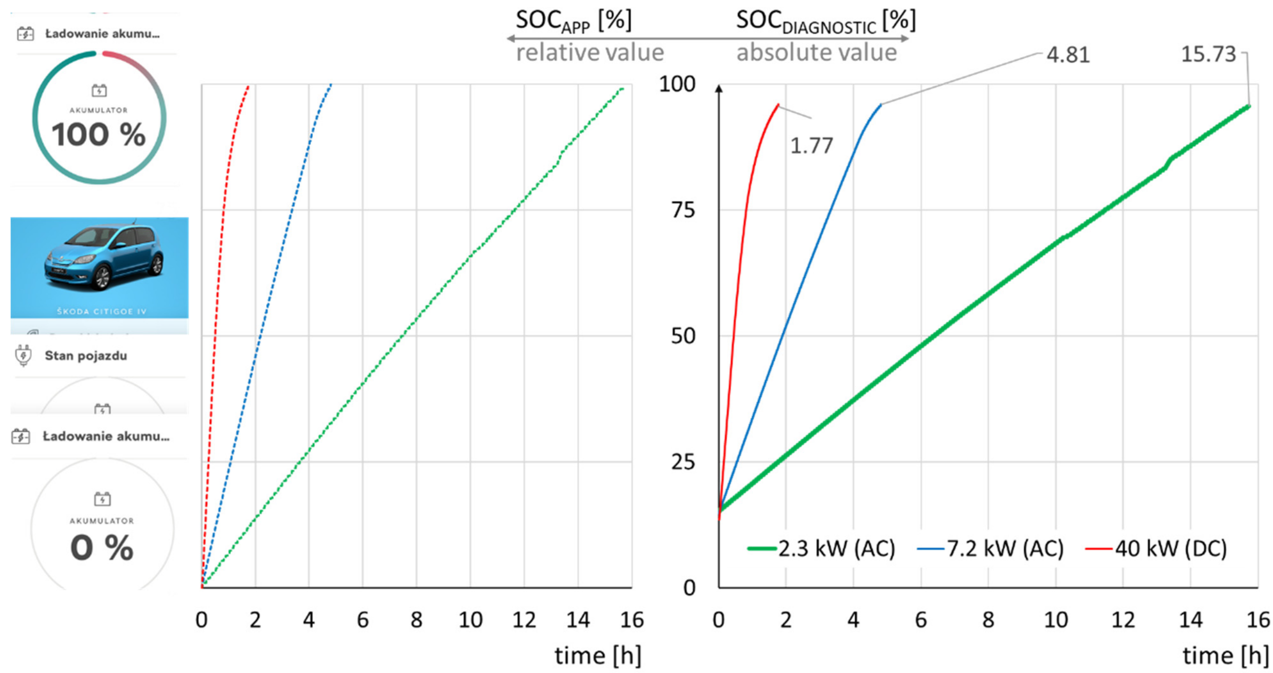


Figure 16. Charging time for the ŠKODA CITIGO^e iV depending on the selected method (comparison of the application's readings with the actual values of the battery charge status—application screenshots shown on the left).

Among available charging methods for automotive Li-ion batteries, AC charging with onboard charging circuit accommodation was selected for analysis. The power was transferred by IEC 62196-2 connection. For better understanding of energy transfer into the car, the measurement was done by acquired specified parameters indirectly through the CAN system with a sampling rate of 1.3 Hz (Figure 17).

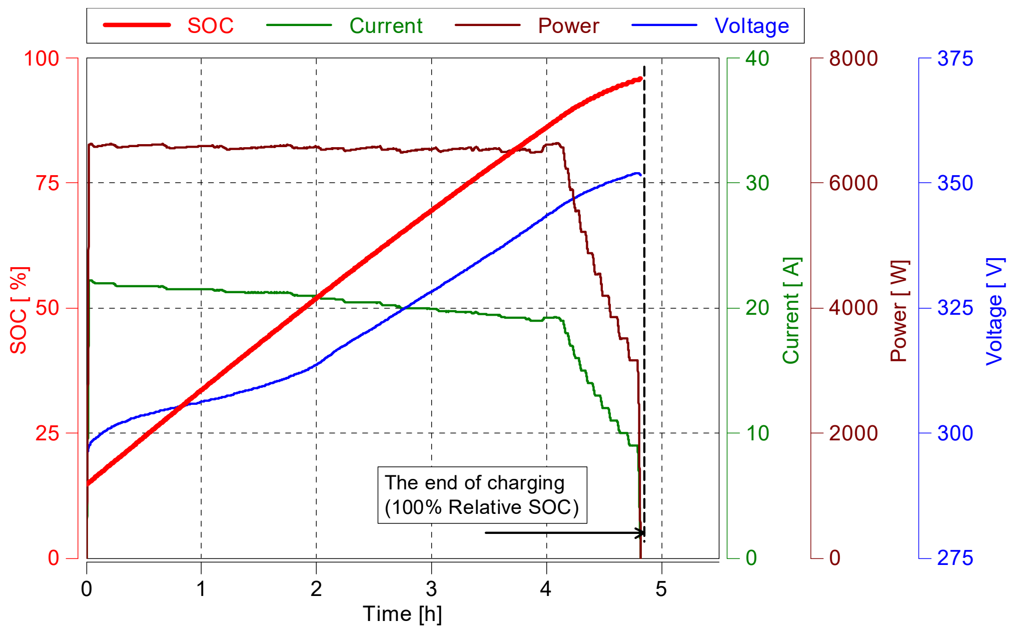


Figure 17. Vehicle charging characteristic for 7.2 kW (AC).

The SOC charging range was 14.8–96% absolute value in 4.8 h. During the first 4 h of charging, the process was stable with constant power. After exceeding 88% SOC, the current value decreased linearly to 8.5 A and then rapidly to 0. During the whole charging cycle, 30 kWh of energy was supplied to the battery.

c. Vehicle energy consumption in RDC in summer and winter conditions

The analyses presented in the authors' previous work [37] on the possibilities of providing power to an electric vehicle by an individual photovoltaic installation of a single-family building were contrasted with the possibilities of connecting to a charging station available in the workplace which is equipped with a much larger PV installation. This paper presents the results of a study correlating the transportation energy requirements of building users and the daily maximum distance that users can travel while consuming the energy produced by the building's PV systems. Based on these analyses, the ranges of the analyzed scenarios were adopted; they assume the utility of the EV at 15, 30, and 45 km of the distance travelled between home and work. Depending on the distance travelled by the EV user, the minimum EV charging frequency is shown in Figure 18.

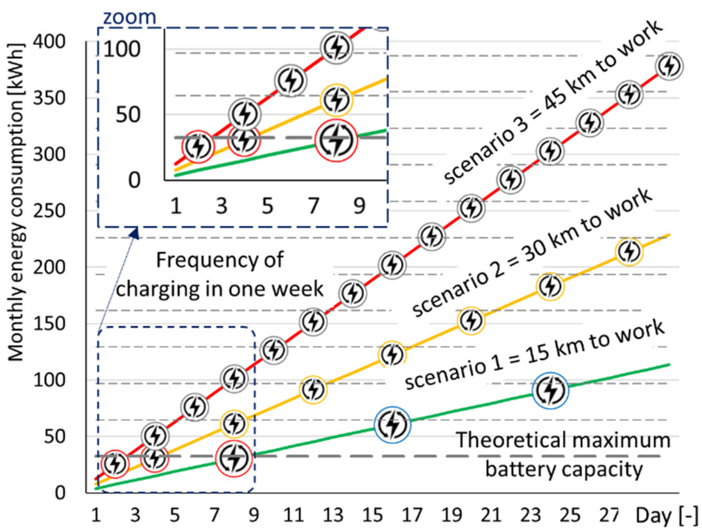


Figure 18. Frequency of charging an electric vehicle in the presented scenarios depending on the distance travelled by the user.

The above graph was developed on the basis of average energy consumption of the vehicle used in both winter and summer in real traffic conditions according to the RDE test procedure. RDC tests were performed according to the procedure, which is described in detail in the article [53]. The tests were performed using a small city vehicle—ŠKODA CITIGO^e iV. The energy consumption of the vehicle was calculated on the basis of the results obtained in real driving conditions. In this test, it is possible to determine the route sections corresponding to driving in urban, suburban, and motorway conditions.

Energy consumption is presented initially by analyzing the change of battery state of charge (SOC), which is colored according to the driving conditions of urban, rural, and motorway routes by colors in Figure 19: green, yellow, and red, respectively.

The fastest decline in SOC is observed at increased vehicle speeds (rural and motorway routes), where less regenerative braking occurs at the same time. The difference in state of charge consumption due to varying weather conditions was ΔSOC = 11%.

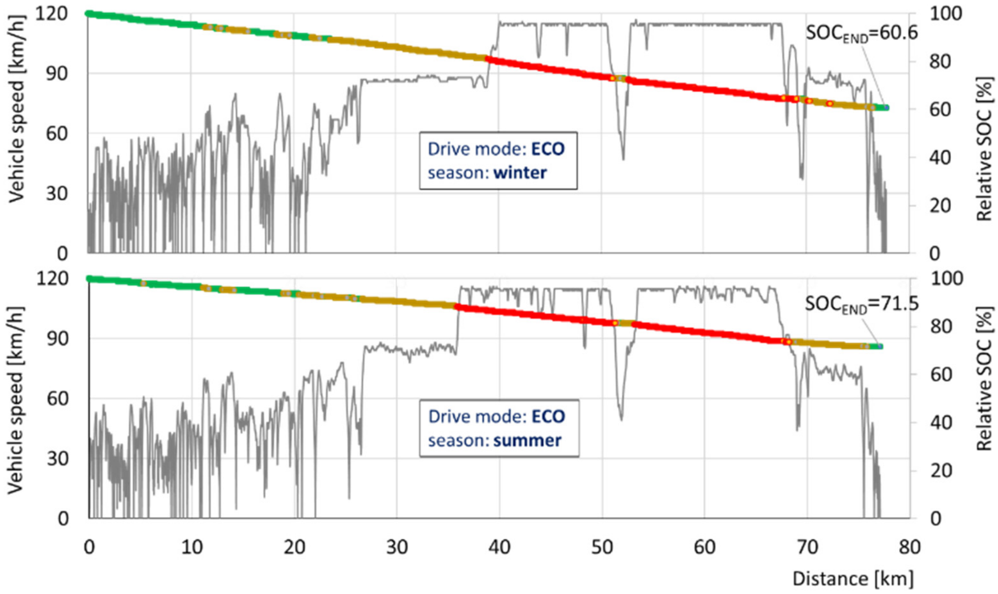


Figure 19. Comparison of the driving conditions (RDC) test for the performed test runs in winter and summer conditions.

The presented routes can be shown in terms of time or distance shares depending on the following vehicle movement parameters: vehicle steady speed (a0 EV), acceleration (a+ EV), standstill, and regenerative braking (a− EV) (Figure 20).

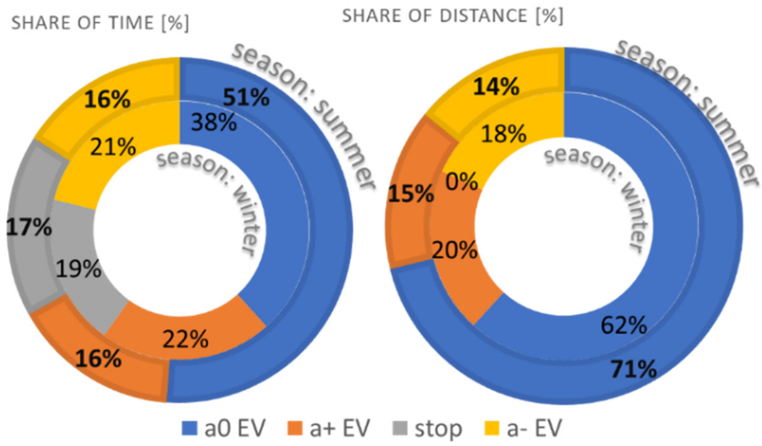


Figure 20. Comparison of the phase motion share during the RDC test in summer and winter conditions.

Individual route segments are characterized by varying amounts of energy consumed and recovered according to varying vehicle movement conditions. The location of the indicated vehicle movement parameters is shown in colored graph against the test time (Figure 21).

The energy transfer into battery (regenerative braking)—Equation (2) and out of battery (discharging)—Equation (3) was determined by the following:

$$\Delta E_{reg} = \sum_{t=0}^{t=t_{max}} U_{BAT} \cdot I_{BAT} dt, \ \left(\text{when}\ \Delta E_i > 0\ \text{and}\ M_{reg} < 0\right) \quad (2)$$

$$\Delta E_{dis} = \sum_{t=0}^{t=t_{max}} U_{BAT} \cdot I_{BAT} dt \quad (3)$$

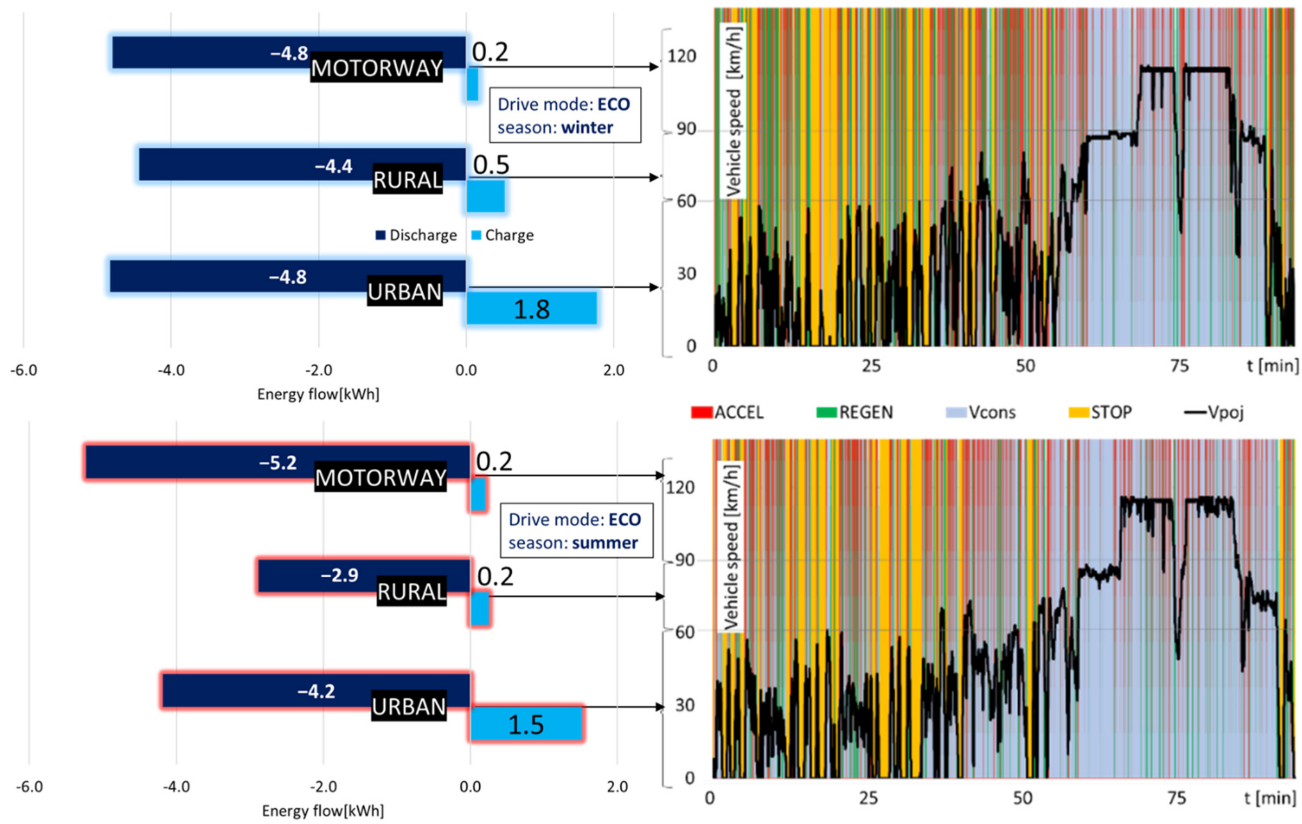


Figure 21. Energy flow for specific route conditions under RDC test conditions.

The lowest energy consumption in the RDC test is recorded in urban and rural sections. In urban driving, the most energy is recovered during braking. Winter driving conditions increase energy consumption in urban and suburban sections but a reduction of 0.4 kWh is recorded in highway conditions. However, such small changes can be caused by individual driving conditions on a particular driving day (variable congestion on the route). Showing the calculated energy consumption per 100 km depending on driving only on the particular route type, as well as an average for the whole RDC test taking into account mixed driving conditions, an average energy consumption of 14 kWh/100 km was achieved for the ŠKODA CITIGOe iV vehicle (Table 3). This value was used to determine the vehicle charging periods presented in the article summary.

Table 3. Summary of vehicle energy consumption estimated on 100 km distance.

Driving Period	RDC	Urban	Rural	Motorway
Winter	14.9	13.82	14.40	16.39
Summer	13.1	11.43	11.15	16.72
Average	14	12.63	12.77	16.55

An electric vehicle is characterized by two states of drivetrain operation; the drivetrain consumes or generates energy from/to a high voltage battery. With respect to the route parameters in the RDC test, therefore, the time and distance intervals in which the vehicle consumes or generates energy were determined in Figure 22a,b (periods in which the vehicle does not consume energy from the battery during standstill are short—in most cases, at standstill, the battery is also discharged for vehicle comfort purposes).

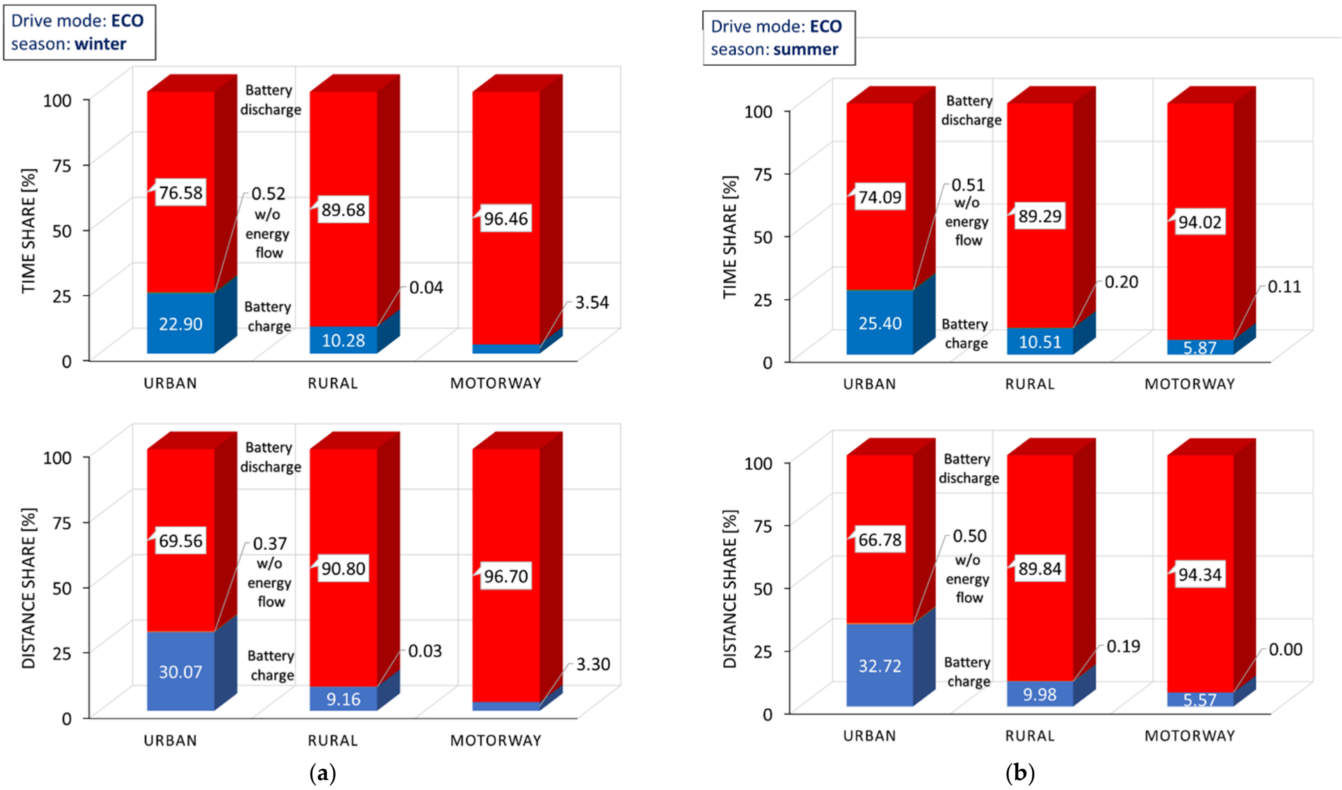


Figure 22. Conditions for the use of the battery energy for: (**a**) winter conditions, (**b**) summer conditions.

When analyzing both distance and time, the greatest amount of energy is recovered during the RDC test phase of urban driving, which also results in lower vehicle energy consumption because the recovered energy can be immediately used for subsequent vehicle acceleration. Energy recovery on the rural section is 3 times lower than in urban driving conditions and even 6–10 times lower in motorway driving conditions.

These values significantly influence the already presented charging frequency (Figure 18). The electric vehicle driven only on short distances on urban roads will consume 30% less energy than the EV on motorways driven at speeds above 90 km/h.

6. Conclusions

Analysis of the energy performance of a real estate–electric vehicle system is the focus of much ongoing research. Alirezaei et al. [54], analyzing this issue based on a model study of a residential building, showed the possibility of reducing the grid energy consumption by 68% with close cooperation of a photovoltaic system and an electric vehicle. The presented opposite approach [55], based on optimal selection of size and type of renewable energy sources installation, shows the possibility of cooperation between a wind turbine (8 kW) and photovoltaic panels (306 m^2). The combination makes it possible to achieve 87.2% of the energy for charging an electric vehicle from renewable sources. When converting from internal combustion vehicles to electric vehicles in a near-zero energy building, a significant increase in energy demand must be taken into account, which, for some research [56], ranged from 27–95% while saving 11–35% total emissions within the building. Another paper [57] focused on the energy consumption of an intelligent building with a car charger, resulting in an energy management algorithm for the heat pump, electric vehicle, energy storage, and other time-varying loads.

An individual contribution to the field of renewable sources utilization is the research results obtained from real objects, which were tested under real operating conditions. The methodology was supplemented by survey research and analysis of basic parameters of an electric vehicle charging station. The building object that was taken into account is an innovative building with significant energy saving potential. In the annual energy balance, taking into account the energy currently sent to the grid, more than 110,495 kWh of energy can be used for charging electric vehicles. Taking into account a daily energy surplus of 310 kWh on average and an 8-hour working day, the maximum number of vehicles charged with alternating current will be between 3 and 12 vehicles at the same time, depending on the charging power. It should be noted, however, that these are preliminary analyses that do not take into account varying daily sunlight conditions. In order to meet the zero-emission assumptions for an electric vehicle, it would be necessary to introduce a vehicle charging control system allowing the exclusive use of the energy produced by photovoltaic panels. However, such assumptions may lead to a conclusion that, on days of unfavorable energy production, it will not be possible to charge the vehicle and the user may be immobilized. Therefore, at the current level of development, it is still necessary for renewable energy sources to cooperate with a regular power supplier.

Table 4 shows the distance that the tested vehicle is able to reach after a one-hour charging period with variable charging power. It also presents the time required to charge the vehicle to reach a distance of 100 km in particular driving conditions.

Table 4. Estimated parameters for charging an EV vehicle using PV installation of the nZEB building.

Energy Available from Photovoltaic Panels				
Energy available on an annual basis [kWh]				**110,495.3**
Energy available for charging during the workday				**310.4 kWh**
EV charging capabilities				
		Charge power		
No. of vehicles that can be charged at the same time during 8 h of work		**3 kW**	**7.2 kW**	**11 kW**
		12.9 (max 12)	5.4 (max 5)	3.5 (max 3)
Range recharged in 1 h				
Type of route	Urban	23.8	57.0	87.1
	Rural	23.5	56.4	86.1
	Motorway	18.1	43.5	66.5
	RDC	21.4	51.4	78.6
Charging time to reach 100 km range				
Type of route	Urban	4.21	1.75	1.15
	Rural	4.26	1.77	1.16
	Motorway	5.52	2.30	1.50
	RDC	4.67	1.94	1.27

Based on data on vehicle energy consumption and the amount of available energy from renewable sources, there is a plan to develop an application that will indicate the percentage of zero-emission propulsion of the currently charged vehicle.

The presented article shows research as a review of the analysis of the energy demand required to power transportation (analysis considers demand: users–vehicles–building), which, in the current times, presents a rapid development of electric vehicles. Knowledge of the energy consumption of an electric vehicle under characteristic driving conditions (consistent with real driving conditions) will allow users to assess the required frequency of vehicle charging. Presentation of the possibility of charging vehicles from photovoltaic installations mounted on large workplace complexes creates the possibility of relieving the electric grid of a city (country). The considerations presented in the article are valid for any location and do not depend on a particular vehicle model. They indicate the correct direction of electromobility considerations taking into account renewable energy sources.

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Abbreviations

BEV	Battery electric vehicle
CAN	Controller Area Network
EV	Electric vehicle
FCEV	Fuel Cell Electric Vehicles
FUDS	Federal Urban Driving Schedule
HEV	Hybrid Electric Vehicles
ICE	Internal Combustion Engines
IEC	International Electrotechnical Commission
LCA	Life Cycle Assessment
MDPI	Mass Drive Performance Index
NEDC	New European Driving Cycle
nZEB	nearly Zero Energy Building
PEVs	Plug-in Electrified Vehicles
PFCEV	Plug-in Fuel Cell Electric Vehicles
PHEV	Plug-in Hybrid Electric Vehicles
PV	Photovoltaic
RDC	Real Driving Conditions
SFUDS	Simplified Federal Urban Driving Schedule
SOC	state of charge
TTW	Tank To Wheel
WLTP	Worldwide Harmonised Light Vehicles Test Procedure
WTT	Well To Tank

References

1. Feng, W.; Zhang, Q.; Ji, H.; Wang, R.; Zhou, N.; Ye, Q.; Hao, B.; Li, Y.; Luo, D.; Lau, S.S.Y. A review of net zero energy buildings in hot and humid climates: Experience learned from 34 case study buildings. *Renew. Sustain. Energy Rev.* **2019**, *114*, 109303. [CrossRef]
2. Szabo, L. The history of using solar energy. In Proceedings of the 2017 International Conference on Modern Power Systems, Cluj-Napoca, Romania, 6–9 June 2017. Available online: https://www.hbs.edu/ris/Publication%20Files/12-105.pdf (accessed on 6 October 2021).
3. Jones, G.; Loubna, B. *Power from Sunshine: A Business History of Solar Energy*; Harvard Business School Working Paper, No. 12–105; Harvard Business Publishing: Boston, MA, USA, 2012.
4. Guarnieri, M. Looking back to electric cars. In Proceedings of the 3rd Region-8 IEEE History of Electro-Technology Conference: The Origins of Electrotechnologies, Pavia, Italy, 5–7 September 2012.
5. The History of the Electric Car. 2014. Available online: https://www.energy.gov/articles/history-electric-car (accessed on 14 April 2021).
6. Autoguide. Available online: https://www.hybridcars.com/one-million-global-plug-in-sales-milestone-reached/ (accessed on 14 April 2021).
7. Du John, V.H.; Jackuline Moni, D.; Gracia, D. A detailed review on Si, GaAs, and CIGS/CdTe based solar cells and efficiency comparison. *Przegląd Elektrotechniczny* **2020**, *96*, 12.
8. Bhatti, A.; Salam, Z.; Aziz, M.; Yee, K.P.; Ashique, R.H. Electric vehicles charging using photovoltaic: Status and technological review. *Renew. Sustain. Energy Rev.* **2016**, *54*, 34–47. [CrossRef]

9. Rafique, S.; Hossain, M.J.; Nizami, M.S.H.; Bin Irshad, U.; Mukhopadhyay, S.C. Energy Management Systems for Residential Buildings With Electric Vehicles and Distributed Energy Resources. *IEEE Access* **2021**, *9*, 46997–47007. [CrossRef]
10. Dettner, F.; Blohm, M. External cost of air pollution from energy generation in Morocco. *Renew. Sustain. Energy Transit.* **2021**, *1*, 100002. [CrossRef]
11. Divyapriya, S.; Amutha; Vijayakumar, R. Design of Residential Plug-in Electric Vehicle Charging Station with Time of Use Tariff and IoT Technology. In Proceedings of the 2018 International Conference on Soft-Computing and Network Security (ICSNS), Coimbatore, India, 14–16 February 2018; pp. 1–5. [CrossRef]
12. Cieslik, W.; Szwajca, F.; Golimowski, W.; Berger, A. Experimental Analysis of Residential Photovoltaic (PV) and Electric Vehicle (EV) Systems in Terms of Annual Energy Utilization. *Energies* **2021**, *14*, 1085. [CrossRef]
13. Jacobs-Crisioni, C.; Kompil, M.; Baranzelli, C.; Lavalle, C. *Indicators of Urban form and Sustainable Urban Transport. Introducing Simulation-Based Indicators for the LUISA Modelling Platform*; JRC Technical Reports; Joint Research Centre: Ispra, Italy, 2015; pp. 1–33.
14. Chiara, B.D.; Deflorio, F.; Pellicelli, M.; Castello, L.; Eid, M. Perspectives on Electrification for the Automotive Sector: A Critical Review of Average Daily Distances by Light-Duty Vehicles, Required Range, and Economic Outcomes. *Sustainability* **2019**, *11*, 5784. [CrossRef]
15. Smallbone, A.; Jia, B.; Atkins, P.; Roskilly, A.P. The impact of disruptive powertrain technologies on energy consumption and carbon dioxide emissions from heavy-duty vehicles. *Energy Convers. Manag. X* **2020**, *6*, 100030. [CrossRef]
16. Palencia, J.C.G.; Nguyen, V.T.; Araki, M.; Shiga, S. The Role of Powertrain Electrification in Achieving Deep Decarbonization in Road Freight Transport. *Energies* **2020**, *13*, 2459. [CrossRef]
17. Kumbaroğlu, G.; Canaz, C.; Deason, J.; Shittu, E. Profitable Decarbonization through E-Mobility. *Energies* **2020**, *13*, 4042. [CrossRef]
18. Canalys: Global Electric Vehicle Sales Up 39% in 2020 as Overall Car Market Collapses. Available online: https://www.canalys.com/newsroom/canalys-global-electric-vehicle-sales-2020 (accessed on 6 October 2021).
19. Statista. Forecasted Energy Consumption of Battery Electric Vehicles (BEV) in Italy in 2030, by Type of Vehicle. Available online: https://www.statista.com/statistics/941996/bev-electricity-consumption-in-italy/ (accessed on 6 October 2021).
20. Sorlei, I.-S.; Bizon, N.; Thounthong, P.; Varlam, M.; Carcadea, E.; Culcer, M.; Iliescu, M.; Raceanu, M. Fuel Cell Electric Vehicles—A Brief Review of Current Topologies and Energy Management Strategies. *Energies* **2021**, *14*, 252. [CrossRef]
21. Jung, H. Fuel Economy of Plug-In Hybrid Electric and Hybrid Electric Vehicles: Effects of Vehicle Weight, Hybridization Ratio and Ambient Temperature. *World Electr. Veh. J.* **2020**, *11*, 31. [CrossRef]
22. Pielecha, I.; Szwajca, F. Cooperation of a PEM fuel cell and a NiMH battery at various states of its charge in a FCHEV drive. *Ekspolatacja Niezawodn. Maint. Reliab.* **2021**, *23*, 468–475. [CrossRef]
23. Janiaud, N.; Vallet, F.-X.; Petit, M.; Sandou, G. Electric Vehicle Powertrain Architecture and Control Global Optimization. *World Electr. Veh. J.* **2009**, *3*, 682–693. [CrossRef]
24. Ahmad, A.; Alam, M.S.; Chabaan, R. A Comprehensive Review of Wireless Charging Technologies for Electric Vehicles. *IEEE Trans. Transp. Electrif.* **2018**, *4*, 38–63. [CrossRef]
25. Feng, H.; Tavakoli, R.; Onar, O.C.; Pantic, Z. Advances in High-Power Wireless Charging Systems: Overview and Design Considerations. *IEEE Trans. Transp. Electrif.* **2020**, *6*, 886–919. [CrossRef]
26. Rafi, A.H.; Bauman, J. A Comprehensive Review of DC Fast-Charging Stations with Energy Storage: Architectures, Power Converters, and Analysis. *IEEE Trans. Transp. Electrif.* **2021**, *7*, 345–368. [CrossRef]
27. Tu, H.; Feng, H.; Srdic, S.; Lukic, S. Extreme Fast Charging of Electric Vehicles: A Technology Overview. *IEEE Trans. Transp. Electrif.* **2019**, *5*, 861–878. [CrossRef]
28. Helmers, E.; Dietz, J.; Weiss, M. Sensitivity Analysis in the Life-Cycle Assessment of Electric vs. Combustion Engine Cars under Approximate Real-World Conditions. *Sustainability* **2020**, *12*, 1241. [CrossRef]
29. Del Pero, F.; Delogu, M.; Pierini, M. Life Cycle Assessment in the automotive sector: A comparative case study of Internal Combustion Engine (ICE) and electric car. *Procedia Struct. Integr.* **2018**, *12*, 521–537. [CrossRef]
30. Cox, B.; Bauer, C.; Beltran, A.M.; van Vuuren, D.P.; Mutel, C.L. Life cycle environmental and cost comparison of current and future passenger cars under different energy scenarios. *Appl. Energy* **2020**, *269*, 115021. [CrossRef]
31. Van Mierlo, J.; Messagie, M.; Rangaraju, S. Comparative environmental assessment of alternative fueled vehicles using a life cycle assessment. *Transp. Res. Procedia* **2017**, *25*, 3435–3445. [CrossRef]
32. Evtimov, I.; Ivanov, R.; Kadikyanov, G.; Staneva, G. Life cycle assessment of electric and conventional cars energy consumption and CO2 emissions. *MATEC Web Conf.* **2018**, *234*, 02007. [CrossRef]
33. Ramanujam, Y.; Malhotra, I.; Thimmalapura, S. A Study of Parameters Influencing Energy Consumption of an Electric Vehicle. In Proceedings of the 2019 IEEE Transportation Electrification Conference (ITEC-India), Bengaluru, India, 17–19 December 2019; pp. 1–6. [CrossRef]
34. Hwang, S.-W.; Ryu, J.-Y.; Chin, J.-W.; Park, S.-H.; Kim, D.-K.; Lim, M.-S. Coupled Electromagnetic-Thermal Analysis for Predicting Traction Motor Characteristics According to Electric Vehicle Driving Cycle. *IEEE Trans. Veh. Technol.* **2021**, *70*, 4262–4272. [CrossRef]
35. Electric Vehicle Database. Available online: https://ev-database.org/ (accessed on 11 October 2021).
36. Grunditz, E.A.; Thiringer, T. Performance Analysis of Current BEVs Based on a Comprehensive Review of Specifications. *IEEE Trans. Transp. Electrif.* **2016**, *2*, 270–289. [CrossRef]

37. Hu, K.; Wu, J.; Schwanen, T. Differences in Energy Consumption in Electric Vehicles: An Exploratory Real-World Study in Beijing. *J. Adv. Transp.* **2017**, *2017*, 4695975. [CrossRef]
38. Berjoza, D.; Jurgena, J. Effects of change in the weight of electric vehicles on their performance characteristics. *Agron. Res.* **2017**, *15*, 952–963.
39. Evtimov, I.; Ivanov, R.; Sapundjiev, M. Energy consumption of auxiliary systems of electric cars. *MATEC Web Conf.* **2017**, *133*, 06002. [CrossRef]
40. El Baghdadi, M.; De Vroey, L.; Coosemans, T.; Van Mierlo, J.; Foubert, W.; Jahn, R. Electric vehicle performance and consumption evaluation. In Proceedings of the 2013 World Electric Vehicle Symposium and Exhibition (EVS27), Barcelona, Spain, 17–20 November 2013; pp. 1–8. [CrossRef]
41. Liu, K.; Wang, J.; Yamamoto, T.; Morikawa, T. Exploring the interactive effects of ambient temperature and vehicle auxiliary loads on electric vehicle energy consumption. *Appl. Energy* **2018**, *227*, 324–331. [CrossRef]
42. Iora, P.; Tribioli, L. Effect of Ambient Temperature on Electric Vehicles' Energy Consumption and Range: Model Definition and Sensitivity Analysis Based on Nissan Leaf Data. *World Electr. Veh. J.* **2019**, *10*, 2. [CrossRef]
43. Schücking, M.; Jochem, P.; Fichtner, W.; Wollersheim, O.; Stella, K. Influencing factors on specific energy consumption of EV in extensive operations. In Proceedings of the EVS29 Symposium, Montréal, QC, Canada, 19–22 June 2016.
44. Tehrani, M.G.; Kelkka, J.; Sopanen, J.; Mikkola, A.; Kerkkänen, K. Electric Vehicle Energy Consumption Simulation by Modeling the Efficiency of Driveline Components. *SAE Int. J. Commer. Veh.* **2016**, *9*, 31–39. [CrossRef]
45. Miri, I.; Fotouhi, A.; Ewin, N. Electric vehicle energy consumption modelling and estimation—A case study. *Int. J. Energy Res.* **2021**, *45*, 501–520. [CrossRef]
46. Wang, B.; Hung, D.; Zhong, J.; Teh, K.-Y. Energy consumption analysis of different BEV powertrain topologies by design optimization. *Int. J. Automot. Technol.* **2018**, *19*, 907–914. [CrossRef]
47. Guo, J.; Jiang, Y.; Yu, Y.; Liu, W. A novel energy consumption prediction model with combination of road information and driving style of BEVs. *Sustain. Energy Technol. Assess.* **2020**, *42*, 100826. [CrossRef]
48. Wang, J.; Besselink, I.; Nijmeijer, H. Battery electric vehicle energy consumption prediction for a trip based on route information. *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.* **2018**, *232*, 1528–1542. [CrossRef]
49. Professional Notebook—Solar Energy. Viessmann 06. 2008. Available online: https://www.viessmann.pl (accessed on 13 October 2021).
50. Cieślik, W.; Szwajca, F.; Golimowski, J. The possibility of energy consumption reduction using the ECO driving mode based on the RDC test. *Combust. Engines* **2020**, *182*, 59–69. [CrossRef]
51. ŠKODA CITIGOe iV Powertrain. Available online: https://www.skoda-storyboard.com/en/skoda-citigoe-iv-4/ (accessed on 13 October 2021).
52. Company Offer Arinea—Smart Energy. Available online: https://wallbox.pl/ (accessed on 13 October 2021).
53. Gis, W.; Pielecha, J.; Merkisz, J.; Kruczyński, S.; Gis, M. Determining the route for the purpose light vehicles testing in Real Driving Emissions (RDE) test. *Combust. Engines* **2019**, *178*, 61–66. [CrossRef]
54. Alirezaei, M.; Noori, M.; Tatari, O. Getting to Net Zero Energy Building: Investigating the Role of Vehicle to Home Technology. *Energy Build.* **2016**, *130*, 465–476. [CrossRef]
55. Zhou, Y.; Cao, S. Investigation of the flexibility of a residential net-zero energy building (NZEB) integrated with an electric vehicle in Hong Kong. *Energy Procedia* **2019**, *158*, 2567–2579. [CrossRef]
56. Rehman, H.U.; Diriken, J.; Hasan, A.; Verbeke, S.; Reda, F. Energy and Emission Implications of Electric Vehicles Integration with Nearly and Net Zero Energy Buildings. *Energies* **2021**, *14*, 6990. [CrossRef]
57. Liberati, F.; Di Giorgio, A.; Giuseppi, A.; Pietrabissa, A.; Habib, E.; Martirano, L. Joint Model Predictive Control of Electric and Heating Resources in a Smart Building. *IEEE Trans. Ind. Appl.* **2019**, *55*, 7015–7027. [CrossRef]