

Article

Analysis of the Development and Parameters of a Public Transport System Which Uses Low-Carbon Energy: The Evidence from Poland

Justyna Patalas-Maliszewska *  and Hanna Łosyk

Institute of Mechanical Engineering, University of Zielona Góra, 65-417 Zielona Góra, Poland; losyk.hanna@gmail.com

* Correspondence: j.patalas@iizp.uz.zgora.pl

Received: 29 September 2020; Accepted: 2 November 2020; Published: 4 November 2020



Abstract: Efforts toward a low-emission economy constitute a common challenge for Polish cities. Solutions are being sought to support Polish, medium-sized cities, that is, cities with about 140,000 inhabitants, to implement and develop low-carbon energy in their public transport systems. This paper proposes and explores a sustainable urban development card for a Polish city, namely, Zielona Góra, the use of which will enable the effects of a public transport system using low-carbon energy to be monitored. This research was based on the two main areas of analysis of a system of low-carbon energy and public transport and were formulated as: (1) Sustainable Development Goals (SDGs) and (2) Indicators of the Satisfaction Rate of Public Transport Passengers (SPTP). This paper used literature studies to determine SDGs as well a questionnaire-cum-survey, which was conducted on a sample of 1022 public transport passengers in Zielona Góra, Poland, to determine SPTP. The results were verified by a real case study of a Polish city, which, in 2019, had the largest fleet of electric buses in Poland; a statistical analysis was also conducted using correlation coefficients. It was determined that the proposed approach allows for low carbon energy public transport to be constantly monitored and analyzed. In the long run, this could be a good benchmark as to how cities might improve their level of sustainability.

Keywords: electric buses; greenhouse gas emissions; low carbon energy public transport; public transport; sustainable development; Polish city

1. Introduction

Transport is the main source of greenhouse gas emissions. According to data provided by the International Energy Agency (IEA), activities should be implemented in the transport sector in the coming decades, in order to reduce CO₂ emissions by 70% in developing countries and by 80% in developed countries in advance of 2050 [1].

1.1. Smart Energy for Communities

In response to the challenges of the modern world such as the energy crisis, rapid climate change, and environmental issues related to the use of fossil fuels and their volatile prices, the undertaking of initiatives in line with the concept: “community energy” is essential for the development of renewable energy sources and local energy management [2–4].

The idea of “community energy” is often presented as activities where communities exhibit a high degree of control of the energy project as well as collectively benefitting from the outcomes either of energy-saving or revenue-generation [5]. Another comprehensive definition is also that presented by Klein and Coffey [6], which presents community energy as “a project or program initiated by a

group of people, united by a common, local geographic location such as a town- or smaller- and/or a set of common interests, in which some, or all, of the benefits and costs of the initiative are applied to this same group of people and which incorporate a distributed energy generation technology for electricity, heat, and transportation, based on renewable energy resources such as solar, wind, water, biomass, geothermal and/or energy conservation/efficiency methods/technologies". An analysis of the literature has shown that the main characteristics of community energy include [7] social initiatives, which are largely driven by social need, motivation, and values. The values adopted vary and may also vary in nature; a sense of a high degree of community results in a high degree of commitment to the community in management and decision-making. Initiatives should aim at a fair distribution of values, costs, and risks; society is not only focused on maximizing the economic benefits.

In the field of smart energy for communities supporting the transition to low carbon energy, an important concept is the virtual power plant (VPP), which appeared as early as the late 1990s. One of the commonly cited definitions of VPPs is that of Pudjianto and others [8], where a VPP is considered to be "a flexible representation of a portfolio of distributed energy resources (DER), which aggregates the capacity of many diverse DER to create a single operating profile from a composite of the parameters characterizing each DER and incorporating spatial (i.e., network) constraints". Literature on the subject distinguishes two classifications of VPPs: commercial and technical due to their roles in the energy system [8]. Among the most popular commercial solutions, smart energy communities supporting a transition to low carbon energy stand out: solar panels, solar farms, and heat pumps.

One example of community energy is the large scale introduction, in many city centers, of electric buses that run on batteries. The biggest advantage of battery-run, electric buses, is zero local emissions as well as the possibility of reducing their operating costs [9]. However, compared to conventional vehicles powered by internal combustion engines, electric buses are somewhat limited when it comes to storing energy since this affects the driving range. When analyzing the driving range, attention should not only be paid to the capacity of the battery used, but also to the environmental conditions and to the conditions of the vehicle including the use of auxiliary, vehicular devices, and the weight of the vehicle as well as the road conditions [10]. The literature on the subject, in connection with uncertainty, the range of electric vehicles running on batteries, presents methods for predicting energy consumption including the results of experiments allowing such as the range of the battery used to be accurately estimated when adopting various parameters of friction, the weather conditions, and/or operation [11,12], and the data-driven methods such as the use of neural networks to determine the energy consumption of electric vehicles [13]. A significant number of models presented take into account dependent variables, which are particularly important when considering city buses. Next to the driving range, attention should be paid to the problem of the growing demand for materials to build electric batteries [14]. As pointed out in [15], the current production of electric vehicles is not close to the total production of passenger cars. In order to increase production, the scenario of increasing the extraction of certain metals, in particular lithium, but also dysprosium, terbium, platinum, neodymium, tantalum, and palladium [15] should be adopted. Due to the popularity of the use of lithium batteries, this material is considered potentially problematic, not only due to its limited resources, but also because it is time-consuming and expensive to recycle; recycling is not fully developed at present. However, it should be emphasized that there are different types of batteries available on the market, which clearly implies risks and limitations. Our research focused on analyzing the effectiveness of implementing electric buses in cities in the context of improving sustainability levels.

Another important parameter, when comparing electric buses to traditional buses with internal combustion engines, is noise. Today, transport is the main source of noise in urban areas, which negatively affects both the health and the general emotional state of residents. Electric buses practically do not emit sounds at low speeds, which significantly affects the quality of life of residents. However, this parameter is also considered in terms of road safety, since it is the noise emitted by moving vehicles that is a key information factor for road users [10]. There has been a higher proportion of road accidents involving pedestrians and cyclists caused by collisions with electric/hybrid vehicles [14]. Woodcock et al. [15]

tested electric buses in UK cities for noise emissions. In the test results, drivers of electric buses agreed that the dearth of noise and vibration in the cab improved both their comfort and that of the passengers. At the same time, they pointed out that the main problem of noise emission is the safety of pedestrians on the roads since safety, as such, is mainly based on hearing.

Our research, as pointed above, focused on analyzing the effectiveness of implementing electric buses in the city. Therefore, a literature analysis on measuring the effectiveness of the use of electric buses in cities is the measurement of greenhouse gas emissions and energy consumption. The results presented by [16] indicate greenhouse gas emissions for transit buses at 211 g CO_{2eq}/km, while the implementation of electric buses aims for the maximum reduction of emissions of CO_{2eq}/km when running. Liu Q. and others [17] presented research on measuring the emission flow of buses powered by different fuels when accelerating from a bus stop in Gothenburg, Sweden. The analysis showed that electric buses emitted significantly fewer harmful gases when starting from a bus stop when compared to diesel buses; this, in turn, affects the amount of PM dust produced and subsequently inhaled by passengers and residents. The undoubted benefit of the implementation of electric buses in affecting the quality of life of residents is the reduction of noise in cities caused by traffic. Studies showed positive results in this area, as Laib F. and others represented in [18]. At a constant speed of 20 km/h, around 25 electric buses were shown to emit noise at the level of one conventionally driven bus. It was also noted that the introduction of electric buses in cities with high traffic has a limited impact on noise reduction due to their low percentage share of public transport. An analysis of the results of the studies found that reducing noise emissions by using electric buses in the city had the greatest benefit when there was a large share of buses in the total traffic and when buses moved at low speeds (up to 50 km/h) in a city where there is a small percentage of additional heavy traffic. Another positive aspect of the introduction of electric buses is energy saving. Nurhadi L. and others [19] pointed out that the electric propulsion system was the most energy-efficient and sustainable choice. The authors also pointed out that existing diesel buses were one of the worst solutions in terms of both energy efficiency and cost, and by far the worst choice in terms of emissions throughout the life cycle. The authors also predict that, compared to a diesel bus, the total cost of ownership over an 8-year period for an electric bus, would be 20% lower.

1.2. The Sustainable Development of the City

A city's increasing environmental pollution requires the implementation of innovative solutions for the sustainable development of the city, especially in the transport sector. The construction of ring roads, the development of environmentally friendly, public transport for passengers as well as the use of alternative energy sources in the supply of vehicles are solutions that will significantly achieve the objectives aimed at sustainable urban development.

In the context of sustainable urban development, Sustainable Development Goals (SDGs) are designed to educate the public, mobilize, and empower all city actors to deal with practical problem-solving and address the specific challenges of poverty and access to infrastructure [20]. It is also important to promote integrated and innovative urban infrastructure design and to promote effective spatial planning. Spatial planning has a significant impact on reducing the negative impact of the use of urban areas. In 2007, New York introduced the concept of #OneNYC for a strong and just city, which is based on the protection of the economy and climate and includes eradicating the poverty of 800,000 people by 2025 and eliminating waste (i.e., the zero waste concept) [21]. Undoubtedly, cities are responsible for the majority of global greenhouse gas emissions, hence the need to develop a strategy for action against climate change and disasters [22]. San Francisco, Copenhagen, Sydney, and Vancouver have set a target of obtaining 100% of the city's energy from renewable sources [21].

However, attention should also be paid to the growing criticism of economic growth and the preservation of the Green Deal [23], especially in the richest countries "one in which economic growth should lose its privileged position as the touchstone of policy and institutional success" [24,25]. It is important to stress that "Although many economies around the world are indeed getting better

at producing commodities more cleanly and efficiently, a process known as ‘relative decoupling’, the overall ecological impact is nevertheless still increasing, because every year, increasing numbers of commodities are being produced, exchanged, and consumed as a result of growing economies” [26]. When introducing goods onto the market that are “safer for the environment”, we do not always act in its favor. One of the paradoxes depicted in the literature of the subject [23], is an example of more fuel-efficient vehicles, where the effect of the rebound is an increase in the number of drivers and a higher number of vehicles purchased than is the case for “less eco” vehicles. In conclusion, it is necessary to raise awareness and actions leading to sustainable development, but the effects of the so-called ‘rebound’, associated with the programs, should not be underestimated.

In addition, the idea of a Smart City has been met with an increasing number of skeptics of this type of solution, raising more and more questions and controversies due to the collection of data and their unrestricted access thereto, thus submitting to the techno-political ordering of society [27–30]. It is indicated that an inability to implement a Smart City solution and the misuse of data can affect public safety and violate the citizens’ right to privacy, which easily does more harm than good [31]. “One important and constant characteristic of these different visions, however, is that they aim to evoke positive change and innovation—At least as its proponents see it—Via digital ICT; essentially, building an IoT—of city-like proportions—by installing networked objects throughout the urban environment (and even in human bodies) for a wide range of different purposes [29]”.

This paper proposes and explores a sustainable urban development card for the Polish city of Zielona Góra, the use of which will ensure sustainable public transport. In 2018, Poland introduced a law on electro-mobility, which imposes an obligation to gradually replace bus rolling stock with zero emission buses by 2028, by a minimum of 30% for cities with over 50,000 residents. The implementation of this solution is aimed at improving the quality of life of residents and reducing greenhouse gas emissions. In Poland, the response to the adopted UN Sustainable Development Goals, which have become a new development map for the world, is the “Sustainable Cities” Program. It is assumed that activities in the field of sustainable urban development, economic growth, and environmental protection are to be undertaken to achieve SDGs by 2030 [22]. Deep-seated changes in Polish cities will necessitate the protection of the environment with simultaneous economic growth. Such assumptions require the implementation of appropriate strategies in many areas of the city’s functioning. One of the cities implementing the “Sustainable Cities” program is Kielce. The flagship idea is the Smart City Platform, which is to provide access to data, its processing, analysis, visualization and sharing, in order to provide public e-services [32]. The City of Kielce also implements a low-emissions economy plan and conducts integrated management of municipal property.

Activities for a low-emissions economy constitute a common challenge for Polish cities because “in the centers of large cities, some 60% of air pollution comes from transport, according to estimates, while in Warsaw, it is as much as 63%; furthermore, six Polish cities are among the most polluted in Europe” [33]. In Poland, 198 electric buses were registered in 2019 as part of a low-emission transport strategy [34]. In July 2019, Zielona Góra had the largest fleet of electric buses in Poland. Therefore, further analysis was based on the case study of the city of Zielona Góra, in order to show a good example of the impact on sustainable urban development with the implementation of electric buses in Polish cities with over 140,000 inhabitants.

The authors have focused their research on analyzing the effectiveness of implementing electric buses in the city of Zielona Góra and on conducting a research survey among passengers with regard to satisfaction with the use of these buses. In order to solve this, we developed sustainable indicators (SD) directly affecting the three main aspects of SD for public transport, *viz.*, environmental, social, and economic dimensions. Therefore, in this work, the two main areas of an analysis of the parameters of a system of low carbon energy public transport were formulated: (1) Sustainable Development Goals (SDGs) and (2) indicators of the Satisfaction Rate of Public Transport Passengers (SPTP). This last proposed solution is an analysis of electric bus parameters and passenger satisfaction in terms of sustainable urban development. Moreover, no research analysis has been carried out on sustainable

urban development the impact of the implementation of electric buses in Polish cities with over 140,000 inhabitants.

Based on the analysis carried out, the need was pointed out to create a new approach to analyzing the system of low carbon energy public transport, combining SDGs and SPTP, the so called sustainable urban development card. Section 2 describes the research materials and methods while Section 3 gives details of the results of the research. Finally, a discussion is provided and the direction of further work is presented.

2. Materials and Methods

2.1. Data Collection

The results of the analysis of the level of sustainable urban development in Poland that was published by Arcadis [35] showed that Poland is still a country with very low sustainable urban development. In order to build the sustainable urban development card, the parameters for the analysis of a system of low carbon energy public transport were formulated, based on the opinions of experts involved in the implementation of the “Sustainable Cities” Program in Poland in two areas: (1) Sustainable Development Goals (SDGs) and (2) the indicators of the Satisfaction Rate of Public Transport Passengers (SPTP). Therefore the studies were carried out in two stages: (1) SDG measurement and (2) main survey studies.

2.1.1. Sustainable Development Goal (SDG) Measurement

The following Sustainable Development Goals (SDGs) were defined:

- SDG_e—Environmental: SDG_{e1}—reduced energy consumption; SDG_{e2}—reduced environmental pollution; SDG_{e3}—increase in benefits to society without compromising future generations.
- SDG_s—Social: SDG_{s1}—customer satisfaction; SDG_{s2}—increasing innovation; SDG_{s3}—comfort of residents
- SDG_c—Economic: SDG_{c1}—price.

The data for calculating the indicated SDG were obtained from the Municipal Department of Transport in the city of Zielona Góra. The energy consumption index was the daily average of kWh/km consumption, which was adopted on the basis of three periods: the last quarters of 2018, 2019, 2020, and August. The remaining SDG values were adopted according to data for August 2020.

2.1.2. Main Survey Studies

The main survey research was carried out at stops and in public transport vehicles on a representative sample of passengers aged 16–75 [$n = 1022$], with an estimated gender and age structure, corresponding to the entire population of the inhabitants of Zielona Góra; the research was conducted in 2019. At least 700 interviews were conducted on electric vehicles and at least 300 were conducted on vehicles with internal combustion engines. The data were collected using a direct questionnaire interview (PAPI). The survey questionnaire (Appendix A) had ten questions: nine closed and one open, in which it was possible to provide interviewees with possible comments of their own, regarding the Green Mountain and the public transport of electric buses, newly put into operation. Information on the gender structure of the respondents is presented in Figure 1, while the age of the respondents is shown in Figure 2.

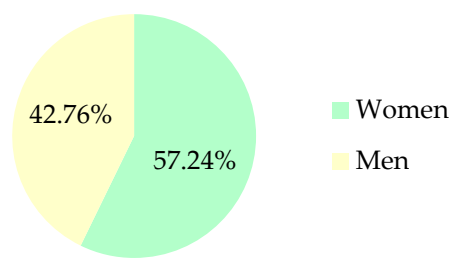


Figure 1. The gender structure of the respondents.

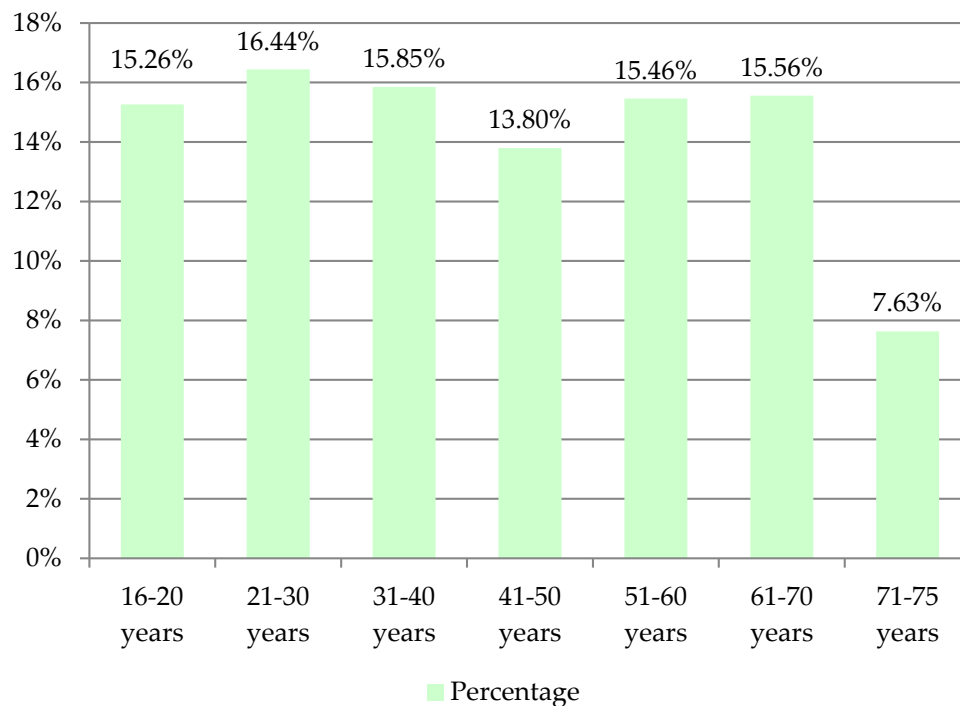


Figure 2. The age of the respondents in %.

The survey asked respondents to identify their age group (aged 16–20, 21–30, 31–40, 41–50, 51–60, 61–70, and 71–75). The survey involved 585 women, representing 57.24% of the total number of respondents, of which the percentage was women: 54.49% aged 16–20, 49.4% aged 21–30, 54.94% aged 31–40 years, 62.41% aged 41–50 years, 59.49% aged 51–60 years, 62.26% aged 61–70 years, and 60.26% aged 71–75. For the opposite sex, 437 men participated in the survey, representing 42.76% of all respondents, of which 45.51% were men aged 16–20, 50.6% aged 21–30 years, 45.06% 31–30 years, 37.59% aged 41–50 years, 40.51% aged 51–60 years, 37.74% aged 61–70%, and 39.74% aged 71–75 years.

Indicators of the satisfaction rate of Public Transport Passengers (SPTP) were defined in the following way:

Factors of SPTP (SPTP₁–SPTP₄) were based on feedback surveys and their sources are listed here: SPTP: “I know the advantages of electric buses in my city”: STPT₁—“Keep Calm” Electric Vehicle, STPT₂—smooth ride, STPT₃—environmentally friendly: ecology, STPT₄—environmentally friendly: air quality is: factor0: not very important/factor1: very important.

Factors for the evaluation of electric buses by passengers of public transport vehicles were based on feedback surveys and their sources are listed here: Evaluation of electric buses: the degree to which a city creates innovative solutions for sustainable urban development, using the scale: factor1: not very important; factor2: not important; factor3: quite important; factor4: important; factor5: very important.

2.2. Case Study: The City of Zielona Góra, Poland

As above-mentioned, the city of Zielona Góra was chosen for further analysis since it has the largest fleet of electric buses in Poland. The city of Zielona Góra, together with the Municipal Department of Transport (MZK) has completed a project entitled “The integrated low-emission public transport system in Zielona Góra”. The city of Zielona Góra is the largest city in Lubuskie Province with about 140,000 inhabitants. The project was implemented from the operational program Infrastructure and Environment 2014–2020 action 6.1. The development of public transport in cities was co-financed by the European Union budget and its value was PLN 284,825,840.94. The project proposed the following components [36]:

- purchase of new, low-floor electric buses (12 m): 43 units;
- purchase of new low-floor diesel buses (18 m): 17 units;
- battery charging infrastructure;
- modernization of the Municipal Department of Transport bus depot;
- construction of a passenger transport interchange;
- canopy at the railway station;
- modernization of the viaduct under the railway tracks, on ul. Batory;
- construction and reconstruction of loops and stops with accompanying infrastructure; and
- modernization of the real-time passenger information system and the MZK management system.

The city of Zielona Góra has been the only city in Poland to replace weekend transport lines with 100% electric buses. In addition, mechanics and drivers from MZK indicate a low failure rate of new vehicles when compared with earlier, complex diesel engines. In total, 11 fast charging stations with a total number of 32 charging stations and one charging station at the depot were established in Zielona Góra. In addition to the fast charging station, there are 25, two-station, free chargers in the city. The fast charging time of one bus is 20 min. A full charge is enough to travel 50 km.

2.3. Research Model

The research model (Figure 3) posits, from the preceding argument, that the implementation of electric buses increases the level of sustainable urban development. The main objective at the local level, in terms of transport, is to increase the safety of traffic users and the quality of life of residents and to reduce environmental damage. Our study focused on the actions taken by the city of Zielona Góra, in order to ensure sustainable public transport.

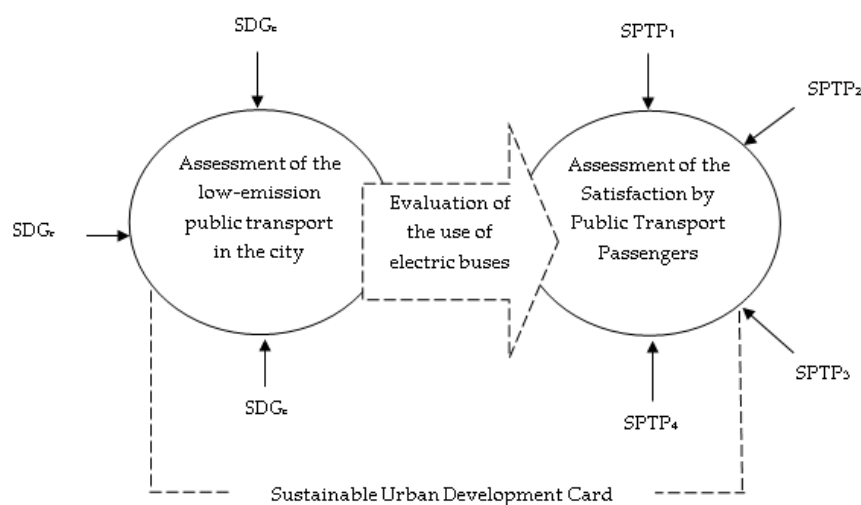


Figure 3. Research model.

2.4. Analytic Method

The research model (Figure 3) was analyzed using the correlation and further regression approach in order to build the sustainable urban development card. A moderated correlation approach, using Statistica version 13.3 (StatSoft Polska Sp. z o.o., Kraków, Poland), was used.

Finally, we proposed the sustainable urban development card (Table 1). The level of sustainable urban development is defined as: 1: unacceptable; 2: low; 3: good; 4: very good; and 5: excellent, based on the values of each of the SDGs obtained. The level of relationships between the Satisfaction Rate of Public Transport Passengers and the advantage of electric buses is also defined as 1: unacceptable; 2: low; 3: good; 4: very good; and 5 as excellent, based on the obtained results of the correlation analysis.

Table 1. Sustainable urban development card.

Sustainable Urban Development	Level	Results
SDG _e	$\frac{\text{level}(\text{SDGe1}) + \text{level}(\text{SDGe2}) + \text{level}(\text{SDGe3})}{3}$	1 or 2 or 3 or 4 or 5
SDG _s	$\frac{\text{level}(\text{SDGs1}) + \text{level}(\text{SDGs2}) + \text{level}(\text{SDGs3})}{3}$	1 or 2 or 3 or 4 or 5
SDG _c	level(SDGc1)	1 or 2 or 3 or 4 or 5
Evaluation of the use of electric buses (E)	$\frac{\text{sum of passenger response levels (scale: 1 to 5)}}{\text{number of responses}}$	1 or 2 or 3 or 4 or 5
STPT ₁	Value of correlation analysis	1 or 2 or 3 or 4 or 5
STPT ₂	Value of correlation analysis	1 or 2 or 3 or 4 or 5
STPT ₃	Value of correlation analysis	1 or 2 or 3 or 4 or 5
STPT ₄	Value of correlation analysis	1 or 2 or 3 or 4 or 5

This article offers an assessment of low-emission public transport and, in addition, an explanation of the influence of the implementation of electric buses on the increased SPTP. On the basis of the current analysis of the literature on the subject and of SDGs defined, in the context of sustainable urban development and the results of the research survey, the approach for the analysis of a system of low carbon energy public transport combining SDGs and SPTP, was defined (Figure 1). A questionnaire was developed, based on which, SPTP studies on a representative sample of passengers of public transport vehicles in Zielona Góra, were conducted. The surveys applied tested the research model (Figure 1) and were developed by defining scales to fit the meaning of the codification of the Satisfaction Rate of Public Transport Passengers.

3. Research Results

Based on the data received from the Municipal Department of Transport, Zielona Góra—and in order to build the Sustainable Urban Development Card for that city—the values of SDGs were obtained (Table 2). The energy consumption index is the daily average of kWh/km consumption, which was adopted on the basis of three periods: the last quarter of 2018, 2019, 2020, and August. The remaining indicator values were adopted according to data for August 2020.

Table 2. Values of Sustainable Development Goals (SDGs) for the city of Zielona Góra.

SDGs	Value	Level
SDG _{e1}	1.23 kWh/km (average daily consumption kWh/km)	4
SDG _{e2}	0 GHG	5
SDG _{e3}	Reducing risk management related to the climate	4
SDG _{s1}	89%	4
SDG _{s2}	Lithium batteries, capacity 175 kWh	4
SDG _{s3}	Noise [dB] = 63	4
SDG _{c1}	One-off ticket price [Polish]: Paper ticket 1.50–3.00 Electronic wallet 1.00–2.60	5

The level of sustainable urban development for each SDG was defined, based on a comparison with conventional diesel buses (Table 3).

Table 3. Comparison of the value of SDGs in the city of Zielona Góra between electric buses and diesel buses.

SDGs	Value: Electric Buses	Value: Buses with a Diesel Engine
SDG _{e1}	1.23 kWh/km (average daily consumption kWh/km)	45l/100 km for 12 m buses, 50l/100 km for articulated buses
SDG _{e2}	0 GHG	924 g CO ₂ eq/poj-km [31]
SDG _{e3}	Reducing risk management related to the climate	-
SDG _{s1}	89%	-
SDG _{s2}	Lithium batteries, capacity 175 kWh	E-card
SDG _{s3}	Noise [dB] = 63	Noise [dB] = 80
SDG _{c1}	One-off ticket price [Polish]: Paper ticket 1.50–3.00 Electronic wallet 1.00–2.60	One-off ticket price [Polish]: Paper ticket 1.50–3.00 Electronic wallet 1.00–2.60

The electricity used in the city for charging electric buses quickly is taken from Enea, while the electricity for charging at the depot is taken from the Combined Heat and Power Plant (gas). Compared to diesel prices, the electricity needed to drive 100 km on an eco-friendly bus is now half the price [37].

The next part of our sustainable urban development card for Zielona Góra is an evaluation of electric buses by passengers of public transport vehicles. The value was based on feedback surveys from a representative sample of passengers aged 16–75 [$n = 1022$] and was conducted in 2019. The level of the evaluation of the use of electric buses is at 4 (Equation (1)).

$$E = \frac{4492}{1022} = 4.39 \quad (1)$$

Table 4 presents descriptive correlations for the main variables included in the research model (Figure 3) using Statistica ver.13.3. The data were carefully examined with respect to linearity, equality of variance, and normality. No significant deviations were detected.

Table 4. Correlation analysis.

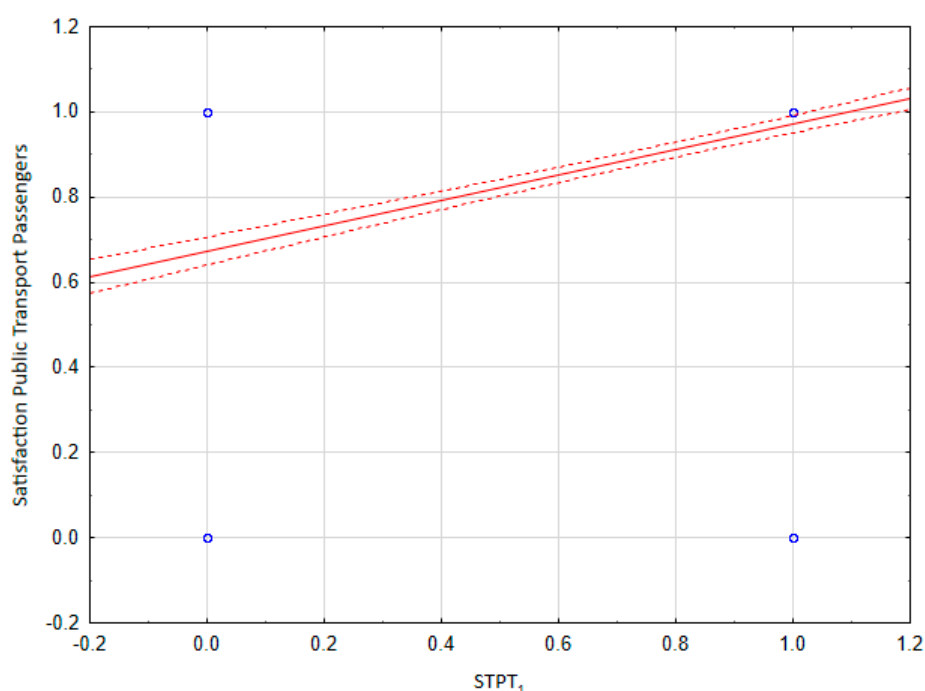
Relations	Correlation	r2	t	p
STPT ₁ —"Keep Calm" Electric Vehicle/Satisfaction Public Transport Passengers	0.4239	0.1797	14.9486	0.0000
STPT ₂ —smooth ride/Satisfaction Rate of Public Transport Passengers	0.0318	0.0010	1.0172	0.3093
STPT ₃ —environmentally friendly: ecology/Satisfaction Public Transport Passengers	0.0027	0.0000	0.0886	0.9294
STPT ₄ —environmentally friendly: air quality/Satisfaction Rate of Public Transport Passengers	−0.0185	0.0003	−0.5908	0.5547

where r2 is the coefficient of determination; T is the value of t statistics examining the significance of the correlation coefficient; and p is the probability value.

The analysis showed one significant relationship between the advantages of using electric buses in the city: "Keep Calm" and the satisfaction of the passengers using public transport. Unfortunately, no significant relationship was found between STPT₂, STPT₃, STPT₄ and the increased satisfaction of public transport passengers. Therefore, to define the nature of significant interactions of the influence of the advantages of using electric buses on the increase in SPTP—in the context of a Polish city—the study tested the hypotheses using regression analyses that estimate this impact (Equation (2)).

$$SPTP = 0.6736 + 0.2978 \times STPT_1 \quad (2)$$

Based on the analysis, it was noticed that the advantages of using electric buses "Keep Calm" increased the satisfaction of public transport passengers (2, Figure 4).

**Figure 4.** Sustainable urban development card.

The statistical results showed that the one advantage examined in using electric buses was the satisfaction of public transport passengers. Finally, Table 5 presents the sustainable urban development card for Zielona Góra, based on the research results in Tables 2 and 4.

Table 5. Sustainable urban development card for a Polish city.

Sustainable Urban Development	Level	Results
SDG _e	4.33	4
SDG _s	4	4
SDG _c	5	5
E	4.39	4
STPT ₁	0.4239	4
STPT ₂	0.0318	1
STPT ₃	0.0027	1
STPT ₄	−0.0185	1

It is clearly obvious that further actions should be applied in increasing the satisfaction of public transport passengers and increasing awareness of them in sustainable urban development. It seems that for the passengers of Zielona Góra, the following factors, namely, a smooth and environmentally friendly ride as opposed to ecology and air quality, are not important in the context of increased comfort.

The proposed sustainable urban development card can be applied to all cities implementing a revision of public transport rolling stock as part of sustainable development. SDGs and STPTs can be expanded or modified in terms of the specific needs of the cities concerned. The proposed solution enables the transport authorities in the city to control undertakings in real time, reduce costs, save resources and energy, implement an environmental policy, and constitutes a database for further actions.

4. Discussion

This work compared the adopted SDGs for electric buses with transit buses. Electric buses have allowed petroleum-based measures for electricity to be completely eliminated. It is important to point out that electricity comes from both the Enea energy distributor and natural gas, which is an alternative source of energy. Another parameter included in the analysis was greenhouse gas emissions, which for transit buses is 924 g CO₂ eq/poj-km, while for electric buses, it is 0 g CO₂ eq/poj-km. It should be stressed, however, that GHG emissions only concern vehicle operation with the possible emissions from additional equipment, machinery, or passengers not being taken into account. The indicator studied, which in the literature of the subject arouses much controversy, was noise. According to the analysis, the noise produced by the new low-emission bus fleet decreased by 17 dB, which positively affects the comfort of life of residents, especially at night, when traffic is very limited. As indicated in the analysis of the literature, the reduction of noise emissions by public transport, during peak hours in medium and large cities, has little bearing on the health and comfort of the population due to the low percentage of traffic. Another aspect related to noise is safety. This parameter was not included in the survey, prompting the authors to examine this dependency in subsequent surveys. An important summary of the results is the overall assessment of the new low-emission public transport fleet by passengers of the MZK in Zielona Góra. MZK received a rating of 4.39, on a scale of 1 to 5, which is a very good result and bodes well for the further achievement of SDGs in the city.

In our example, we created a sustainable urban development card in order to monitor improvements in the state of the atmosphere through the sustainable and efficient use of energy carriers [37]. Due to the changes introduced in 2019, the Municipal Transport Department in Zielona Góra commissioned a study on the quality of transport services concerning the evaluation of new rolling stock by passengers. The Municipal Transport Department in Zielona Góra has also introduced changes to the availability and price of tickets that are beneficial for passengers. Using an electronic wallet allows for cheaper travel than a paper ticket. In order to facilitate the purchase of a travel ticket, the passenger can use several forms: e-card, electronic wallet, paper wallet, application (app).

Bus tickets have also been used in card readers, which allows you to pay for the ticket with a bank card or smartphone. Today, residents of Zielona Góra can benefit from the facilities introduced including the transfer center at the railway station, low-emission and silent electric buses, and an extensive, passenger information system. The fleet of buses implemented is passenger-friendly and, importantly, four times quieter than diesel buses as well as cheaper to maintain and are much greener.

In Zielona Góra, the low-emission public transport project will continue to be developed. A contract has been signed for another 12 electric buses; ultimately the city wants to switch to 100% electric buses and give up conventional buses altogether. Bus manufacturer URSUS is also pledging changes to further reduce its environmental impact by increasing battery capacity from 175 kWh to 250 kWh [38]. The solutions introduced are part of the sustainable development strategy of Zielona Góra. In addition to reducing environmental pollutants, the introduction of electric buses has reduced noise emissions. The average noise emission of an electric bus during a stop-over is about 64 dB, while for the diesel-powered bus, it is 80 dB. Another aspect worth paying attention to is the use of gas as an energy source for charging electric buses. In terms of the work of electric buses in Zielona Góra, it should be emphasized that [39]:

- buses connect 430 times a day in order to charge up;
- on average, a bus charges up to 23 kWh and a maximum of 68 kWh of energy on a single charge;
- the longest route between charging is 43 km and charging time, after this mileage, is 17 min as a maximum; and
- the annual electricity consumption of MKZ buses in 2019, amounted to more than 2400 mWh.

5. Conclusions

The sustainable urban development card presented can be a good benchmark as to how cities can improve their level of sustainability. The idea, as presented, is an innovative approach to monitoring and analyzing low carbon energy public transport. The issue of SDGs in countries and cities is of key importance on a global scale. The new approach combines the SDGs, STPTs, and E as well as the research methods of survey and correlation analysis.

Thanks to the implementation of our card, it is possible:

- to present a level of sustainable urban development;
- to evaluate the adopted SDGs, STPTs, and E;
- to obtain a table defining the level of the Sustainable Urban Development, enabling the recommended corrective actions to be determined; and
- to constantly monitor the corrective actions implemented in the city.

As with all studies, this study had certain limitations, which further research should be able to overcome. First, the application of a model was shown in the example of the Polish city investigated and all the indicators were measured at the same time; it would, therefore be useful to provide such research over a longer period of time. Second, it should be borne in mind that an increase in energy efficiency may lead to fewer energy savings than would be expected by simply multiplying the change in energy efficiency by the energy use *prior to the change* [40]. These conclusions and limitations suggest proposals for the direction of future research, especially in the context of extending the proposed approach to include the aspect of measuring the so-called “rebound effect”.

Author Contributions: Conceptualization, J.P.-M.; Methodology, J.P.-M. and H.L.; Software, J.P.-M. and H.L.; Validation, J.P.-M.; Formal analysis, J.P.-M. and H.L.; Investigation, J.P.-M.; resources, J.P.-M. and H.L.; data curation, J.P.-M. and H.L. writing—original draft preparation, J.P.-M. and H.L.; Writing—review and editing, J.P.-M. and H.L.; Visualization, J.P.-M. and H.L.; Supervision, J.P.-M.; Project administration, J.P.-M.; Funding acquisition: J.P.-M. and H.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare that there are no conflict of interest.

Appendix A

Table A1. The Survey Questionnaire.

No	Questions	Answer
1.	How do you evaluate the public transport in Zielona Góra in general, with particular reference to the services of MZK Zielona Góra)?	(a) Very good (b) Good (c) Adequate (d) Inadequate, because . . . (e) I have no opinion
2.	Are you satisfied with the introduction of electric buses in Zielona Góra?	(a) Very good (b) Good (c) Adequate (d) Inadequate, because . . . (e) I have no opinion
3.	Have you already travelled on the new electric buses?	(a) Yes (b) No (c) I have no opinion
4.	What do you think of these buses?	(a) Very good (b) Good (c) Adequate (d) Inadequate, because . . . (e) I have no opinion
5.	What do you think is the greatest advantage of electric buses in my city; please choose one advantage	(a) “Keep Calm” Electric Vehicle, (b) Smooth Ride, (c) Environmentally Friendly: ecology, (d) Environmentally friendly: air quality (e) I have no opinion
6.	Do you think the introduction of electric buses is important for creating innovative solutions for sustainable urban development?	(a) Very important (b) Important (c) Quite important (d) Not important (e) Inadequate (f) I have no opinion
7.	Do you think the introduction of electric buses has had a significant impact on air quality in the city?	(a) Yes (b) No, because . . . (c) I don’t know
8.	Should the city of Zielona Góra continue to invest in electric buses?	(a) Yes (b) No, because . . . (c) I don’t know

References

1. International Energy Agency. Available online: <https://www.iea.org/> (accessed on 18 October 2020).
2. Hashmi, M.; Hanninen, S.; Maki, L. Survey of smart grid concepts, architectures, and technological demonstrations worldwide. In Proceedings of the IEEE PES Innovative Smart Grid Technology Latin America (ISGT LA), Medellin, Colombia, 19–21 October 2011; IEEE: Piscataway, NJ, USA, 2011; pp. 1–7.
3. Saboori, H.; Mohammadi, M.; Taghe, R. Virtual Power Plant (VPP), definition, concept, components and types. In Proceedings of the Asia-Pacific Power Energy Engineering Conference, Wuhan, China, 25–28 March 2011; IEEE: Piscataway, NJ, USA, 2011.
4. Tahmasebi, M.; Pasupuleti, J. Self-scheduling of wind power generation with direct load control demand response as a virtual. *Indian J. Sci. Technol.* **2013**, *6*, 5443–5449. [\[CrossRef\]](#)
5. Seyfang, G.; Park, J.J.; Smith, A. A thousand flowers blooming? An examination of community energy in the UK. *Energy Policy* **2013**, *61*, 977–989. [\[CrossRef\]](#)

6. Klein, S.J.W.; Coffey, S. Building a sustainable energy future, one community at a time. *Renew. Sustain. Energy Rev.* **2016**, *60*, 867–880. [\[CrossRef\]](#)
7. Summeren, L.; Wieczorek, A.; Bombaerts, G.J.; Verbong, G. Community energy meets smart grids: Reviewing goals, structure, and roles in Virtual Power Plants in Ireland, Belgium and the Netherlands. *Energy Res. Soc. Sci.* **2020**, *63*, 101415. [\[CrossRef\]](#)
8. Pudjianto, D.; Ramsay, C.; Strbac, G. Virtual power plant and system integration of distributed energy resources. *Renew. Power Gener. IET* **2007**, *1*, 10–16. [\[CrossRef\]](#)
9. Pihlatie, M.; Kukkonen, S.; Halmeaho, T.; Karvonen, V.; Nylund, N.O. Fully electric city buses—the viable option. In Proceedings of the IEEE International Electric Vehicle Conference (IEVC), Florence, Italy, 17–19 December 2014; IEEE: Piscataway, NJ, USA, 2014.
10. Asamer, J.; Graser, A.; Heilmann, B.; Ruthmair, M. Sensitivity analysis for energy demand estimation of electric vehicles. *Transp. Res. Part D Transp. Environ.* **2016**, *46*, 182–199. [\[CrossRef\]](#)
11. Wang, J.; Besselink, I.J.M.; Nijmeijer, H. Battery electric vehicle energy consumption modelling for range estimation. *Int. J. Electr. Hybrid Veh.* **2017**, *9*, 79. [\[CrossRef\]](#)
12. Vepsäläinen, J.; Kivekäs, K.; Otto, K.; Lajunen, A.; Tammi, K. Development and validation of energy demand uncertainty model for electric city buses. *Transp. Res. Part D Transp. Environ.* **2018**, *63*, 347–361. [\[CrossRef\]](#)
13. Shankar, R.; Marco, J. Method for estimating the energy consumption of electric vehicles and plug-in hybrid electric vehicles under real-world driving conditions. *IET Intell. Transp. Syst.* **2013**, *7*, 138–150. [\[CrossRef\]](#)
14. Beckers, C.; Besselink, I.; Nijmeijer, H. Assessing the impact of cornering losses on the energy consumption of electric city buses. *Transp. Res. Part D* **2020**, *86*, 102360. [\[CrossRef\]](#)
15. Woodcock, A.; Topolavic, S.; Osmond, J. The multi-faceted public transport problems revealed by a small scale transport study. In *Advances in Human Aspects of Road and Rail Transportation*; Stanton, N.A., Ed.; CRC Press: San Francisco, CA, USA, 2013; pp. 321–331.
16. Jwa, K.; Lim, O. Comparative life cycle assessment of lithium-ion battery electric bus and Diesel bus from well to wheel. *Energy Procedia* **2018**, *145*, 223–227. [\[CrossRef\]](#)
17. Liu, Q.; Hallquist, A.M.; Fallgren, H.; Jerksjö, M.; Jutterström, S.; Salberg, H.; Hallquist, M.; Le Breton, M.; Pei, X.; Pathak, R.K.; et al. Roadside assessment of a modern city bus fleet: Gaseous and particle emissions. *Atmos. Environ. X* **2019**, *3*, 10044. [\[CrossRef\]](#)
18. Laib, F. Modelling noise reductions using electric buses in urban traffic. A case study from Stuttgart, Germany. *Transp. Res. Procedia* **2019**, *37*, 377–384. [\[CrossRef\]](#)
19. Nurhadi, L.; Boren, S.; Ny, H. A sensitivity analysis of total cost of ownership for electric public bus transport systems in Swedish medium sized cities. *Transp. Res. Procedia* **2014**, *3*, 818–827. [\[CrossRef\]](#)
20. Urban SDG. Available online: <http://urbansdg.org/about/> (accessed on 22 September 2020).
21. Local Governments for Sustainability. Available online: <https://www.local2030.org/library/234/ICLEI-SDGs-Briefing-Sheets-04-The-importance-of-all-Sustainable-Development-Goals-SDGs-for-cities-and-communities.pdf> (accessed on 19 September 2020).
22. UNGC. Available online: <https://ungc.org.pl/programy/zrownowazone-miasta/> (accessed on 21 September 2020).
23. Alexander, S. Planned economic contraction: The emerging case for degrowth. *Environ. Politics* **2012**, *21*, 349–368. [\[CrossRef\]](#)
24. Stiglitz, J.; Sen, A.; Fitoussi, J.P. *Mis-Measuring Our Lives: Why GDP Doesn't Add Up*; The New Press: New York, NY, USA, 2010.
25. Property beyond Growth: Toward a Politics of Voluntary Simplicity. Available online: www.simplicityinstitute.org/publications (accessed on 19 October 2020).
26. Jackson, T. *Prosperity without Growth: Economics for A Finite Planet*; Earthscan: London, UK, 2009.
27. Angelidou, M. Smart cities: A conjuncture of four forces. *Cities* **2015**, *47*, 95–106. [\[CrossRef\]](#)
28. Kitchin, R. Making sense of smart cities: Addressing present shortcomings. *Camb. J. Reg. Econ. Soc.* **2015**, *8*, 131–136. [\[CrossRef\]](#)
29. Sadowski, J.; Pasquale, F. The Spectrum of Control: A Social Theory of the Smart City. First Monday 2015, 20. Available online: <https://firstmonday.org/ojs/index.php/fm/article/view/5903/4660> (accessed on 22 September 2020).
30. Zuboff, S. *The Age of Surveillance Capitalism: The Fight for a Human Future at the New Frontier of Power*; Profile Books: London, UK, 2019.
31. Citron, D.K.; Pasquale, F. Network accountability for the domestic intelligence apparatus. *Hastings Law J.* **2011**, *62*, 1441–1494.

32. Almine. Available online: https://almine.pl/smart_city_przyklady_polska/ (accessed on 22 September 2020).
33. UN Global Compact. Zrównoważone Miasta. Życie w Zdrowej Atmosferze. 2016. Available online: <https://ungc.org.pl/wp-content/uploads/2016/10/Raport-Zr%C3%B3wnowa%C5%BCona-miasta.pdf> (accessed on 20 September 2020).
34. InfoBus. Available online: http://infobus.pl/polski-rynek-autobusow-elektrycznych-lipiec-2019_more_117202.html (accessed on 23 September 2020).
35. Ranking of Sustainable Polish Cities, Arcadis, Warsaw, Poland. 2018. Available online: <https://www.arcadis.com/media/6/0/D/%7B60DA8546-A735-430A-BF9A-6114B0362FD7%7D%7DRanking%20Polskich%20Miast%20Zrownowazonych%20Arcadis%20FINAL.pdf> (accessed on 19 September 2020).
36. Langner, B.; Newelski, J. Integrated System of a Public Transport System which Uses Low-Carbon Energy: (in Polish). In Proceedings of the MZK Conference, Zielona Góra, Poland, 30 September 2020.
37. The Methodology for Assessing Greenhouse Gas Emissions, Warsaw 2015. Available online: https://bip.zielonagora.pl/system/obj/65592_RAPORT_cz.1_-_programy_strategie.pdf (accessed on 22 September 2020).
38. Subdisy Map. Available online: <https://mapadotacji.gov.pl/projekty/746900/> (accessed on 1 September 2020).
39. Gorzow. Available online: <https://gorzow.tvp.pl/48962949/2-lata-elektrycznych-autobusow-w-zielonej-gorze-jak-sie-sprawdzaja> (accessed on 2 September 2020).
40. Gillingham, K.; Rapson, D.; Wagner, G. The Rebound Effect and Energy Efficiency Policy. *Rev. Environ. Econ. Policy* **2015**, *10*, 68–88. [CrossRef]

Publisher’s Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).