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Intelligent and Environmentally Friendly Solutions in Smart Cities' Development—Empirical Evidence from Poland

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Abstract: This study presents a comprehensive analysis aiming to identify the implementation level of intelligent and environmentally friendly solutions (IEFS) in cities in Poland, and barriers impeding their development. Based on a representative sample of 280 cities, it was evident that the implementation level of IEFS in Poland is relatively very low. The most common barriers to IEFS implementation as indicated by representatives of city authorities were high costs, lack of adequate funds, and lack of awareness of benefits resulting from applying IEFS. Nevertheless, regression analyses showed that the IEFS implementation level was mostly affected by cities' population size and perception of individual IEFS as integral elements of the smart city concept. It was also revealed that the high costs of implementing IEFS, the lack of their inclusion in local development strategies, the lack of appropriate legal regulations, the lack of widespread good practices, and the resistance of inhabitants to change and to new technologies perceived as impediments had significant negative effects on the implementation level of specific IEFS. Furthermore, the analyses demonstrated that perceiving certain issues as barriers did not hinder the implementation of such solutions. Based on a discussion of the results, relevant recommendations and directions for future research are proposed.

Keywords: smart city; intelligent and environmentally friendly solutions; barriers; Poland

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1. Introduction

In 2020, 56% of the world's population lived in cities, and it is expected that the urban population will continue to grow in the coming years and exceed 70% in 2050 [1]. For municipal authorities, this increase in urban population density is associated with social, economic, logistical, and environmental challenges which cities must confront to ensure a high quality of life for residents.

Due to the dynamic development of innovative technologies, cities are increasingly implementing intelligent solutions aiming to improve the quantity and quality of public services provided to residents [2]. Advanced information and communication technologies (ICT) such as smart devices, mobile networks, data storage technologies, and software applications have created smart cities (SC). SC monitor and integrate working conditions of the entire urban infrastructure and its elements, optimize the use of resources, and monitor safety while maximizing the quality of services provided to the community [3].

Ideally, SC create an urban space where resources and opportunities are used more effectively; however, this requires the integration of activities in various areas of the city where it is possible to implement intelligent solutions. Although the literature has specified a different number of SC dimensions (e.g., refs. [4–7]), the six most frequently mentioned dimensions of SC are: smart economy, smart people, smart governance, smart mobility, smart environment, and smart living [8]. Each of these dimensions is crucial for the functioning of cities, but in recent years, smart environments have been emphasized due to the necessity for solutions that limit the scale of environmental problems that cities are struggling with. These problems primarily concern: the growing demand for energy and water reported by city residents; the growing demand for raw materials in connection with growing consumption; increasing air pollution because of, among other causes, increased car traffic in cities; and an increase in the amount of waste generated by city residents.

Technology development has influenced cities to implement advanced technologies to become smarter. These technologies are crucial for smart cities because they can increase the smart city's sustainability and improve the citizens' quality of life [9]. Intelligent (smart) solutions are of particular importance and combine innovative technologies, both in terms of hardware and software. The term 'smart' refers to the intelligence contained in the solution that enables the hardware to collect and transfer data between different systems, while 'solution' refers to the integration of hardware, services, and software, creating a greater value than an alternative where these components are sourced separately [10]. Intelligent solutions are widely used in many areas of life, from smart offices or cars to smart cities [11]. This trend is also visible in the field of environmental protection, where various examples of intelligent solutions in cities can be observed [12–17]. The implementation of such solutions results in an overall improvement in the quality of the environment; therefore, they can be referred to as intelligent and environmentally friendly solutions (IEFS). Despite the benefits of introducing IEFS, city authorities often decide not to use intelligent solutions due to implementation barriers [18,19]. As such, it is important to identify the implementation level of IEFS in cities and identify barriers to their implementation.

Relatively few studies have comprehensively examined the specificity and implementation level of a wide spectrum of IEFS and barriers to their implementation; rather, they look at specific SC dimensions and IEFS implemented (e.g., refs. [20–24]). For example, various studies have addressed technical aspects of implementing innovative solutions such as wireless sensor networks, internet of things (IoT), or ICT in the field of environmental protection (e.g., refs. [20–23,25–30]). Other studies have presented methodologies and results of SC assessments such as the level of pollutant emissions, the amount of segregated waste, or the amount of energy generated from renewables (e.g., refs. [15,31–35]). Moreover, few researchers have carried out comprehensive analyses in this area based on large research samples [13,36]. Furthermore, one of the few studies that looked at barriers to the implementation of IEFS focused on SC waste management systems [19].

To address the identified research gap, this study was conducted on a sample of cities located in a medium-sized European country, Poland. According to the CIMI Cities in Motion Index, there are only two cities representing Poland among the smart cities included in the ranking, and they have been classified at the middle level [37]. Moreover, other research revealed that even the largest Polish cities appeared to be only partially successful in the implementation of SC strategies [38]. This confirms the necessity for further research on the level of implementation of intelligent solutions in the SC concept and on the barriers preventing such implementation in this context. This research appears to be novel and adds new insights to the knowledge on SC in Poland, including municipal priorities [38], barriers to the implementation of intelligent transport [39], logistics solutions [40], sustainable mobility and transport decarbonization [41], electric public transport [42], creative and intelligent space safety [43], sharing economies' initiatives in the context of SC [44], interdependencies of SC areas [45], and multicriteria analysis of SC [31,46]. Furthermore, we intended to provide some recommendations for policy makers, city authorities, managers, and practitioners to support and facilitate IEFS implementation as an integral element of SC. Therefore, the main aim of this paper was to identify the specificity and implementation level of IEFS in cities in Poland and barriers impeding their development. The research was carried out from an institutional point of view, as it was based on the perspective of city authorities. It was intended to address the following research questions:

- To what extent are IEFS implemented in cities in Poland?
- To what extent are specific IEFS perceived as integral components of SC?
- What are the barriers to the implementation of IEFS?
- What is the influence of relevant barriers on the implementation level of specific IEFS?

The remainder of this paper is organized as follows. Section 2 presents the results of the literature review in the field of IEFS and SC barriers. The research methodology is described in Sections 3 and 4 presents and discusses results. Finally, the concluding remarks and limitations of this study are presented in Section 5.

2. Literature Review

2.1. Intelligent and Environmentally Friendly Solutions in Smart Cities

Smart cities increasingly use intelligent technologies to solve environmental problems. These technologies have a wide range of applications in different areas and usually rely on the construction and maintenance of a wireless sensor network (WSN), IoT, ICT, machine learning technologies, and deep learning technologies [47].

IEFS are usually used in SC to monitor and ensure adequate environmental quality, particularly air quality. For this reason, cities create smart environmental quality monitoring systems using stationary and/or mobile sensor nodes based on IoT technology. The data collected in real-time by the sensors are sent wirelessly, processed using machine learning or deep learning algorithms, and used, e.g., to create models of environmental quality and detect changes in the environment [12,27,48]. They can then be transferred to residents of the SC using special platforms and mobile applications [49,50].

Wireless sensor networks based on IoT are also used in indoor air quality monitoring systems. The analyzed data collected from sensors are the basis for making decisions about the need to, for example, increase ventilation or reduce the level of air conditioning in order to improve conditions in a given room [51–53].

Smart and environmentally friendly buildings are another example of IEFS. In smart buildings, a network of wireless sensors communicate with each other to collect and analyze big data in real-time. Then, the sensors act on remote control systems, controlling conditions inside the building to optimize energy consumption [54,55].

Smart meters are commonly used IEFS in SC. Their functioning is based on the concept of the IoT, which enables the collection, storage, analysis, and transmission of information on the consumption of a given medium in real-time [56]. For example, smart water meters automate the process of reading and exchanging readout data on water consumption levels, provide feedback to consumers, and help detect leaks [25,57,58]. Another example is smart energy meters, one of the basic elements of a smart grid, which ensure the exchange of information on energy consumption between energy suppliers and consumers [59–61].

There are several intelligent solutions for water distribution management (e.g., refs. [62–64]) and wastewater management (e.g., refs. [65–67]). IEFS applications create smart water and sewage monitoring systems. Due to aging municipal water and sewage systems, and the increased demand for water resources in cities, these systems face numerous problems such as leaks and ruptures in pipes, causing water and soil contamination and difficulties optimizing water use [68]. To deal with these problems, SC create intelligent water and sewage grids using wireless sensor networks. The IoT monitors the status of water and sewage networks in real-time and generates alerts to detect irregularities in the proper functioning of the water supply and sewage network [69].

IEFS have been used to respond to the growing demand for energy in cities. Smart cities are looking for solutions that, while ensuring a reliable and uninterrupted energy supply, increase efficiency and reduce the negative environmental impacts of fossil fuels. Intelligent energy systems meet the demand for energy with renewables and increase the possibility of receiving energy from prosumers. This system is based on the construction of an intelligent technologies infrastructure in the following areas: (1) monitoring, diagnostics, and control of energy consumption, (2) collecting and analyzing data to determine energy demand and optimize energy consumption, (3) dispersing sources of energy production and construction to create an intelligent network that integrates renewable and nonrenewable resources [30,56,70].

Intelligent solutions also are used in waste management. These solutions are mainly based on radio frequency identification (RFID), WSN, and IoT, allowing for the monitoring of volume and content of waste in waste containers, the temperature and humidity of waste, and its illegal storage [71]. The use of smart waste management systems increases waste collection efficiency and contributes to emission reductions based on the more effective planning of waste collection routes from filled containers in densely built-up residential areas [72–74].

Another application is smart natural disaster management systems. These systems are usually based on IoT technologies and allow for the collection of data which are processed and used to detect and predict imminent natural disasters, assess the destructive force of such events, and respond to and alert city residents if necessary [75–77].

Intelligent solutions are also being used in street lighting. Smart street lighting is based on LED technology and is equipped with sensors and drivers that allow street lighting to be turned on and off automatically depending on the time of day [28,78,79]. This can be supported by a system that collects and analyzes environmental data in real-time to introduce changes in street lighting functioning [80,81]. In addition, renewables can be used to power intelligent street lighting in tandem with traditional power sources [82]. The use of such solutions contributes to a significant reduction in energy demand in SC.

Reducing negative environmental impacts is possible based on the introduction of environmentally friendly means of public transport, which are energy-saving and minimize transport-related greenhouse gas emissions [83]. Cities can implement new technologies (e.g., autonomous vehicles and electric vehicles such as electric cars and electric bicycles) and new business models and social practices (e.g., shared mobility) to create intelligent and environmentally friendly transport systems [42,84]. These systems can be supported by modern ICT infrastructures and IoT tools, enabling the storage, processing, and analysis of big data sets, e.g., for electric mobility as a municipal service [85].

2.2. Barriers to SC Implementation and Development

The research on IEFS implementation barriers is limited; however, existing studies on impediments to SC allude to potential barriers in IEFS development. Various perspectives were used to determine SC implementation and development barriers, including local government or city authorities' perspective (e.g., refs. [86–88]), citizens' or users' perspective (e.g., refs. [89–91]), and project managers' perspective (e.g., refs. [92,93]). Different areas were reviewed and various methods were applied to determine SC impediments, creating a complicated picture of this research area [94].

Studies on SC barriers often cover extensive sets of impediments assigned to various categories. For example, Razmjoo et al. [95] investigated 22 barriers assigned to five categories: governance, social, technology, environmental, and economic. Mosannenzadeh et al. [96] identified 35 barriers in nine categories (i.e., policy, administrative, legal and regulatory, financial, market, environmental, technical, social, and information and awareness), while Braga et al. [94] identified 220 criteria grouped into six clusters (i.e., technology, mobility, people, energy and environment, governance, and economy). Analyzed barriers are often connected and interact in numerous ways [96], but existing studies highlighted key factors that may impede SC implementation and development.

Primary barriers to SC development revolve around financing and governance [97–99], including difficulties accessing financing, complex bureaucratic processes, and outdated legislative frameworks [100]. Funding and regulatory barriers were the main barriers to the implementation of smart urban decarbonization processes [101]. Inconsistency in regulations and limited capital availability and funding sources were the main issues preventing investment in SC [102]. Insufficient external financial support was the key barrier to implementing smart and sustainable energy city projects in the EU [96]. Other key barriers in this area were limited access to capital [103] and urban financial problems [104].

In the area of regulation, successful legal system reorganization was critical to implementing SC [105]. Legal impediments were perceived by project managers as major barriers to SC projects [92]. Moreover, the lack of regulatory norms and policies was a dominant barrier to waste management [19]. Political issues can also create barriers [106].

Goyal et al. [107] described the inadequate development of SC policies as a main barrier. Generally, insufficient planning for SC development hinders SC implementation [108,109]. Successful SC projects must be embedded in a comprehensive city planning vision [110]. Sound SC policies also are important in catalyzing the acceptance of smart technological solutions by citizens [111,112].

Cost is another key barrier. Balta-Ozkan et al. [113] discussed the reliability and cost of technology. Costs associated with the implementation and maintenance of smart urban technologies and smart home products was found to be a major barrier to widespread practice [106,114,115]. Perceived cost and usefulness of SC applications also impacted users' intentions to adopt technologies [116,117]. Providing individual utility users with accurate information was deemed critical in helping them take costs and environmental impacts into account when choosing SC solutions [110].

Razmjoo et al. [95] indicated that the main SC impediments were old technologies and improper access to new technologies. Moreover, Cubric [118] emphasized technical aspects critical to artificial intelligence adoption in SC. The lack of technological knowledge impeded SC development [97] because smart solutions are usually multiple and complex technologies [102]. Therefore, the lack of standardization and widespread good practices were deemed critical barriers to SC implementation [19,119]. Nevertheless, Letaifa [120] claimed that the main issues impeding SC were a focus on technology instead of service provision, having a clear vision and plans, and political leadership.

A lack of trust in the technologies is a related challenge for SC development [121]. Nepane et al. [122] showed that trust in SC technologies positively influenced stakeholders' intention to adopt them. Lack of trust and social acceptance, and concerns about information security and data privacy, are also key barriers to implementing SC [106,113,119,123].

Knowledge building and creating relationships with external partners to avoid conflicts of interests with municipal authorities, citizens, and business [109] are important issues when initiating SC projects [124]. A lack of alignment between different actors during implementation are critical barriers [100]. Other studies have emphasized the crucial role of developing human capital and encouraging citizen participation [98], public involvement [94,97,105], cooperation among partners [96], private–public participation [95], and collaborative networks [125]. Moreover, close cooperation with end users and local stakeholders was found to be necessary to identify effective SC solutions [110].

Previous research also identified environmental barriers to SC, including population growth [97], insufficient environmental concerns [98], lack of attention to the environment [95], and the need for preservation and sustainable economic development [94]. Therefore, decreasing the environmental impacts of SC was identified as an important future challenge [126].

Alderete [127] demonstrated that awareness of the SC concept was a predictor of performing SC activities. Furthermore, citizens' acceptance of ICT-based SC services was found to positively affect perceived quality of life [128], but people's resistance to change and new technologies can prevent SC implementation [129].

In general, technological progress is dependent on population size and income level [130–132]. In this context, Caragliu and Del Bo [133] indicated that higher levels of urban smartness were associated with higher urban real gross domestic product and population density. Moreover, De Wijs et al. [134] found that city population size had positive effects on SC awareness. However, Neirotti et al. [135] found that urban density, not population size, was a predictor of specific SC domain development.

An overview of the literature review results is presented in Figure 1.

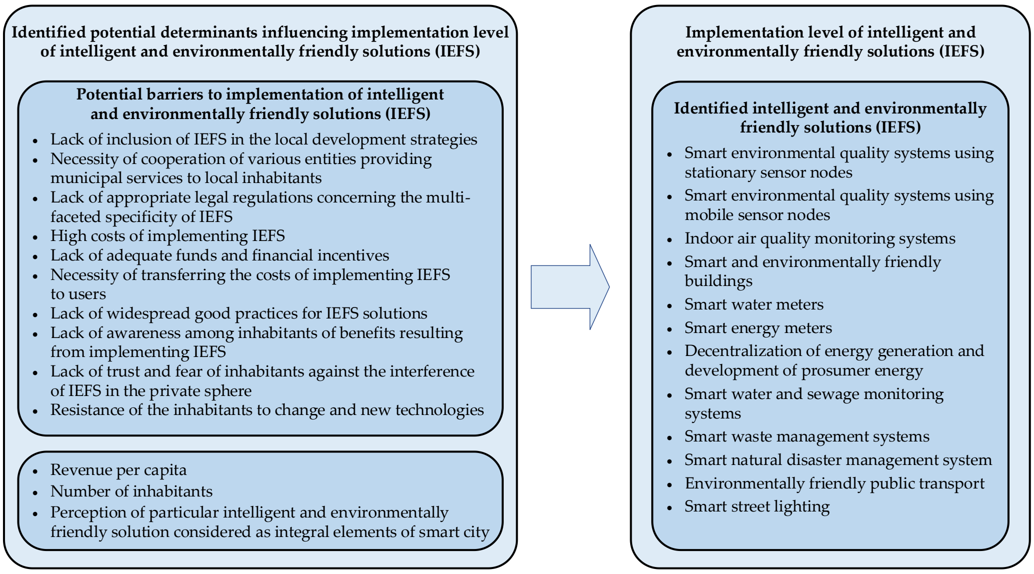

Figure 1. An overview of the literature review results.

3. Materials and Methods

To answer the research questions, this study encompassed a three-step process, including a literature review to indicate and define input variables, a survey to obtain appropriate data on the analyzed variables, and results analysis and interpretation.

3.1. Input Variables and Research Sample

The first step of the research process comprised a critical subject-specific literature review [136,137]. The aim of this review was to explore, analyze, and synthesize existing knowledge on IEFS and barriers impeding the implementation and development of SC.

The following keywords and Boolean operators were adopted to search for relevant publications identifying and describing specific IEFS and barriers to SC implementation: ("smart cit*" OR "intelligent cit*" OR "digital cit*" OR "virtual cit*" OR "cyber cit*" OR "networked cit*" OR "knowledge cit*" OR "wisdom cit*" OR "ubiquitous cit*" OR "real-time cit*" OR "hybrid cit*") AND ("environ* protection" OR "environment"); "smart solution*" AND ("environ*" OR "green"); "intelligent solution*" AND ("environ*" OR "green"); "emerging technolog*" AND ("environ*" OR "green"); "smart environment" AND "solution*"; "smart environment" AND "technolog*"; ("smart cit*" OR "intelligent cit*" OR "digital cit*" OR "virtual cit*" OR "cyber cit*" OR "networked cit*" OR "knowledge cit*" OR "wisdom cit*" OR "ubiquitous cit*" OR "real-time cit*" OR "hybrid cit*") AND ("barrier" OR "obstacle" OR "imped*").

Relevant publications were searched for in two bibliographic databases: the Web of Science Core Collection and Scopus. Title, abstract, and keywords were used as the search fields. Only articles and conference papers in English were considered. The search initially included articles published up to October 2019. In order to exclude articles which were not directly related to the subject of IEFS and SC barriers despite the presence of the searched-for query wordings in the title, abstract or keywords, a preliminary screening of publication titles and abstracts was carried out. In addition, the set of identified publications on IEFS and on SC barriers was extended with articles found as a result of backward snowballing and an additional search in databases such as: EBSCO, ScienceDirect, Wiley Online, Springer Link, and IEEE Xplore. The identified publications were subject to content analysis to determine the current state of knowledge and which variables, methods, and data sources were applied in relevant studies. It should be noted that at the stage of the analysis and discussion of the results obtained in the survey, in order to account for the updated body of literature, a new search was conducted with the same query wordings for items published in the period from October 2019 to April 2022.

Based on the extensive literature review, input variables were defined and their inclusion was justified. Twelve dependent variables were established, and data on these variables were collected based on the question: "To what extent are the following IEFS implemented in your city?" Each respondent was asked to indicate the degree of implementation of the twelve solutions shown in Table 1. The implementation level was indicated with the following options: 0—not implemented, 1—implemented to a small extent, 2—implemented to a moderate extent, 3—implemented to a large extent, 4—implemented to a very large extent. They could also choose "I do not know/Refusal," but it was decided that further analyses would exclude those who answered this way to avoid distorting results of the statistical analysis [138,139].

Independent variables were the potential barriers to the implementation of IEFS. Data on these variables were based on the question: "In the opinion of city authorities, do the following issues constitute barriers to the implementation of IEFS?" Each respondent could rate ten barriers, listed in Table 1, using a 5-point Likert-type scale (1—disagree, 5—agree).

Control variables were revenue per capita and population size of relevant cities based on the following questions: "What is the revenue per capita in your city? and "What is the number of city inhabitants?" Considering revenue per capita, respondents could select one of the following categories: 1—up to 1000 PLN, 2—1001–2000 PLN, 3—2001–3000 PLN, 4—3001–4000 PLN, 5—4001–5000 PLN, and 6—above 5000 PLN. For population size, respondents could indicate the following: 1—up to 5000 inhabitants, 2—5001–10,000 inhabitants, 3—10,001–25,000 inhabitants, 4—25,001–50,000 inhabitants, 5—50,001–100,000 inhabitants, and 6—over 100,000 inhabitants.

Moreover, respondents were asked if they considered IEFS an integral element of SC based on the question: "In the opinion of city authorities, should the following IEFS constitute an integral element of SC?" Each respondent could rate the twelve IEFS, listed in Table 1, using a 5-point Likert-type scale (1—disagree, 5—agree).

Table 1. Overview of input variables.

Variable	Variable Code	No. of Observations	Scale Type	References
Dependent variables				
Smart environmental quality systems using stationary sensor nodes	IEFS01	264	Ordinal	[14,27,47,48,140,141]
Smart environmental quality systems using mobile sensor nodes	IEFS02	249		[12,49,50,142–144]
Indoor air quality monitoring systems	IEFS03	236		[51–54,145–148]
Smart and environmentally friendly buildings	IEFS04	241		[55,111,149–152]
Smart water meters	IEFS05	220		[25,57,58,153,154]
Smart energy meters	IEFS06	209		[29,59,60,155,156]
Decentralization of energy generation and development of prosumer energy	IEFS07	232		[30,56,70,157–159]
Smart water and sewage monitoring systems	IEFS08	216		[62–65,67–69,160]
Smart waste management systems	IEFS09	233		[47,71,72,74,161–163]
Smart natural disaster management system	IEFS10	252		[75–77,164]
Environmentally friendly public transport	IEFS11	251		[42,83,85,165,166]
Smart street lighting	IEFS12	257		[28,78–82]
Control variables				
Revenue per capita	Rev	280	Interval	[132,133,135]
Number of inhabitants	PopSize	280	Interval	[130–133,135]
Perception of IEFS considered as integral elements of SC based on opinion about each individual item IEFS"i"(i = 01, . . . , 12)	IEFSSC"i'	280	Ordinal	[119,127,128]

Table 1. *Cont.*

Variable	Variable Code	No. of Observations	Scale Type	References
Independent variables—Barriers				
Lack of inclusion of IEFS in the local development strategies	B01	280	Ordinal	[19,107,109–112,120]
Necessity of cooperation of various entities providing municipal services to local inhabitants	B02	280		[94,96,97,100,105,109,124,125]
Lack of appropriate legal regulations concerning the multifaceted specificity of IEFS	B03	280		[19,92,100–102,105]
High costs of implementing IEFS	B04	280		[98,107,113–118]
Lack of adequate funds and financial incentives	B05	280		[96,98–100,103,106]
Necessity of transferring the costs of implementing IEFS to users	B06	280		[96,110,115]
Lack of widespread good practices for IEFS solutions	B07	280		[95,97]
Lack of awareness among inhabitants of benefits resulting from implementing IEFS	B08	280		[94,95,106]
Lack of trust and fear of inhabitants against the interference of IEFS in the private sphere	B09	280		[113,121–123,167]
Resistance of the inhabitants to change and new technologies	B10	280		[96,129]

The second step was a survey conducted at the end of 2019 into 2020. It was carried out by a professional research agency, and the sampled cities represented all sixteen voivodeships of Poland. The CATI (computer-assisted telephone interview) method and, in some cases, at the respondents' request, the CAWI (computer-assisted web interview) method were applied. CATI is a voice call surveying method in which a trained interviewer calls the respondents, conducts interviews with them according to previously prepared questions, and saves their answers. The interviewer can easily check whether all questions have been answered. In the CAWI method, the interviewees answer questions in a survey posted on the Internet or intranet. Both methods can be successfully used for survey data collection, especially in the case of large research samples, where the completeness and consistency of answers are important [168]. The sample was created to maintain the structure of cities in Poland by provinces. It was conducted through a random method, assuming a confidence level of 95% and a maximum error of 5%. The survey was addressed to representatives of city authorities responsible for city development and the implementation of relevant strategies and plans. Consequently, correctly completed questionnaires from 280 cities located in Poland were obtained, constituting a sample of 29.4% of all Polish cities.

3.2. Descriptive and Statistical Analysis

The third step of the research process was data analysis and interpretation. It began with a general description of the results for the question on implementation level of the twelve indicated IEFS, opinions of city authorities about whether these solutions should constitute an integral element of SC, and barriers impeding their implementation.

Thereafter, the collected data were subjected to a regression analysis. Considering the ordered character of the dependent variable, where the investigated assessment of the implementation level took on the values of 0–4, the ordered logistic regression model [169,170] was used. The logistic regression model is one of the most common tools used in the social sciences for such dependent variables; it is also the model most frequently applied if discrete variables with two or more values are considered [171,172]. In its logit form, the model used in this study is expressed by Equation (1) (the codes used in the equation are taken from Table 1):

$$\text{logit } P(\text{IEFS}_i \geq j) = \beta_{0j} + \sum\nolimits_{a=1}^{10} \beta_a B_a + \beta_b \text{ERev} + \beta_c \text{PopSize} + \beta_d \text{IEFSSC}_i \quad (1)$$

where:

$P(\text{IEFS}_i \geq j)$—conditional probability that variable IEFS_i is higher than or equal to "j".

IEFSSC_i—one variable of IEFSSC_i (i = 01, . . . , 12), corresponding to the analyzed dependent variable of IEFS_i (i = 01, . . . , 12).

β_{0j}—value of free terms for individual values of dependent variable j—1,2,3,4.

B_a—value of the assessment of the importance of barriers made by municipal authorities, where a = 01, . . . , 10.

$\beta_{a,\ldots,e}$—regression coefficients; the method of the estimation of these coefficients is based on so-called maximum likelihood techniques [170].

For each independent and control variable, the following values were calculated: regression coefficient β, the coefficient standard error, and the OR value corresponding to the coefficient along with its confidence interval. Results of the ordered logistic regression analysis made it possible to determine the impact of the perception of individual barriers by city authorities and the values of control variables on the implementation level of individual IEFS. The value of regression coefficient β reflects the impact magnitude, and its sign denotes the impact direction. The OR values indicate odds that the implementation level of a given solution would be one level higher (if OR > 1) or lower (if OR < 1) if the assessment of the barrier importance or the value of the control variable were one level higher.

The backward stepwise logistic regression method, based on the model of proportional hazards, was used [171,173]. This method results in the calculation of one set of indicators, β, for each independent variable. It assumes building a regression model by stepwise restriction of independent variables, with the final model being limited to variables with a statistically significant effect on the dependent variable at the assumed threshold level of significance, e.g., no greater than 0.05 [171]. To evaluate the variability of the obtained results, standard errors in regression coefficient β and confidence intervals of the OR values were calculated.

Each of the models was tested for goodness of fit to data using the Pseudo R-squared Nagelkerke indicator [174]. The values of the statistics are included in the 0–1 interval, where a higher value of the indicator means the model predicts the dependent variable values more accurately. However, as stated by Hosmer and Lemeshow [171], in the case of logistic regression, even low R-squared values may indicate a fair level of goodness of fit.

The quality of the obtained models was verified by calculating the probability values (p) of the goodness-of-fit Chi-squared test [171,175] and the parallel lines Chi-squared test [169]. A p-value for the goodness-of-fit Chi-squared test lower than 0.05 suggests a statistically significant level of goodness of fit. A p-value higher than 0.05 in the case of the parallel lines Chi-squared test suggests the required assumption of proportionality in the ordered logistic regression has been met.

In the final phase of the study, the obtained results were interpreted, and conclusions were drawn.

4. Results and Discussion

4.1. Descriptive Analysis

Analysis of the collected data began with a description of the responses obtained from the survey. In the first stage, representatives of city authorities determined the extent to which their city had implemented the twelve IEFS identified based on the literature review. The obtained results are presented in Figure 2. Respondents could indicate the implementation level of a given solution or its lack of implementation. It was also possible to refuse to answer due to a lack of knowledge about the topic or not wanting to make a self-assessment. In accordance with the adopted methodology, refusals were not included in the statistical analysis; hence, the percentages presented in Figure 2 refer to the number of observations indicated in Table 1.

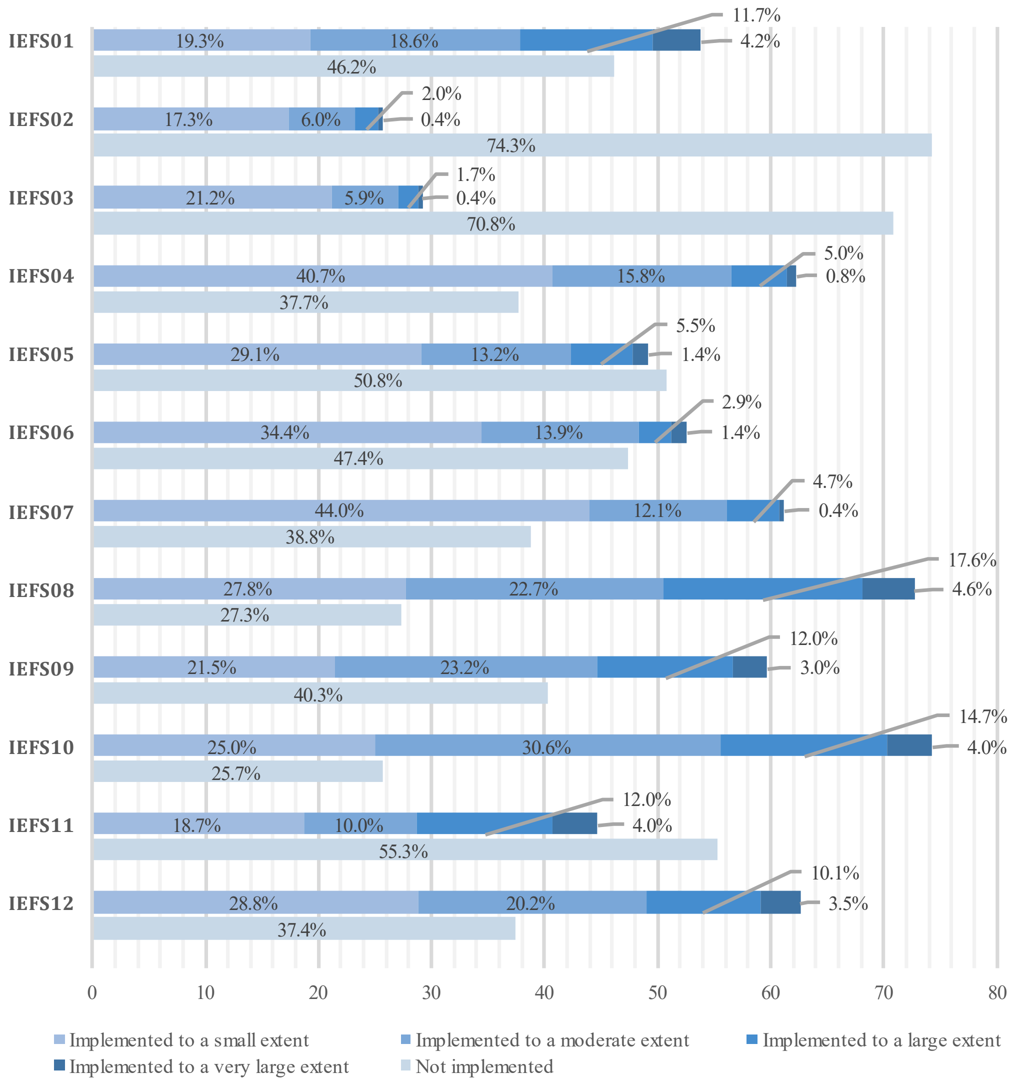

Figure 2. The IEFS implementation level in the surveyed cities.

The most frequently implemented IEFS were smart natural disaster management systems, smart water and sewage monitoring systems, smart street lighting, and smart and environmentally friendly buildings. In the case of the above-mentioned solutions, any implementation level was indicated by, respectively, 74.3%, 72.7%, 62.6%, and 62.3% of the cities. The least frequently chosen solutions were smart environmental quality systems using mobile sensor nodes and indoor air quality monitoring systems. The lack of implementation of these solutions was indicated by, respectively, 74.3% and 70.8% of the cities. On the other hand, the implementation of IEFS to a large extent was declared in smart water and sewage monitoring systems (4.6%) and smart environmental quality systems using stationary sensor nodes (4.2%).

In the next step, the surveyed respondents expressed opinions about whether specific IEFS should be considered an integral element of SC. The obtained results are presented in Figure 3.

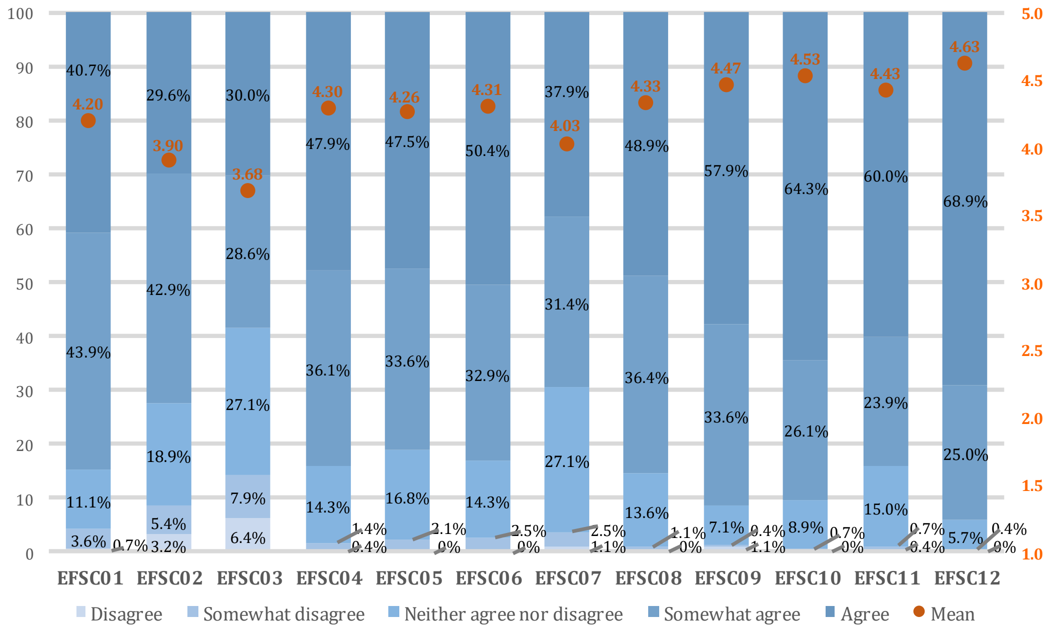

Figure 3. Perception of IEFS considered an integral element of SC by the surveyed cities.

Most of the surveyed cities agreed or somewhat agreed that each of the twelve IEFS should be considered an integral element of SC. This was reflected in the means calculated for each solution, the values of which ranged from 3.68 to 4.63. Solutions most frequently chosen as important elements of SC were smart street lighting (mean: 4.63), smart disaster management systems (4.53), and smart waste management systems (4.47). Respondents were least convinced that indoor air quality monitoring systems (3.68) and smart environmental quality systems using mobile sensor nodes (3.90) should be part of SC.

In the next step, respondents expressed their opinions on whether specific issues were viewed by city authorities as barriers to the implementation of IEFS. The obtained results are shown in Figure 4.

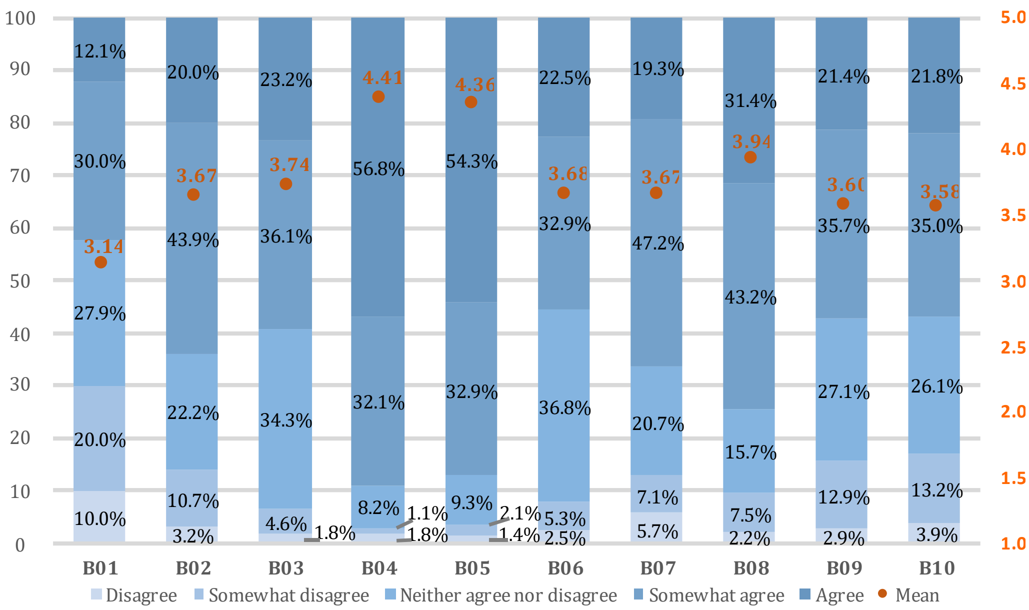

Figure 4. Opinions of the surveyed cities on the importance of barriers to the implementation of IEFS.

In every case, except the lack of inclusion of IEFS in local development strategies, representatives of city authorities generally agreed that the indicated issues were barriers to the implementation of IEFS. This was confirmed by the means for nine out of the ten barriers under analysis, which fell in an interval of 3.58–4.41. Issues usually indicated as barriers were high costs of implementing IEFS (mean: 4.41), lack of adequate funds and financial incentives (4.36), and lack of awareness among inhabitants of benefits resulting from implementing IEFS (3.94). The least frequently selected barrier to the implementation of IEFS was their lack of inclusion in local development strategies (3.14).

4.2. Statistical Analysis

The next stage of analysis was a regression analysis to determine and compare the impact of specific variables on the implementation level of IEFS. Results (regression coefficient values, together with the SE, the OR, the CI, the Nagelkerke Pseudo R-squared indicator, and the results of the goodness-of-fit tests and the tests of parallel lines for individual regression models) are listed in Table 2.

Table 2. Backward stepwise ordinal logistic regression analysis results.

Variable	IEFS01 (*n* = 264)		IEFS02 (*n* = 249)		IEFS03 (*n* = 236)	
	***B* (SE)**	**OR (95%CI)**	***B* (SE)**	**OR (95%CI)**	***B* (SE)**	**OR (95%CI)**
Control variables						
Rev						
PopSize	0.74 ** (0.09)	2.10 (1.75–2.51)	0.46 *** (0.11)	1.58 (1.28–1.95)		
IEFSSC”i” [1]			0.34 * (0.17)	1.40 (1.03–1.96)	0.56 *** (0.15)	1.76 (1.31–2.36)
Barriers						
B01					−0.27 * (0.13)	0.76 (0.59–0.98)
B02						
B03			−0.47 ** (0.19)	0.63 (0.43–0.90)	−0.50 ** (0.18)	0.61 (0.43–0.86)
B04	−0.36 * (0.15)	0.70 (0.53–0.93)	−0.58 ** (0.18)	0.56 (0.39–0.81)		
B05						
B06						
B07						
B08						
B09			0.37 * (1.6)	1.45 (1.06–2.00)	0.58 ** (0.19)	1.79 (1.24–2.59)
B10					−0.34 * (0.17)	0.71 (0.51–0.99)
Test	value	*p*	value	*p*	value	*p*
Nagelkerke Pseudo R-squared	0.27		0.21		0.16	
Goodness-of-fit test—Chi-squared	75.6	<0.001	44.64	<0.001	16.85	0.002
Test of parallel lines—Chi-squared	4.05	0.67	22.54	0.13	16.19	0.18

Variable	IEFS04 (*n* = 241)		IEFS05 (*n* = 220)		IEFS06 (*n* = 209)	
	***B* (SE)**	**OR (95%CI)**	***B* (SE)**	**OR (95%CI)**	***B* (SE)**	**OR (95%CI)**
Control variables						
Rev						
PopSize	0.20 * (0.09)	1.22 (1.02–1.44)	0.47 *** (0.10)	1.60 (1.32–1.93)	0.44 *** (0.10)	1.55 (1.02–1.86)
IEFSSC”i” [1]	0.36 * (0.16)	1.43 (1.05–1.96)	0.35 * (0.17)	1.42 (1.01–1.98)		
Barriers						
B01	−0.30 ** (0.10)	0.74 (0.60–0.90)				
B02					0.32 * (0.15)	1.38 (1.03–1.86)
B03					−0.40 * (0.17)	0.67 (0.47–0.94)
B04						
B05	−0.36 * (0.16)	0.70 (0.51–0.96)				
B06	0.28 * (0.14)	1.32 (1.04–1.75)				
B07			−0.32 * (0.13)	0.73 (0.57–0.93)	−0.28 * (0.13)	0.76 (0.58–0.98)
B08						
B09						
B10						
Test	value	*p*	value	*p*	value	*p*
Nagelkerke Pseudo R-squared	0.17		0.19		0.21	
Goodness-of-fit test—Chi-squared	27.32	<0.001	40.59	<0.001	44.29	<0.001
Test of parallel lines—Chi-squared	35.28	0.15	9.74	0.37	45.50	0.22

Table 2. *Cont.*

Variable	IEFS07 (n = 232)		IEFS08 (n = 216)		IEFS09 (n = 233)	
	B (SE)	OR (95%CI)	*B (SE)*	OR (95%CI)	*B (SE)*	OR (95%CI)
Control variables						
Rev						
PopSize			0.61 *** (0.11)	1.85 (1.50–2.27)	0.21 * (0.10)	1.23 (1.02–1.49)
IEFSSC"i" [1]	0.88 *** (0.16)	2.40 (1.74–3.31)	0.50 * (0.20)	1.64 (1.12–2.41)		
Barriers						
B01						
B02			0.40 ** (0.15)	1.48 (1.11–1.99)	0.32 * (0.14)	1.38 (1.04–1.83)
B03						
B04			−0.46 * (0.21)	0.63 (0.41–0.96)		
B05						
B06						
B07	−0.41 *** (0.12)	0.67 (0.53–0.85)				
B08						
B09						
B10						
Test	value	p	value	p	value	p
Nagelkerke Pseudo R-squared	0.17		0.28		0.12	
Goodness-of-fit test—Chi-squared	39.57	<0.001	66.36	<0.001	10.85	<0.001
Test of parallel lines—Chi-squared	4.81	0.57	49.70	0.11	1.89	0.60

Variable	IEFS10 (n = 252)		IEFS11 (n = 251)		IEFS12 (n = 257)	
	B (SE)	OR (95%CI)	*B (SE)*	OR (95%CI)	*B (SE)*	OR (95%CI)
Control variables						
Rev	0.16 * (0.08)	1.18 (1.04–1.38)	0.23 * (0.10)	1.26 (1.04–1.52)		
PopSize	0.23 ** (0.09)	1.26 (1.06–1.50)	0.83 *** (0.11)	2.37 (1.90–2.97)	0.42 *** (0.08)	1.52 (1.29–1.80)
IEFSSC"i" [1]					0.66 ** (0.22)	1.94 (1.25–3.00)
Barriers						
B01						
B02						
B03						
B04						
B05			−0.39 ** (0.15)	0.68 (0.51–0.91)		
B06					−0.29 * (0.12)	0.75 (0.59–0.95)
B07						
B08						
B09						
B10						
Test	value	p	value	p	value	p
Nagelkerke Pseudo R-squared	0.11		0.40		0.18	
Goodness-of-fit test—Chi-squared	17.38	<0.001	113.79	<0.001	47.74	<0.001
Test of parallel lines—Chi-squared	5.37	0.50	43.3	0.29	9.86	0.36

Note: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. [1]—represents one variable of IEFSSC"i" (i = 01, . . . , 12), corresponding to the analyzed dependent variable of IEFS"i" (i = 01, . . . , 12). Table includes final results for each adopted model of the stepwise ordinal logistic regression. If no value is indicated, it means that a given independent variable failed to meet the statistical significance condition ($p < 0.05$), and as such, was not included in the end model.

Values obtained from testing the regression models indicated their statistically significant level of goodness of fit and established that the proportionality condition had been met, which confirmed their appropriate statistical quality. Moreover, the Pseudo R-squared values included in the 0.11–0.40 interval pointed to a relatively high goodness of fit of the models.

Results of the analysis showed that each of the control variables and barriers included in the model, except for the lack of awareness among inhabitants of benefits resulting from implementing IEFS, had an effect on the implementation level of IEFS. The absence of the above-mentioned barrier as an essential obstacle to specific solutions may come as a surprise, especially considering it was generally ranked the third most important barrier of all those under analysis. However, this may suggest that the lack of awareness among inhabitants of the benefits resulting from implementing IEFS was perceived as a barrier with a similar gravity regardless of whether the analyzed cities had implemented such solutions to some extent or they had not implemented them at all.

More populated cities had higher implementation levels for ten of the IEFS, including: environmentally friendly public transport (OR = 2.37), smart environmental quality systems using stationary sensor nodes (OR = 2.10), smart water and sewage monitoring systems (OR = 1.85), smart water meters (OR = 1.60), smart environmental quality systems using mobile sensor nodes (OR = 1.58), smart energy meters (OR = 1.55), smart street lighting (OR = 1.52), smart natural disaster management system (OR = 1.26), smart waste management systems (OR = 1.23), and smart and environmentally friendly buildings (1.22). In general, within Kremer's framework, technological change depends on population size [132]. Moreover, according to Klasen and Nestmann [131], an increase in population means an increase in the number of potential suppliers of new technologies. Specifically, more densely populated cities generate appropriate connectivity, infrastructure, and demand for technological innovations. It follows that due to the greater number of potential users of IEFS, they seem to be much easier to implement in larger cities.

The results also showed that cities with higher revenue per capita had higher implementation levels of environmentally friendly public transport (OR = 1.26) and a smart natural disaster management system (OR = 1.18). In general, this is in line with the study presented by Caragliu and Del Bo [133] which indicated higher levels of urban smartness were associated with a higher urban real gross domestic product. Moreover, it should be noted that environmentally friendly public transport and smart natural disaster management systems are complex and costly solutions [77,84]; therefore, it may be assumed that wealthier cities can afford them more easily.

Perceiving certain IEFS as integral SC elements was a predictor of implementation in seven cases: decentralization of energy generation and development of prosumer energy (OR = 2.40), smart street lighting (OR = 1.94), indoor air quality monitoring systems (OR = 1.76), smart water and sewage monitoring systems (OR = 1.64), smart and environmentally friendly buildings (OR = 1.43), smart water meters (OR = 1.42), and smart environmental quality systems using mobile sensor nodes (OR = 1.40). This is consistent with the findings of Alderete [118] stating that the more aware people were of the SC concept, the more likely they were to take up smart activities. The study's results suggest that city authorities who were more aware of IEFS as integral elements of the SC concept were more likely to implement them.

Cities indicating the lack of inclusion of IEFS in local development strategies as a barrier to implementation exhibited lower implementation levels for smart and environmentally friendly buildings (OR = 0.74) and indoor air quality monitoring systems (OR = 0.76). These findings suggest the importance of sufficient strategies and plans for implementation of SC solutions [107–109]. These results may also suggest that, in Poland, the development of SC policies that consider such initiatives, particularly the implementation of smart and environmentally friendly buildings, is rather poor. Therefore, it seems vital that IEFS should be included in urban development plans based on properly defined objectives and measurable targets [110].

Perceiving the necessity for the cooperation of various entities providing municipal services to local inhabitants as a barrier was associated with a higher implementation level of smart water and sewage monitoring systems (OR = 1.48), smart energy meters (OR = 1.38) and smart waste management systems (OR = 1.38). These results are counterintuitive, considering that participants who indicated the above-mentioned barrier still had a higher implementation level for specific IEFS. Perhaps only after these solutions had been implemented did cities realize how significant a barrier this was.

In cities where the lack of appropriate legal regulations for the multifaceted specificity of IEFS was considered a barrier, the odds were lower of having a higher implementation level for the following three solutions: indoor air quality monitoring systems (OR = 0.61), smart environmental quality systems using mobile sensor nodes (OR = 0.63), and smart energy meters (OR = 0.67). The lack of appropriate regulatory standards was found to be the dominant barrier for waste management in SC in one study [19]. The important role of proper regulatory frameworks for SC governance was also emphasized in another study [98]. Our study confirmed that appropriate legal regulations are important to the implementation of specific IEFS, especially environmental quality monitoring systems and smart energy meters.

In cities which viewed the high costs of implementing IEFS as a barrier, the odds were lower of having a higher implementation level for smart environmental quality systems using mobile sensor nodes (OR = 0.56), smart water and sewage monitoring systems (OR = 0.63), and smart environmental quality systems using stationary sensor nodes (OR = 0.70). It was expected that the high costs of implementing IEFS would be a significant barrier in more cases; however, these results confirmed that the costs associated with the adoption of smart urban technologies can seriously impede their widespread application [115], which can also have an impact on the intention to use them [116,117].

Results also suggested that cities viewing the lack of adequate funds and financial incentives as a barrier had lower implementation levels of environmentally friendly public transport (OR = 0.68) and smart and environmentally friendly buildings (OR = 0.70). This is in line with findings from previous studies emphasizing that the huge funds required for the successful development of SC solutions and funding constraints related thereto were the main difficulties to overcome [101,106,107]. This is mostly due to the limited availability of capital and insufficient external financial support for SC projects [96,102]. In several studies, the lack of adequate funds and financial incentives was indicated as a significant barrier to the implementation of two very specific IEFS under analysis [84,149]. These results indicated that ensuring appropriately targeted external funds and sufficient financial incentives, especially for the most capital-intensive SC solutions, is extremely important to their widespread implementation in cities.

Cities which considered the necessity for transferring the costs of implementing IEFS to users as a significant barrier had lower implementation levels for smart street lighting (OR = 0.75), but a higher level for smart and environmentally friendly buildings (OR = 1.32). Some previous studies indicated the importance of providing accurate information on the costs and environmental impacts of specific SC solutions if end users chose and actually used them [110]. Our study suggests that the necessity to transfer costs of implementing IEFS to users prevented cities from implementing smart street lighting. This may have been due to the fear that all city inhabitants would be burdened with the costs of implementation, and that not all members of the community would accept this. The opposite was true for smart and environmentally friendly buildings. The extra costs could be transferred to direct users of specific facilities. Perhaps cities were more willing to implement such IEFS because they did not fear it would be necessary to transfer implementation costs to individuals not directly benefiting from the solution.

The lack of widespread good practices for IEFS was perceived as a barrier in cities where the implementation levels of decentralization of energy generation and development of prosumer energy (OR = 0.67), smart water meters (OR = 0.73), and smart energy meters (OR = 0.76) were lower. The lack of standardization and widespread good practices was earlier revealed as a crucial impediment to the implementation of the SC concept [19,119]. Our study shows that this is especially important for specific solutions that impact a majority of city inhabitants. It is important to take up actions supporting and popularizing good practices related to specific IEFS to facilitate their common use.

Viewing a lack of trust and fear of inhabitants regarding the interference of IEFS with the private sphere as a barrier turned out to be a predictor of a higher implementation level of indoor air quality monitoring systems (OR = 1.79) and smart environmental quality systems using mobile sensor nodes (OR = 1.45). These results suggest that viewing the lack of trust and fear of inhabitants against the interference of IEFS with the private sphere as a barrier did not hinder the analyzed cities from implementing solutions which in the opinion of the city inhabitants could intrude on their privacy. However, it is also possible that only after specific solutions had been implemented did city authorities realize how significant the barrier was. Regardless, trust in SC solutions is one of the critical issues affecting the sufficient development of the SC concept [121]. Trust can influence the intentions of potential users to adopt smart solutions [122]. Therefore, trust building and social acceptance development constitute a crucial challenge to city authorities to overcome existing impediments in this area.

Cities which viewed the resistance of inhabitants to change and new technologies as a barrier demonstrated a significantly lower level of the implementation of indoor air quality monitoring systems (OR = 0.71). A previous study indicated that the resistance of people to change prevented SC implementation [129]. Our study suggests that this is the case especially for solutions causing greater concern about, and risk of, potential privacy violations [123]. Therefore, before implementing such solutions, local authorities should inform city inhabitants how, and for what purpose, specific smart technologies can be used.

5. Conclusions

The continuous and rapid process of urbanization has led to a series of environmental problems that become obstacles to the sustainable development of cities. For this reason, care for the environment becomes an important issue in city management and forces city authorities to look for solutions to reduce the environmental impacts of dense human settlement [176].

This study has two main theoretical contributions. First of all, it offers a complete overview of the main areas of the IEFS applications. Furthermore, it extends the existing research on barriers to SC implementation and development in the IEFS context.

As part of this research, twelve IEFS were analyzed. The results have shown that the level of IEFS implementation in Poland is relatively very low. The IEFS usually implemented by cities were smart natural disaster management system, smart water and sewage monitoring systems, and smart street lighting. Three quarters of the surveyed cities indicated that smart environmental quality systems using mobile sensor nodes and indoor air quality monitoring systems had not been implemented.

It is worth noting that the vast majority of surveyed cities considered all twelve analyzed IEFS as integral SC elements. Most cities expressed this opinion in relation to smart street lighting, smart disaster management systems, and smart waste management systems. The most common barriers to IEFS implementation indicated by surveyed cities were high costs of implementing IEFS, lack of adequate funds and financial incentives, and lack of awareness among inhabitants of benefits resulting from implementing IEFS.

Interestingly, IEFS implementation was largely associated with greater population size (such a dependence was observed in the case of ten out of twelve solutions) and perception of individual IEFS as integral elements of the SC concept (significant relationships for seven out of twelve solutions). Larger cities report greater demands for urban services; hence, larger cities must implement solutions to a greater extent to meet this demand. Moreover, awareness of the essence and need to implement the SC concept is growing.

Revenue per capita showed a significantly higher implementation level for two solutions: environmentally friendly public transport and smart natural disaster management systems. This suggests that cities more often choose intelligent solutions instead of traditional ones (regardless of the level of revenue per capita); however, the implementation of the two above-mentioned solutions requires significant expenditures which not every city can afford.

The high costs of implementing IEFS, the lack of inclusion of IEFS in local development strategies, the lack of appropriate legal regulations concerning the multifaceted specificity of IEFS, the lack of widespread good practices for IEFS, and the resistance of the inhabitants to change and new technologies were perceived as impediments. Each had a negative effects on the implementation level. Nevertheless, despite the perception of the presence of three specific barriers, implementation levels were higher. These cases concerned: the necessity of cooperation of various entities providing municipal services to local inhabitants, the lack of trust and fear of inhabitants regarding the interference of IEFS in the private sphere, and the necessity of transferring the costs of implementing IEFS to users. In the discussion of the results, the potential reasons for these rather surprising results were presented.

One barrier—the lack of awareness among inhabitants of the benefits resulting from implementing IEFS—was not a predictor of the implementation of any of the analyzed IEFS. Nevertheless, it can be presumed that this impediment is of great importance both for cities that have implemented IEFS (regardless of implementation level) and for cities that have not yet implemented them.

Based on the results, it was possible to make some recommendations for policy makers, city authorities, managers, and practitioners about IEFS implementation as an integral element of SC.

Firstly, cities should consider IEFS implementation to a greater extent in their development strategies. This is due to the fact that IEFS implementation brings a number of environmental and social benefits, which are useful for the inhabitants and the environment, even if most of them are not expressed in monetary terms. For this reason, when deciding whether to implement or not implement particular IEFS, city authorities should not only consider the value of the financial effects generated by specific IEFS, but also perform a cost–benefit analysis that takes into account the value of all types of effects generated by a given smart solution [177].

Secondly, the introduction of appropriate legal regulations seems to be one of the preconditions for more efficient and effective IEFS implementation in cities. Therefore, it is a challenge for policy makers at the national and local level to develop appropriate regulations supporting and facilitating IEFS implementation. Furthermore, the companies and professionals developing IEFS should actively engage in the process of creating relevant legal regulations and urban development policies as part of social participation [178].

Thirdly, since the high costs of implementing the IEFS and the lack of financing sources have turned out to be significant barriers to implementation, cities should intensify the search for external sources of financing that would cover some or all of the costs of implementing the most capital-intensive IEFS. In practice, various models of financing IEFS implementation can be used, including funding, i.e., subsidies received from public funds with no expectation of repayment, and financing, i.e., providing an amount of capital to be repaid with interest by one or more institutions [179]. City authorities may also encourage the companies and professionals developing and offering specific IEFS to participate in public–private partnerships, in which a public entity and a private partner could share the IEFS implementation [180].

Fourth, before deciding to implement IEFS, cities should carefully analyze whether the implementation of a given solution will require cooperation with other entities, and if so, whether such cooperation will be possible and to what extent will it affect the proper functioning of a given IEFS. Therefore, city authorities, in collaboration with professionals, should organize trainings and workshops focused on developing collaboration capabilities, including coordination relationships, relational skills, communication, conflict resolution, etc. [181]

Fifth, cities should continually take appropriate actions to inform the public and disseminate good practices concerning specific IEFS. The companies and professionals developing specific IEFS should participate actively in these activities. In particular, they should focus on presenting the advantages resulting from IEFS application [182]. City dwellers should be informed about the function of a given IEFS, about the benefits of its introduction for the whole city and for each individual inhabitant, and about whether there is a risk that the costs of implementing a given IEFS will be passed on to residents. In addition, cities should continually build citizens' trust in IEFS to reduce their resistance to changes and new technologies and any fear that IEFS will interfere with their privacy.

This research, like other studies, has limitations which also illuminate opportunities for future research. The analysis was based on subjective self-reported data derived from representatives of city authorities. Unfortunately, there were no sufficient alternatives to gathering these data. However, the reported low implementation level of IEFS suggests that the surveyed respondents did not overestimate or over-represent implementation levels. This research was carried out from an institutional point of view based on city authorities' perspective; thus, it would be very interesting to, instead, in the future, survey public users of IEFS. This study was based on cross-sectional data. In the future, panel data with samples kept permanent over time would make it possible to test and determine relations between the analyzed variables. Moreover, the analysis was limited to evaluating selected variables describing the specificity of IEFS. There are other relevant aspects affecting implementation, e.g., drivers or perceived benefits that other researchers can consider. In addition, future studies may explore changes in importance of relevant barriers and their causal relations in IEFS development. It would also be interesting to examine the specificity of other intelligent solutions related to the smart city transformation in areas such as public safety, health, education, tourism, or entertainment [9]. Since the research used a large and representative research sample, results can be generalized to the national level of Poland, which represents a medium-sized European country; however, since the survey was restricted to cities in Poland, its geographical scope is another limitation. This means that results can be transferable to other countries with similar socioeconomic features, but future exploration should focus on countries with different economic characteristics and institutional contexts (e.g., developing vs. developed, small vs. large, closed vs. open economies).

Nevertheless, the aim of this study was to identify the specificity and implementation level of IEFS in cities in Poland and barriers impeding their development. Despite the above-mentioned limitations, we believe that this research constitutes an important contribution to the literature on the implementation of IEFS and the development of SC.

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