

## Article

# A Distance-Based AHP-DEA Super-Efficiency Approach for Selecting an Electric Bike Sharing System Provider: One Step Closer to Sustainability and a Win–Win Effect for All Target Groups

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**Abstract:** Existing research on electric bike sharing systems (e-BSS) emphasises the importance of the sustainability of the systems and the need to respect the views of all stakeholders when planning e-BSS. However, this research overlooks the fact that the sustainability of e-BSS depends to a large extent on the skills and knowledge of the parties who select an electric bike provider, which in most cases is the investor in the e-BSS. There is no previous paper that provides support for investors in (1) defining a set of criteria for selecting a provider that takes into account all of the three domains of sustainability (economic, social, and environmental) and (2) developing a tool that best meets sustainability standards on the one hand and the needs and requirements of all stakeholders (including e-bike users and investors) on the other hand. A distance-based analytic hierarchy process/data envelopment analysis (AHP-DEA) super-efficiency approach was proposed and applied to adapt DEA to the needs of predefined groups by using slack variables. The approach takes into account the fact that not all outputs have a positive impact on the final outcome; the approach also allows decision-makers to define the hierarchical structure of the importance of the criteria directly based on the responses of the selected group. A case study in Slovenia illustrated the application of the approach.

**Keywords:** sustainable e-BSS; provider selection; sustainable criteria; distance-based AHP; slack-based DEA model



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## 1. Introduction

The increasing use of cars causes various forms of environmental pollution such as nitrogen oxides, carbon monoxide and hydrocarbons pollution [1], increased traffic congestion, and increased number of car accidents; consequently, the increasing use of cars has a deleterious effect on the quality of life for citizens [1–4]. Many urban authorities, accordingly, encourage residents to use bike sharing systems (BSS) and, lately, have also encouraged the use of electric bike sharing systems (e-BSS) for last and first mile transportation needs [2]. e-BSS operate in public spaces within urban areas by offering the rental of self-service and short-term e-bikes from a fixed number of stations that are distributed around a city [3,4]. The system consists of e-bikes, vending stations, and charging stations, the latter of which provides access to bikes, collects data to bill the bike user, identifies a bike when it is returned [5], and provides other support systems. e-BSS do not only solve environmental problems but also address various problems that often plague bike users (such as hilly terrain, long distances, or the need to shower after commuting) [6–10].

The establishment of sustainable e-BSS is a major challenge in an environment where there are no government regulations that could promote sustainability. Under such conditions, the sustainability of e-BSS depends mainly on the local investor in e-BSS, which can be a local government/municipality, a private operator (a for-profit organization, non-profit organization, public transport provider, advertising company, etc.) or a municipality in combination with any other aforementioned organization. The local investors are expected to design e-BSS that provide the best return on investment in three domains of sustainability (economic, social, and environmental sustainability) and address the needs of the main stakeholders. An e-bike sharing system, as a mode of transport, often plays an important role in the transportation system of an urban area. As such, this system needs to be integrated into urban development in a way that serves its target groups (daily commuters, tourists, etc.). Therefore, the main stakeholders of e-BSS are investors, providers, and e-bike users. E-bike users include daily commuters (employees, students, retirees) and tourists. E-bike providers are organisations that either provide e-bike services but do not plan and invest in these services or provide e-bike services and also invest in them (local governments/municipalities typically only provide land for e-bike stations). The investors in an e-bike sharing system could be local authorities/municipalities (they plan and invest in these types of systems but do not provide the services associated with these systems), but also service providers (they invest in, provide, and manage e-bike sharing services).

To successfully invest in these systems, either type of investor should understand the expectations and requirements of e-bike users. They should also have a clear understanding of the importance of their own system criteria and those of the bicycle users. However, it is questionable whether these investors do understand all of these prerequisites for successful e-bike system investments.

e-BSS have attracted a great deal of research attention in recent years. Most of the studies related to e-BSS are focused on the history of BSS and technological advancements [11,12], the strengths, weaknesses, and challenges of e-bikes [7,10,13,14], technical analysis of bikes or batteries [1,13,15,16], a comparative analysis of bikes [17], a market analysis of providers [18], and the habits and characteristics of e-bike users [11,13,19,20].

The sustainability challenges of e-BSS have been addressed so far, but not comprehensively. Some researchers focused their attention on environmental sustainability. Climate impacts through the use of e-bikes were assessed in several studies. Most of these studies considered the greenhouse gas emissions (GHG) emitted by e-bikes [21]. A few articles analysed the environmental impact of e-bikes and e-bike battery production and recycling [21–23]. The social perspective of sustainability (customer expectations and requirements in terms of the products and services offered) has been addressed as well, but to a lesser extent than the environmental perspective [9,11,13,19,20,24–27]. The same goes for the economic impact of e-BSS [9,25,28].

No research currently exists on e-BSS sustainable provider selection. Two studies on BSS provider selection [29,30] and one on ordinary bike provider selection were found [31]. Park, Kremer et al. (2018) [31] used the multi-attribute utility theory (MAUT) to determine the provider region and used a multi-objective integer linear programming model to identify final provider candidates and optimal order quantities [31]. They paid attention to the simultaneous integration of regional economic, social, and environmental factors in global supply chain design. They confirmed that a multi-objective sustainable decision made using a multiple sourcing strategy leads to a supply chain that is different from the types of supply chains produced through single-objective non-sustainable decisions [31]. Liu et al. (2019) [29] combined a quality function deployment (QFD) with a partitioned Bonferroni mean (PBM) operator in an interval type-2 fuzzy environment. QFD enables the provider evaluation criteria to act in accordance with the characteristics of a purchased service. The PBM operator assumes that all criteria are divided into several groups. Criteria in the same groups are assumed to be interrelated. Criteria in different groups are assumed to be irrelevant. Interval type-2 fuzzy sets were found to efficiently express vagueness and imprecision [29]. The second study conducted by Liu et al. (2020) [30] integrates the

linguistic spherical fuzzy numbers (Lt-SFNs) used for expressing the public's language evaluation information. Lt-SFNs has a wider information expression range. Then, the linguistic spherical fuzzy weighted averaging (Lt-SFSWA) operator was used, since it can aggregate the group linguistic evaluation information. At the end the multi-attributive border approximation area comparison method (MABAC) was applied due to the possibility of selecting an optimal alternative from a plurality of alternatives.

In summary, only three studies were discovered that partly coincide with the topic of this paper. Liu et al. (2020) [30] evaluated shared bike projects rather than providers but found a fairly reliable evaluation index system based on interviews with shared bike users, grouped and weighted according to the frequency of shared bike use. Tian et al. (2018) [32] propose an evaluation of a smart bike sharing system. Their evaluation index system is less robust, based on market research and only four expert reviews, but is still useful for determining a sustainable supplier rating index system. Liu et al. (2019) [29] tested the applicability of quality function deployment with partitioned Bonferroni mean operator in a fuzzy environment of interval type-2 using a bike-sharing case study. Their research was particularly useful in selecting potential survey respondents.

Despite a large number of studies on e-BSS, there are still many gaps that prevent municipalities from selecting the sustainable provider that meets all stakeholders' needs:

1. The simultaneous consideration of several sustainability domains and stakeholders in the context of e-BSS has not yet been explored in depth. There is a lack of systematically combined criteria of all sustainability domains that best reflect the needs and requirements of all stakeholders. Furthermore, the significance of the requirements of the different stakeholders and their comparison is also unknown. The same applies to the mutual influence of criteria within one dimension of sustainability and also between different domains of sustainability. Neglecting this fact and ignoring the different weights of the requirements/needs can lead to the selection of a non-optimal provider in terms of sustainability and the needs of all stakeholders.
2. Many methods of very different characteristics exist to select a sustainable provider. Given Plepys and Singh (2019) [33], Zhang et al. (2015) [34], and Winslow and Mont (2019) [35], the most appropriate approach for assessing the sustainability of a sharing system, where e-BSS belongs, is an input-output approach, based on "need-feature-benefit" analysis, which jointly fulfils biker's, local governments', and providers' needs. The data envelopment analysis (DEA) method is the most frequently used among those based on the mentioned approach. It is an easy, uncomplicated method to use. Still, it has several weaknesses—sensitivity to measurement errors [36], insufficiency in terms of evaluating absolute effectiveness, inability to allow the use of statistical test tools because it is a non-parametric method [37], lack of random faults in the method disable extraction of the measurement methods, and the roughness in the data [38]—thus often integrating the method with sophisticated techniques [39], which are too complicated for municipalities that are not familiar with them and do not support the latest real problems in the providers' selection.
3. In the case of a sustainable provider selection, undesirable outputs (e.g., pollution) are inevitably produced along with desirable outputs. They have a negative impact on the efficiency of a provider and have to be reduced, while there are a series of criteria that have to be improved. Efficiency assessment, which considers undesirable criteria is frequently overlooked in previous studies, although it could change the ranking of alternatives.

Two objectives have been set to overcome the above-mentioned gaps. The first goal of this article is to create a comprehensive set of criteria that covers all three domains of sustainability and reflects the needs and requirements of communities and e-bike users.

Secondly, this study supports municipalities with a distance-based AHP-DEA super-efficiency approach with several methods, which allows the adaptation of the DEA decision model to the needs of predefined groups of stakeholders using slack variables. On the one hand, the approach takes into account the fact that not all outputs have a positive impact

on the final outcome. Some of them may have a negative impact or be neutral, but on the other hand, it allows the city municipality to define the hierarchical structure of the criteria importance directly from the responses of the selected group of stakeholders.

Based on these objectives, this study will address the research questions:

- RQ1. Which assessment criteria best describe the characteristics of e-BSS that meet the requirements/needs of different stakeholders' categories?
- RQ2. Which DEA approach enables decision-makers to customise the importance of criteria to different categories of stakeholders but is, on the other hand, user-friendly enough for decision-makers that are not familiar with sophisticated multi-criteria decision-making tools?

This study provides a more holistic than usual view of e-BSS characteristics that meet all stakeholders' needs and requirements. The presented tool also assists a municipality in finding such a balance among these characteristics, which brings win-win solutions to all stakeholders. In this way, bike users get a better service, which leads to an increase in the use of e-BSS, which in turn increases the profitability of the e-BSS and its sustainable efficiency. Both results, set of characteristics and the approach, also enable the detection of weaknesses and opportunities of e-BSS providers, contributing to raising the quality of service and improving the company's competitive advantage in the domestic and possibly even European Union environment. For example, in case an e-BSS provider is not optimal, the associated optimal peers are listed by DEA. Peers suggest the most closely related optimal competitor and slack variables, which criteria has to be increased or decreased, and for which value. A weighted set of e-BSS characteristics could also serve as a baseline to draft legislation to regulate sustainability in this area.

This paper is structured as follows: Section 2 contains the results of the literature review. In Section 3, a methodological approach is presented in detail. The paper is continued with a numerical example, followed by the presentation of the results and discussion. We end the article with a conclusion that includes the limitations of the paper and suggests future research.

## 2. Theoretical Background

This study reviewed the literature in three directions: (1) sustainable assessment criteria for selecting an e-BSS provider, (2) applying a DEA for sustainable provider selection, and (3) sustainable e-BSS and e-BSS provider assessment. Multiple literature sources (scientific articles, books, project's reports, and conference papers), detected on Web of Science, Google Scholar, and Scopus, were reviewed in all three above-mentioned directions.

### 2.1. Criteria for Evaluating an e-BSS Provider

An increasing number of studies has only indirectly analysed various elements, criteria, or factors of e-BSS sustainability. A maximum of two domains of sustainability, but never all three, were addressed in any study at once. In addition, no research has addressed this challenge systematically and comprehensively.

Edge and Gotfield (2017) [10] found that Canadian governance stakeholders who influence transport reforms believe in GHG emissions reduction but are concerned over the costs of building infrastructure and the safety of riders in the limited road space.

Significant challenges for e-BSS are costs of e-bikes and costs of renting, weight, and range of bikes, easy use of e-bikes (smart bikes, real-time information about stations, and available bikes) [2,20,27], easy maintenance of bikes, station location choice, and separate cycle lines. According to Meireles et al. (2013) [11], safe design to avoid vandalism is also a must. Given Alvarez-Valdes et al. (2016) [40], the quality of the BSS greatly depends on the proper distribution of bikes. Jiménez et al. (2016) [41], therefore, applied data mining tools and developed a new ratio for measuring the effectiveness degree of each station of BSS. Additional luggage carrying capacity of an electric bike was requested by the users in one paper only [9].

Jackson (2019) [24] examined barriers to achieve e-bike commuting on a large scale and revealed that the price of the bike, access to bikes, and costs of renting are significant for riders. Offering social benefits (number of e-bikes, access e-bikes for lower-income employees, and students) by the e-BSS would increase the degree of e-bikes usage. Implementation feasibility and government costs are, on the other hand, criteria to encourage the implementation of e-BSS.

Kämper et al. (2016) [21] emphasise that the environmental benefits of e-BSS are high but could be even higher by increasing the lifetime of the battery. They claim that significant capacity losses can occur even before the first use of an e-bike and, therefore, suggest improving battery treatment until sale. Battery rental can be expanded as well.

Cherry et al. (2009) [22] calculated the environmental impact of production and use of e-bikes and concluded that lead is one pollutant on which e-bikes perform poorly. Lead-acid batteries can be replaced by nickel-metal hydride and lithium-ion batteries, which reduces the weight of the e-bike, increases the lifespan (two to three times) of the battery—but also its price. Liu et al. (2015) [23], on the other hand, suggest increasing the lifetime of lead-acid batteries by controlling the charging process during manufacturing and by designing a smart power system to avoid over-discharge. Besides, metals that were found to be a key driver of environmental impacts can be replaced by other material. According to Campbell et al. (2016) [25], all e-bike environmental problems are results of a lack of governmental regulation.

Several surveys performed on profiles and habits of e-bikers revealed that e-BSS or e-bikes are appreciated by both women and men [7,20]. E-bikes are more prevalent among middle-aged riders [19,26] during pleasant weather [13,25,42]. The higher weight, lower safety (in case laws prohibit e-bikes from using cycling paths), and range anxiety are often reported as weaknesses [8,11,42] of e-bikes. However, easy access to the e-BSS station increases not only the use of e-bikes but also the satisfaction with e-BSS [20]. Environmental concerns are very rarely exposed as a reason for using e-BSS [26].

Studies of Tian et al. (2018) [32] and Liu et al. (2020) [30] were the only ones that at least partially met the needs of this paper. Tian et al. (2018) [32] present the evaluation index of the smart BSS, consisting of four aspects (bikes, payment, internet services, and green practices) and eighteen criteria (number of bikes, bike diversity, bike comfort, ease of use, safety performance, hourly price of renting, type of payment, ease of payment, mobile applications (APP), functions of APP, environmentally friendly material in manufacturing, management, and practice of recycling). Liu et al. (2020) [30] divide an evaluation index system of shared bikes into three aspects: hardware configurations (appearance of bike and riding comfort), software configuration (deposit and price), and spatial layout (availability). Based on these two last studies and all other mentioned studies, a holistic set of assessment criteria, which considers all three domains of sustainability, was designed (Table 1). Literature review steps performed on criteria for selecting a sustainable e-BSS supplier are presented in the first two paragraphs Section 3.1.

“Six types of conceptual frameworks or typologies for sustainability indicators exist: domain-based; goal-oriented; sectoral; issue-based; causal; and combination” [43]. All frameworks are complementary and not completely different [44]. The sustainable development goals (SDGs) [45] represent a combined goal-based and issue-based framework. Each of the 17 goals covers one area and is sub-defined in several targets [44]. The Social, Technological, Economical, Environmental, and Political (STEEP) framework is a domain-based framework, which consists of five principle domains: economic, social, environmental, technological, and political [44,46]. The Monitoring Sustainable Development (MONET) typology is a causal-based framework, which consists of six categories: level, capital, input/output, efficiency, disparities, and response [47]. Criteria evaluation in this paper was performed by using the three most frequently used domains of STEEP framework (social, economic, and environmental domain). The STEEP framework is used in case of “scenario analysis where someone has to understand which driving forces might affect an organisation” [46,48,49], in our case, the e-BSS provider.



**Table 1.** Full set of sustainable criteria for e-BSS provider evaluation.

|                        | Criteria  | Reference                     |
|------------------------|---|-------------------------------|
| Environmental criteria | The number of e-bikes that the provider can equip with solar cells  | [5,7,15,16,18]                |
|                        | The number of charging stations that the provider can equip with solar cells  | [5]                           |
|                        | Number of environmental standards that the provider implemented   | [2]                           |
|                        | Type of battery/battery recycling (environmental pollution)   | [8,9,11,12,16–19,21–24,26]    |
|                        | Battery lifecycle   | [11,12,18,24,26]              |
| Economic criteria      | E-bike range  | [5,8,11,12,15,18,21,24–26]    |
|                        | How many times a day does the provider offer redistribution of e-bikes from full charging stations to empty ones/response time in case of need to redistribute e-bikes from full charging stations to empty charging stations | [5,7,11,18,24,40]             |
|                        | The price paid by the municipality to establish an e-bike sharing system (e-BSS)  | [5,7,11,12,15,18,21,24,26,42] |
|                        | Credit rating of the provider   | [50–52]                       |
|                        | The number of e-bikes that the provider can provide   | [16,40,49]                    |
|                        | Response time in case of e-bike or station failure/time provision of spare parts  | [2,11,12,15,26,40]            |
|                        | Battery charging speed  | [5,9,12,15,16,18,26]          |
|                        | Possibility of storing e-bikes at the provider if the system is not operating (e.g., winter months)   | [50–52]                       |
|                        | Battery lifecycle/warranty period of battery  | [11,12,18,24,26]              |
|                        | The number of hours per day the provider needs a call centre to help customers  | [50–52]                       |
| Social criteria        | The amount of funds that the provider allocates to the community (e.g., weaker, vulnerable groups, disability associations, sponsorship)  | [53]                          |
|                        | Number of scholarships per year advertised by the provider  | [53]                          |
|                        | Number of women/number of men employed by the provider  | [54]                          |
|                        | Number of employees from more vulnerable groups (e.g., disabled people) employed by the provider  | [54]                          |
|                        | The number of the e-bikes with an adjustable seat/handlebar/suspension  | [2,7,11,15,17,27,28,32,42]    |
|                        | Number of e-bikes with frame sizes for women/men/children   | [2,8,15,18,32,40,42]          |
|                        | Number of e-bikes with navigation and Global Positioning System (GPS)   | [2,7,11,15,18,24,27,32,55]    |

In addition to the criteria listed in Table 1, the following criteria were also detected in the literature: sufficient number of charging stations, capacity of charging stations, location of charging stations, proximity of the bicycle rental system from the accommodation, system operation time and arranged cycling routes, payment options, battery locations, damage bike management, ensuring the safety of the wheels during charging, and pos-

sibility of advertising on bicycles or charging stations. We did not place these criteria in Table 1, as the values of these criteria are already determined in the application by the investor and do not depend on the supplier. All suppliers must achieve the same values. These criteria, therefore, do not differentiate suppliers. “Seat height adjustment without additional tools” criterion was also not included in Table 1, since e-BSS bikes need to be user-friendly. We cannot expect a user to be equipped with additional tools. “Lower environmental pollution” is the only criterion that we combined with the “battery type” criterion. In the case of e-bikes, batteries are the ones that pollute the environment. The amount of environmental pollution, however, depends on the type of battery.

## 2.2. Selecting a Sustainable Provider by Using the DEA Method

In recent years a large number of authors applied DEA to assess sustainable providers (e.g., 956 articles were found in ScienceDirect). Due to the large number of articles, we decided to analyse most of those from the last two years only (2018–2020).

To obtain a strong order for the importance weights of ordinal rank gradations and to remove subjectivity from rank discrimination, a revised voting AHP (VAHP) was proposed by Pishchulov et al. (2019) [56]. Izadikhah and Saen (2019b) [57] suggest using a methodology based on DEA for ranking providers in a voting system. To eliminate the selection of worse providers, Diouf and Kwak (2018) [58] propose to develop providers and not only evaluate existing ones. Fuzzy AHP (FAHP) and DEA were used in this case for ranking and a managerial analysis to assess the impact of important criteria on provider selection. Pantha et al. (2020) [59] integrate DEA with an evolutionary algorithm, differential evolution (DE), to make the provider’s efficiency more precise and acceptable. A very flexible DEA model for performance evaluation of sustainable providers in the presence of deterministic, stochastic, and fuzzy data in one framework was developed by Tavassoli et al. (2020) [60]. Izadikhah and Saen (2019a) [61] focus their attention on ranking. They used a context-dependent DEA approach to suggest a new clustering based on values of attractiveness and progress. They rank efficient, weak efficient, and non-extreme efficient decision-making units (DMUs). Amindous (2018) [62] developed the integrated modular fuzzy inference system (FIS) and assurance region DEA model to help decision-making areas with the unlimited number of criteria and alternatives.

A two-stage DEA model (activities are organised in two separate stages) in the presence of uncontrollable inputs and undesirable outputs was used to select a provider in the plastics industry [63]. An additive DEA model was used by Dobos and Vörösmarty (2020) [39] to manage the problem of negative data in either input or output factors. Tavassoli and Saen (2019) [64] propose a super-efficiency stochastic DEA model to measure the relative efficiency of the provider in the presence of zero data. Alikhani et al. (2019) [65] utilise interval type-2 fuzzy sets to quantify inputs and apply the super-efficiency DEA model to evaluate sustainable providers.

By comparing fuzzy DEA and fuzzy technique for order of preference by similarity to ideal solution (TOPSIS) authors Rashidi and Cullinanen (2019) [66] revealed that the provider rankings are not perfectly correlated, which is problematic for decision-makers. By testing the sensitivity to the number of providers (excluding one provider and adding one imaginary provider), the fuzzy TOPSIS generates a consistent ranking of providers, even when the number of providers was changed. However, fuzzy DEA failed to generate a consistent ranking. The reason for the inconsistency is the method’s algorithms.

Wang et al. (2018) [67] are among few who emphasised the flexibility and practicality of the method hybrid FAHP and green DEA for the decision-makers (edible oil production).

In summary, we found that most of the papers are methodology-oriented rather than oriented around the sustainable selection provider problem. Two issues are most frequently considered in these studies: (1) precision of ranking of providers and (2) efficiency of negative or zero data management. Only one paper was found to be useful for the practice.

### 2.3. A Framework of Sustainable e-BSS and e-BSS Provider Evaluation

No study was found to evaluate the sustainability of e-BSS providers nor BSS providers, partly due to the lack of appropriate methodology and data to assess the sustainability [33]. Nevertheless, we found four studies that guided us in constructing the framework of the methodological approach.

The first study [33] relates the sharing economy in general and highlights three challenges to evaluate the sustainability implications: (1) the diversity of business models, (2) inadequate information about sharing activities (a sharing economy engages not only companies but also individuals from which; however, data are difficult to obtain), and (3) different modelling approaches for sustainability assessment (input-output approach).

In the second article, a more profound insight into the characteristics of sustainable BSS was performed [34]. Firstly, analysis of BSS cannot be fully completed by considering single and not multiple perspectives: transport planning, system design, and business models. A bike-sharing system, as a “green” transport mode, plays an important role in the transport system of an urban area. As such, it needs to be integrated into urban development to serve the target groups (daily commuters, tourists, etc.) in the best possible way. However, since BSS is a product service system, it is necessary to consider both elements together, the service and the product. For example, only investment into equipment (tracking system, lend-and-return system, etc.) without investment into bikes, bike lines, and appropriate locations of dock stations will not bring success. This kind of BSS designing approach, in view of Zhang et al. (2015) [34], requires “solution-oriented partnership” of local authorities, investors, providers, and users, “need-feature-benefit” analysis, including a clear definition of inputs in the system, activities, and outputs from the system.

The study of Winslow and Mont (2019) [35], the latest article on the value created by sharing organisations in BSS, developed an analytical framework, which offers a better understanding of how value is created. The authors investigated not only positive value (economic and social value) but also destroyed value (through negative impacts) caused by BSS. The authors found that the environmental value that three organisations, investigated in the article, create is closely interlinked with the social value and that these values outweigh the negative impact of their operations.

The last reviewed article, Andreassen et al. (2018) [68], offers a better understanding of fundamental decisions made by the platform company (in our case the municipality) that shapes the value proposition and factors that affect them. The authors claim that matching customer preferences with provider preferences is critical for a long-lasting and sustainable relationship. They suggest selecting the appropriate provider by defining the “right” criteria, setting a strict selection process, and applying the method able to match all stakeholders needs.

## 3. Methodology

The proposed methodology is based on several approaches: (1) a criteria definition using a literature review, an online survey and distance-based AHP (DAHP), (2) a super-efficiency slack-based DEA model, and (3) a final validation of results using a real numerical example in Slovenia.

### 3.1. Definition and Assessment of Criteria

In this study, much attention was paid to the definition of appropriate criteria for selecting a sustainable e-BSS supplier. To achieve this purpose, multiple literature sources, detected on Web of Science, Google Scholar, and Scopus, were systematically reviewed (47 scientific articles, five project’s reports, seven conference papers). The keywords for the search were: e-bicycle sharing system AND selecting provider AND sustainable criteria OR selection criteria. Based on the review of 59 articles, a set of criteria was designed and then classified by the authors into three groups according to the domains of sustainability (Table 1). The fact that the classification of criteria is based on the findings of the literature review and not on the judgement of the authors is the added value of this paper.



It is true, however, that in some cases, it turned out that the criteria could be divided into two groups. In these cases, the authors decided at their own discretion. Three groups of criteria, including criteria within each group of sustainability dimension, were then assessed for their importance using an online survey conducted in Slovenia. The data collection took place from 5 May 2020 to 24 June 2020. The survey was aimed at two primary target groups of stakeholders: Slovenian local governments (municipalities) that have already implemented e-BSS or intend to implement it in the future and Slovenian residents that are already using, plan to use, or would like to use e-BSS, but do not have the opportunity to do so.

The survey had two main topics: (1) an assessment of the importance of the sustainability dimension by each target group and (2) an assessment of the importance of criteria within each dimension of sustainability by using the Likert scale. Before the survey was launched, a pre-test by two researchers that are familiar with e-BSS and four users of e-BSS was performed to prevent biases. Some questions were revised to be more precise. One recall was needed after the initial contact. Three hundred and fifty persons in total participated (93 employees of municipalities and 257 users or potential users of e-BSS). Representativeness was achieved in the municipalities, as 93 out of 212 municipalities that exist in Slovenia participated in the survey. Small municipalities, large municipalities, as well as urban municipalities participated in the survey. The representativeness of the users was achieved by inviting existing BSS users who already have experience with the use of ordinary bicycles and know enough the advantages and disadvantages of existing BSS systems to participate in the survey. In order to obtain the opinion of those users who have experience with e-bikes, we asked e-bike sellers and companies that perform e-bike servicing, to forward the survey to their customers or e-bike buyers. With these two measures, we obtained a smaller number of responses, but we achieved greater credibility of the survey results. The results are presented in Section 4.

### 3.2. Distance-Based Analytic Hierarchy Process

In this section, a new method to obtain a hierarchy structure and weights of criteria using just the results of a survey is proposed. The newly defined approach is reliable and, at the same time, user-friendly for those who need to solve multi-criteria decision-making problems (MCDMs).

The approach is based on the systematic Saaty's AHP tree structure, which is clear and easy to understand. However, a newly proposed method does not even require the decision-maker to perform all the necessary pairwise comparisons. Instead, the authors enable the use of AHP to obtain the scores directly from the survey statistics.

The proposed method is very close to VAHP. Both methods, DAHP and VAHP [56,69,70], are based on the idea that it is much easier for a decision-maker to sort the criteria in descending order than to compare them in pairs [56,69,70]. However, DAHP maintains the AHP maximum eigenvalue consistency check and can be used to reduce the low discriminating power of the DEA method. Following, the steps of the DAHP method are presented.

Firstly, it is possible to consider criteria of just one level in the tree structure (in case of multiple levels the proposed steps can be used at each level) without losing generality. The criteria at the chosen level ( $C_1, \dots, C_n$ ) are presumably independent.

The pairwise criteria comparisons scores are defined by using data obtained from the survey statistics. This step must be repeated at each level. Weights obtained at each level must then be joined to obtain the final weights. Weights will then be used in the DEA model to highlight some features that are in comparison to others considered more in comportment with the expectations of the selected DMs group.

Let  $K$  be the total number of the responder to the survey and  $F = \{(f_{i1}, \dots, f_{in}) : i = 1, \dots, n\}$  the set of ranking vectors associated with the criteria set.

Each element  $f_{ij} \in F$  is the number of surveyors that put criteria  $C_i$  at the  $j$ -th place on the scale of criteria,  $0 \leq f_{ij} \leq K$  for  $i, j = 1, \dots, n$ .

On the base of the defined set,  $F$  criteria can be ranked, from the most important to less relevant, by the relation: “criterion  $C_i$  is more important than the criterion  $C_j$ ” or in an equivalent form “ $C_i \succ C_j$ ” when  $\sum_{l=1}^n (f_{il} - f_{jl}) \cdot a^{l-1} \geq 0$ , where  $a = \min_{t \in \mathbb{N}} \{10^t | f_{ij} \leq 10^t; i, j = 1, \dots, n\}$ .

In the second step, the distances between all pairs of criteria are measured. Then, the maximum distance between all pairs of criteria is computed as:

$$D = \max_{0 \leq i \leq j \leq n} \left\{ d(C_i, C_j) = \sqrt{\sum_{l=1}^n (f_{il} - f_{jl})^2} \right\}. \quad (1)$$

The defined distance will be used in the next step to define the AHP pairwise comparisons matrix.

The criteria  $(C_1, \dots, C_n)$  importance, expressed by weights  $(w_1, \dots, w_n)$ , can be computed using the techniques of the AHP method and the set  $F$  of ranking vectors, which contain preferences of the survey’s participants. The relevance of criteria are general, not absolute, but depend on the needs of the surveyed group [71].

The pairwise comparison matrix  $A$  is defined based on previously defined relation and distance. The elements  $a_{ij}, i, j = 1, \dots, n$  of the matrix are defined using Equation (1) and the Saaty evaluation scale from 1 to 9 [72]:

$$a_{ij} = \begin{cases} \left[ \frac{9 \cdot d(C_i, C_j)}{D} \right]; & C_i \succ C_j \\ 1; & C_i = C_j \\ 1 / \left[ \frac{9 \cdot d(C_i, C_j)}{D} \right]; & C_j \succ C_i \end{cases} \quad \text{for } i, j = 1, \dots, n. \quad (2)$$

The comparisons matrix  $A$  is reciprocal and has only one eigenvalue  $\lambda_{max}$  different from zero. Let  $w$  be the associated right eigenvector. The components of  $w$  are the criteria weights. Using Saaty’s method, based on the arithmetic mean, a proper approximation of the components of the principal eigenvector can be computed as [73]:

$$w_i = \frac{1}{n} \sum_{j=1}^n \frac{a_{ij}}{A_j} \quad \text{for } i = 1, \dots, n; \quad (3)$$

where  $A_j = \sum_{i=1}^n a_{ij}$  for  $j = 1, \dots, n$ .

Because of approximations used, the consistency of the method must be checked by using the maximum eigenvalue ( $\lambda_{max}$ ) technique [74,75]. The Consistency Index (CI) is defined as [74,75]:

$$CI = \frac{\lambda_{max} - n}{n - 1}; \quad \lambda_{max} = \sum_{i=1}^n A_i \cdot w_i. \quad (4)$$

where the approximation of the maximum eigenvalue is.

Then, the Consistency Ratio (CR) is computed as the quotient between the Consistency Index and the Random Index (RI) [76]. In case of consistency, the Consistency Ratio must be less or equal to 0.1.

The Consistency Ratio is a tool to evaluate the transitivity of criteria preferences ordering. This is closely related to expert knowledge and the objectivity of decision-making. So, the Consistency Ratio is a proper tool when the AHP method is used as a MCDM method.

In the proposed method, the Consistency Ratio value may be higher than 0.1, as the AHP method may be based on a sample of respondents who may have a lack of knowledge of the problem under investigation, especially if it is new and complex.

In this article, the authors choose to use AHP as a research tool for a new complex problem instead of a decision tool. The method is based on survey results, so our main concern was to select a sample representative of the population that is not composed of

experts on the problem. The aim of the proposed method is to obtain the opinion of those involved in policymaking in order to improve it and to design the proposals in such a way that they can be accepted [77,78].

### 3.3. Background of Slack-Based DEA and Super-Efficiency Measure

DEA is a nonparametric method used to evaluate the efficiency of DMUs by analysing the efficiency of obtained outputs relative to inputs [79]. Finding the benchmarks of DMUs is thus one of the most important purposes of DEA [80]. DEA has the capacity to lead to the best-practice frontier [79].

In the proposed DEA method, the authors consider the preferences of the decision-maker and also the preferences of possible future customers that are available from the survey data analysis. The criteria evaluation, based on the AHP method, are used to obtain the most preferred DMUs in each target group (municipalities or users).

In the original formulation of the DEA ratio model, it is possible to distinguish between the (1) input-oriented model, where the efficiency can be increased through the reduction in inputs, while outputs are held constant, and (2) the output-oriented model, where the roles are reversed [81].

The basic DEA model is a non-parametric data-oriented method with linear fractional conditions and a goal function very often used to evaluate the performances of peer entities [82]. The basic formulation of the DEA model does not allow direct implementation. For this reason, the DEA model is written in linear form: (1) the Charnes, Cooper, and Rhodes (CCR) input or output-oriented model [79], or (2) the Banker, Charnes, and Cooper (BCC) input, or output-oriented model [83].

Moreover, the CCR model yields the same efficiencies regardless of whether it is input or output-oriented; the BCC model results are case sensitive.

Let  $X = [x_{ij}] \in R^{m \times n}$  be the input matrix and  $Y = [y_{ij}] \in R^{s \times n}$  be the output matrix.  $DMU_0$  is the target DMU,  $x_0 = (x_{10}, \dots, x_{m0})$  is the input vector and  $y_0 = (y_{10}, \dots, y_{s0})$  is the output vector. In practice, the input set  $X$  and also the output set  $Y$  can be composed of desirable and undesirable elements. There are typically two schemes for measuring the efficiency of DMUs: radial and non-radial. The first scheme assumes a proportional change in inputs (or outputs), and remaining slacks are not directly considered for inefficiency. On the other hand, non-radial models deal with slacks individually and independently for inputs and outputs. In this case, they are integrated into an efficiency measure called efficiency slacks-based measure (SBM). The SBM is frequently used, since it has higher discriminatory power and also detects more sources of inefficiencies compared with other DEA radial models [84].

Generally, the authors use a non-separable SBM model, based on the inability of separate desirable outputs from undesirable ones. In this formulation, a reduction in undesirable outputs certainly requires a cut in desirable outputs [85].

The SBM model can be updated in order to split outputs into desirable and undesirable without assuming a correlation between them [85]. Next, this model will be proposed. Let the production possibility set (PPS) be defined as all convex combinations of inputs and separate desirable and undesirable outputs:

$$PPS = \left\{ (x, y) \in R^{m \times s} \left| \begin{array}{l} x \geq \sum_{i=1}^n \lambda_i x_i; y \leq \sum_{i=1}^n \lambda_i y_i; y = y^D \cup y^U; y^D \in R^{s1 \times n}; \\ y^U \in R^{s2 \times n}; s1 + s2 = s; \lambda_1 \geq 0, \dots, \lambda_n \geq 0 \end{array} \right. \right\} \quad (5)$$

The output set is split into two parts: desirable outputs  $y^D$  and undesirable outputs  $y^U$ . Let the target  $DMU_0$  be described as:

$$\begin{aligned} x_0 &= \sum_{i=1}^n \lambda_i x_i + s^-, \\ y_0 &= \sum_{i=1}^n \lambda_i y_i - s^+, \end{aligned} \quad (6)$$

where  $s^- \in R^m$  and  $s^+ \in R^s$  are positive slack vectors that indicate the input excess and the output shortfall. The output slack vectors are composed of desirable  $s^{D+}$  and undesirable  $s^{U+}$  output shortfall. Based on the proposed definitions, it is possible to define an efficiency measure  $\rho$  on the SBM non oriented model (a combination of input and output-oriented cases) in a fractional form [86]:

$$\rho = \min_{\lambda, s^-, s^+} \left\{ \frac{1 - \frac{1}{m} \sum_{i=1}^m \frac{s_i^-}{x_{i0}}}{1 + \frac{1}{s} (\sum_{i=1}^{s1} \frac{s_i^{D+}}{y_{i0}} + \sum_{i=1}^{s2} \frac{s_i^{U+}}{y_{i0}})} \right\}, \quad (7)$$

subject to:

$$\begin{aligned} \sum_{i=1}^n x_{ji} \lambda_i + s_j^- &= x_{j0}, \quad j = 1, \dots, m, \\ \sum_{i=1}^n y_{ki}^D \lambda_i - s_k^{D+} &= y_{k0}, \quad k = 1, \dots, s1, \\ \sum_{i=1}^n y_{ki}^U \lambda_i - s_k^{U+} &= y_{k0}, \quad k = 1, \dots, s2, \\ \lambda &\geq 0, \quad s^- \geq 0, \quad s^+ \geq 0. \end{aligned} \quad (8)$$

In case of output-oriented models,  $\rho \geq 1$ . The output-oriented SBM model with a constant return to scale of variables is defined as [87]:

$$\rho = \min_{\lambda, s^-, s^+} \left\{ \frac{1}{1 - \frac{1}{s} (\sum_{i=1}^{s1} \frac{s_i^{D+}}{y_{i0}} + \sum_{i=1}^{s2} \frac{s_i^{U+}}{y_{i0}})} \right\}, \quad (9)$$

subject to:

$$\begin{aligned} \sum_{i=1}^n x_{ji} \lambda_i + s_j^- &= x_{j0}, \quad j = 1, \dots, m, \\ \sum_{i=1}^n y_{ki}^D \lambda_i - s_k^{D+} &= y_{k0}, \quad k = 1, \dots, s1, \\ \sum_{i=1}^n y_{ki}^U \lambda_i - s_k^{U+} &= y_{k0}, \quad k = 1, \dots, s2, \\ \lambda &\geq 0, \quad s^- \geq 0, \quad s^+ \geq 0. \end{aligned} \quad (10)$$

A deficiency of the DEA models and also of SBM DEA models is a low discriminating power between optimal solutions. For the optimal rank of DMUs, a super-efficiency score is defined in a restricted production possibility set as [85,88,89]:

$$\overline{PPS} = PPS \setminus (x_0, y_0). \quad (11)$$

The super-efficiency measure,  $\delta$  is defined as a quotient of two indices: the distance in the input space and the distance in the output space. The measure is a-dimensional:

$$\delta = \frac{\frac{1}{m} \sum_{i=1}^m \frac{\overline{x_i}}{x_{i0}}}{\frac{1}{s} \sum_{i=1}^s \frac{\overline{y_i}}{y_{i0}}}. \quad (12)$$

The super-efficiency model is defined as [84,88,90]:

$$\min \left\{ \frac{\frac{1}{m} \sum_{i=1}^m \frac{\overline{x_i}}{x_{i0}}}{\frac{1}{s} \sum_{i=1}^s \frac{\overline{y_i}}{y_{i0}}} \right\}, \quad (13)$$

subject to:

$$\begin{aligned} \bar{x} &\geq \sum_{\substack{i=1, \\ i \neq 0}}^n \lambda_i x_i; \\ \bar{y} &\leq \sum_{\substack{i=1, \\ i \neq 0}}^n \lambda_i y_i; \\ \bar{x} &\geq x_0 \text{ and } \bar{y} \leq y_0; \\ \lambda &\geq 0. \end{aligned} \quad (14)$$

Thus, with the help of an SBM DEA model, efficient DMUs can first be identified. Then, they are ranked by the super-efficiency model.

By combining the proposed steps, the authors propose a method that can define a classification of the most efficient DMUs from the statistical preference data: taking into account both the characteristics (requirements) of the designed respondent group and the influence (negative or positive) of the evaluated criteria.

#### 4. Numerical Example

The feasibility and applicability of the defined approach were tested using a case study from Slovenia. Due to various financial incentives from the European Community BSSs have been established in major cities in Slovenia in the last few years. Conventional BSS are still in the lead, while only nine e-BSSs have been implemented in 21 cities. The Slovenian market for providers of e-BSS is, consequently, extremely small. Many providers offer only e-bikes or charging stations; only three companies in Slovenia offer a complete e-BSS solution. The first provider (DMU<sub>1</sub>) is a company whose main activity is the establishment and management of e-BSSs. The second provider (DMU<sub>2</sub>) is the largest among all three providers as regards income and number of employees. Its main activity is the organisation and implementation of bus transport services. The third provider (DMU<sub>3</sub>) is a very well-known producer and trader of traditional and, in the last few years, e-bikes, in Slovenia. A numerical example, therefore, consists of three real and 21 fictional providers of e-BSS. However, the characteristics of the fictitious providers (Table 2 for the characteristics: battery lifecycle, the number of charging stations that the provider can equip with solar cells, etc.) are very similar to the real ones.

In Slovenia, municipal bodies exclusively establish e-BSS systems. Municipalities seek bidders through public tenders. The criteria for selection are more or less the same and cover only two domains of sustainability, economic and partly social. There are currently no incentives to offer sustainable e-BSS systems, without excluding any dimension of sustainability. There are very likely two reasons: a lack of regulation or incentives from public authorities and a lack of knowledge and tools to make it easier for municipalities to select a sustainable provider.

**Table 2.** Criteria set weights.

|                                   | Target Group: Municipalities<br>Pillar Level | Target Group: Users<br>Pillar Level | Criteria Description   | Target Group: Municipalities<br>Final Level | Target Group: Users<br>Final Level | Final Selection<br>of Criteria |
|-----------------------------------|--|-------------------------------------|--|---|------------------------------------|--------------------------------|
| Environmental criteria            | 0.6486                                       | 0.2364                              | Battery lifecycle  | 0.3386                                      | 0.0801                             |                                |
|                                   |  |                                     | The number of charging stations that the provider can equip with solar cells | 0.1249                                      | 0.0070                             | Selected                       |
|                                   |  |                                     | Type of battery  | 0.0942                                      | 0.0251                             | Selected                       |
|                                   |  |                                     | Number of environmental standards that the provider implemented              | 0.0663                                      | 0.0384                             | Selected                       |
|                                   |  |                                     | The number of e-bikes that the provider can equip with solar cells           | 0.0245                                      | 0.0858                             | Selected                       |
| Consistency Ratio (CR) = 0.3413 * |  |                                     |  |   | CR = 0.1196                        |                                |



Table 2. Cont.

|                   | Target Group: Municipalities<br>Pillar Level | Target Group: Users<br>Pillar Level | Criteria Description   | Target Group: Municipalities<br>Final Level | Target Group: Users<br>Final Level | Final Selection<br>of Criteria |
|-------------------|--|-------------------------------------|--|---|------------------------------------|--------------------------------|
| Economic criteria | 0.2946                                       | 0.7013                              | The price paid by the municipality to establish an e-bike sharing system (e-BSS)   | 0.0579                                      | 0.0720                             |                                |
|                   |  |                                     | Credit rating of the provider  | 0.0308                                      | 0.0176                             | Selected                       |
|                   |  |                                     | The number of e-bikes that the provider can provide  | 0.0135                                      | 0.0647                             |                                |
|                   |  |                                     | Warranty period of battery   | 0.0513                                      | 0.0344                             | Selected                       |
|                   |  |                                     | Response time in case of e-bike or station failure   | 0.0214                                      | 0.1044                             | Selected                       |
|                   |  |                                     | Time provision of spare parts  | 0.0078                                      | 0.0142                             |                                |
|                   |  |                                     | How many times a day does the provider offer redistribution of e-bikes from full charging stations to empty ones                         | 0.0149                                      | 0.0505                             |                                |
|                   |  |                                     | Response time in case of need to redistribute e-bikes from full charging stations to empty charging stations                             | 0.0093                                      | 0.0369                             | Selected                       |
|                   |  |                                     | E-bike range   | 0.0538                                      | 0.2226                             | Selected                       |
|                   |  |                                     | Battery charging speed   | 0.0258                                      | 0.0658                             |                                |
|                   |  |                                     | Possibility of storing e-bikes at the provider if the system is not operating (e.g., winter months)                                      | 0.0082                                      | 0.0181                             |                                |
|                   |  |                                     |  | CR = 0.5238 *                               | CR = 0.2768 *                      |                                |
| Social criteria   | 0.0567                                       | 0.0623                              | The number of hours per day the provider needs a call centre to help customers   | 0.0172                                      | 0.0068                             | Selected                       |
|                   |  |                                     | The number of e-bikes with an adjustable seat  | 0.0114                                      | 0.0125                             |                                |
|                   |  |                                     | The number of e-bikes with suspension  | 0.0015                                      | 0.0012                             |                                |
|                   |  |                                     | Number of e-bikes with navigation and Global Positioning System (GPS)  | 0.0036                                      | 0.0063                             |                                |
|                   |  |                                     | Number of e-bikes with frame sizes for women/men/children  | 0.0081                                      | 0.0201                             | Selected                       |
|                   |  |                                     | The amount of funds that the provider allocates to the community (e.g., weaker, vulnerable groups, disability associations, sponsorship) | 0.0052                                      | 0.0044                             | Selected                       |
|                   |  |                                     | The number of e-bikes with adjustable handlebar  | 0.0020                                      | 0.0034                             |                                |
|                   |  |                                     | Number of scholarships per year advertised by the provider   | 0.0028                                      | 0.0023                             |                                |
|                   |  |                                     | Number of women, number of men, employed by the provider   | 0.0008                                      | 0.0020                             |                                |
|                   |  |                                     | Number of employees from more vulnerable groups (e.g., disabled people) employed by the provider   | 0.0042                                      | 0.0034                             |                                |
|                   | CR 0.1053                                    | CR = 0.1016                         |  | CR = 0.3087 *                               | CR = 0.2598 *                      |                                |

\* The CR value is more than 20%, so the obtained ranking expresses the opinion of a group of non-expert respondents.

#### 4.1. Computation of Criteria Weights and Definition of the Final Set of Criteria

By using the online survey, presented in Section 2.1, the full set of criteria presented in Table 1 was assessed and ranked according to importance. Then, the DAHP method, defined in Section 3.2, is used to obtain the criteria weights. Results are presented in Table 2.

Table 2 shows that the importance of the criteria varies considerably according to

the target groups. For example, the environmental criterion “The number of e-bikes that the provider can equip with solar cells” has been assessed as the least important by municipalities. In contrast, e-bike users consider that criterion to be the most important. In determining the final set of criteria, we selected, where possible, those criteria that were most important for both target groups. In the case of related criteria (those criteria that concern different aspects of the same e-BSS characteristic), the one that most appropriately represents the group is selected. In case one target group assessed one criterion as the most or highly important and the other as the least or not so important, then the criterion was also selected, with the exception of the criteria “Battery lifecycle” and “The price paid by the municipality to establish an e-Bike Sharing System”. These two criteria have been assessed as the most important by municipalities. However, municipalities in Slovenia already set the minimum value, which the supplier must achieve, in the tender. So, in Slovenia, all providers meet this minimum requirement, and there is no difference among them. The final selection of criteria is shown in the last column of Table 2. It should be emphasised that the ranking of criteria in Table 2 is the result of the opinion of Slovenian target groups, and it is not possible to generalise this. The definition of a general model requires a larger number of samples composed of respondents that are experts. Additionally, respondents must be allowed to harmonise their opinions to obtain a consistent ranking that can be used as a decision-making tool.

#### 4.2. DEA Implementation

The estimation of e-BSS provider was done by using the CCR output-oriented DEA model that enables changing (increasing, decreasing) outputs while maintaining constant inputs. The chosen approach and division of variables into input and output encourage the e-BSS providers to act sustainably, as outputs are adapted to the needs and wishes of target groups by taking into account all three domains of sustainability (social, economic, and environmental). Besides, the use of slack variables allows the separation of model outputs into desirable and undesirable. The CCR output-oriented slack-based DEA model thus highlights the shortcomings of certain providers that are not detected by the most frequently used BCC DEA model. Table 3 presents the input and output variables that are used in the case study. Variables are divided into desirable and undesirable.

In Slovenia, there are only three providers who can offer and manage the entire e-BSS; these are the potential DMUs for the DEA model. There are quite a few providers of e-bikes and charging stations who do not offer a comprehensive service. These providers could be included as DMUs in our simulation, which, however, would not contribute to raising the sustainable efficiency of those providers who already offer a comprehensive service. That way, we would just maintain the status quo.

DEA models have a great capacity of discrimination if there is an appropriate ratio between the number of DMUs and the number of variables (input, output). The most frequently used “rule of thumb” proposes having at least two times more DMUs than the sum of the number of inputs and outputs; otherwise, the DEA may lose discriminating power [91]. Table 3 shows that there are five input and seven output variables. According to the rule of thumb, at least 24 DMUs are needed to make the DEA model efficient. Therefore, 21 DMUs, with characteristics comparable to real ones in the Slovenian market, are added to the existing three providers that provide a comprehensive service. Such added DMUs allow the provider to check its effectiveness in case of Slovenian market competitiveness increase or stricter legislation in this area. Table 4 presents the original DMU data and associated units of measurement. Data from Table 4 were weighted by using weights from Table 2 to associate peculiarities of each target group to DMUs.

**Table 3.** Input and output variables of the DEA model.

| Notation         | Description  | Unit of Measurement  | Sustainability Domain | Desirable/Undesirable |
|------------------|--|----------------------|-----------------------|-----------------------|
| Input Variables  |  |                      |                       |                       |
| $x_1$            | Number of environmental standards that the provider implemented  | Not negative integer | environmental         | D                     |
| $x_2$            | Warranty period of battery   | Year                 | economic              | D                     |
| $x_3$            | Credit rating of the provider  | Not negative integer | economic              | D                     |
| $x_4$            | The number of hours per day the provider needs a call centre to help customers   | Hours                | social                | D                     |
| $x_5$            | The amount of funds that the provider allocates to the community (e.g., weaker, vulnerable groups, disability associations, sponsorship) | Euro (€)             | social                | D                     |
| Output Variables |  |                      |                       |                       |
| $y_1^U$          | Minimal response time in case of e-bike or station failure   | Minutes              | economic              | U                     |
| $y_2^U$          | Response time in case of need to redistribute e-bikes from full charging stations to empty charging stations                             | Minutes              | economic              | U                     |
| $y_1^D$          | The number of charging stations that the provider can equip with solar cells   | Percentage           | environmental         | D                     |
| $y_2^D$          | Type of battery  | Percentage           | environmental         | D                     |
| $y_3^D$          | The number of e-bikes that the provider can equip with solar cells   | Percentage           | environmental         | D                     |
| $y_4^D$          | E-bike range   | Kilometre (km)       | economic              | D                     |
| $y_5^D$          | Number of e-bikes with frame size for women  | Percentage           | social                | D                     |

**Table 4.** Original, unweighted data for DMUs.

|                    | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$      | $y_1^U$ | $y_2^U$ | $y_1^D$ | $y_2^D$ | $y_3^D$ | $y_4^D$ | $y_5^D$ |
|--------------------|-------|-------|-------|-------|------------|---------|---------|---------|---------|---------|---------|---------|
| DMU * <sub>1</sub> | 0     | 2     | 2     | 24    | 6221.18    | 5       | 15      | 0       | 100     | 0       | 80      | 0       |
| DMU <sub>2</sub>   | 1     | 2     | 1     | 24    | 475,579.55 | 5       | 15      | 100     | 100     | 0       | 100     | 0       |
| DMU <sub>3</sub>   | 0     | 2     | 2     | 24    | 8582.10    | 5       | 15      | 100     | 100     | 0       | 100     | 0       |
| DMU <sub>4</sub>   | 1     | 1     | 1     | 12    | 5231.40    | 10      | 10      | 0       | 100     | 0       | 100     | 100     |
| DMU <sub>5</sub>   | 2     | 2     | 2     | 12    | 3245.56    | 0       | 0       | 50      | 0       | 100     | 100     | 50      |
| DMU <sub>6</sub>   | 1     | 2     | 1     | 12    | 33,250.45  | 20      | 20      | 0       | 0       | 50      | 100     | 100     |
| DMU <sub>7</sub>   | 1     | 2     | 3     | 24    | 4563.20    | 30      | 30      | 100     | 100     | 100     | 100     | 50      |
| DMU <sub>8</sub>   | 2     | 1     | 1     | 24    | 4578.70    | 5       | 5       | 50      | 50      | 50      | 100     | 50      |
| DMU <sub>9</sub>   | 0     | 1.5   | 2     | 24    | 6789.45    | 15      | 15      | 0       | 100     | 100     | 100     | 0       |
| DMU <sub>10</sub>  | 3     | 2     | 4     | 12    | 23,760.67  | 10      | 10      | 100     | 0       | 0       | 100     | 50      |
| DMU <sub>11</sub>  | 0     | 2     | 2     | 24    | 9678.56    | 0       | 0       | 0       | 0       | 0       | 80      | 100     |
| DMU <sub>12</sub>  | 1     | 2     | 3     | 12    | 1245.89    | 5       | 5       | 0       | 50      | 50      | 100     | 100     |
| DMU <sub>13</sub>  | 2     | 2     | 2     | 12    | 6758.21    | 10      | 10      | 50      | 100     | 100     | 100     | 0       |

Table 4. Cont.

|                   | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$     | $y_1^U$ | $y_2^U$ | $y_1^D$ | $y_2^D$ | $y_3^D$ | $y_4^D$ | $y_5^D$ |
|-------------------|-------|-------|-------|-------|-----------|---------|---------|---------|---------|---------|---------|---------|
| DMU <sub>14</sub> | 0     | 2.5   | 1     | 10    | 5678.45   | 20      | 20      | 100     | 100     | 50      | 100     | 100     |
| DMU <sub>15</sub> | 1     | 2     | 4     | 24    | 23,459.45 | 25      | 25      | 100     | 0       | 100     | 100     | 0       |
| DMU <sub>16</sub> | 1     | 2     | 1     | 11    | 5670.34   | 30      | 30      | 100     | 100     | 50      | 100     | 100     |
| DMU <sub>17</sub> | 2     | 3     | 1     | 12    | 6570.45   | 10      | 10      | 0       | 50      | 0       | 100     | 0       |
| DMU <sub>18</sub> | 0     | 1     | 1     | 24    | 6759.89   | 0       | 0       | 50      | 100     | 0       | 80      | 100     |
| DMU <sub>19</sub> | 4     | 1.5   | 2     | 10    | 2345.87   | 5       | 5       | 50      | 50      | 50      | 100     | 50      |
| DMU <sub>20</sub> | 1     | 3     | 2     | 11    | 5468.67   | 5       | 5       | 100     | 0       | 100     | 100     | 100     |
| DMU <sub>21</sub> | 1     | 2     | 2     | 24    | 23,450.56 | 10      | 10      | 100     | 100     | 50      | 100     | 100     |
| DMU <sub>22</sub> | 2     | 2     | 4     | 23    | 4578.56   | 25      | 25      | 0       | 50      | 0       | 100     | 50      |
| DMU <sub>23</sub> | 3     | 1     | 3     | 10    | 3456.67   | 15      | 15      | 50      | 50      | 0       | 100     | 100     |
| DMU <sub>24</sub> | 0     | 1     | 2     | 11    | 7689.67   | 20      | 20      | 100     | 0       | 50      | 100     | 50      |

\* Decision-making unit (DMU).

## 5. Results and Discussion

The efficiency of Slovenian providers of the entire e-BSS (real and fictional) was evaluated using the output-oriented CCR DEA model with slack variables and separable outputs. Then, optimal DMUs were ranked by using the super-efficiency model. The CCR DEA models are based on a “constant return to scale” requirement, which is more appropriate than the “variable returns to scale”, since it requires strictly consistency of providers in their sustainable efforts. A combination of the software Excel and MATLAB was used to perform the analysis.

Table 5 presents the results of the simulations. Firstly, the efficiency of DMUs in the current situation (see Table 5, original values columns) was evaluated for each target group. It is possible to note that only real provider DMU<sub>2</sub> results are optimal for both target groups. The other two providers (DMU<sub>1</sub> and DMU<sub>3</sub>) are not optimal.

In the next simulation, all environmental criteria were increased by 10%. In this case, all three real providers (DMU<sub>1</sub>, DMU<sub>2</sub>, and DMU<sub>3</sub>) became optimal for both target groups. DMU<sub>3</sub> was the most optimal of the three real providers. If the Slovenian state would establish stricter regulations in this area, and municipalities would prefer an environmentally friendly provider, then the DMU<sub>3</sub>'s effort and investment in environmental protection would pay off. In the current situation, however, its investment in environmental protection does not pay off. The same goes for DMU<sub>1</sub> (see Table 5, increase in environmental criteria 10% columns).

In cases when all social criteria were increased by 10%, municipalities recognised all three real providers as optimal (DMU<sub>1</sub> was besides DMU<sub>17</sub> evaluated the most optimal provider, see bold marked values in Table 5), while the users were more selective, and only DMU<sub>2</sub> was elected as optimal. These results confirm the findings of the authors cited in the literature review, who argue that several stakeholders need to be considered when selecting a provider. Consequently, these results demonstrate the originality of our approach to choosing a sustainable provider, which takes into account not only all three domains of sustainability but also the opinions of different target groups. The provider selection approach presented in this paper highlights and compares the needs of the different target groups.

**Table 5.** Simulation for target groups using output-oriented slack-based DEA model (with separable outputs) and the super-efficiency model.

|                   | Target Group: Municipalities |                        |  |                        |                                 |                        | Target Group: Users |                        |  |                        |                                 |                        |
|-------------------|------------------------------|------------------------|--|------------------------|---------------------------------|------------------------|---------------------|------------------------|--|------------------------|---------------------------------|------------------------|
|                   | Original Values              |                        | Increase in Environmental Criteria 10% |                        | Increase in Social Criteria 10% |                        | Original Values     |                        | Increase in Environmental Criteria 10% |                        | Increase in Social Criteria 10% |                        |
|                   | Efficiency Score             | Super-Efficiency Score | Efficiency Score                       | Super-Efficiency Score | Efficiency Score                | Super-Efficiency Score | Efficiency Score    | Super-Efficiency Score | Efficiency Score                       | Super-Efficiency Score | Efficiency Score                | Super-Efficiency Score |
| DMU* <sub>1</sub> | 1.0118                       | -                      | 1                                      | 0.9215                 | 1                               | 1                      | 1.0118              | -                      | 1                                      | 0.8949                 | 1.0825                          | -                      |
| DMU <sub>2</sub>  | 1                            | 0.8543                 | 1                                      | 0.8543                 | 1                               | 0.8543                 | 1                   | 0.7989                 | 1                                      | 0.7989                 | 1                               | 0.7989                 |
| DMU <sub>3</sub>  | 1.0148                       | -                      | 1                                      | 0.9313                 | 1                               | 0.9272                 | 1.0148              | -                      | 1                                      | 0.9313                 | 1.0437                          | -                      |
| DMU <sub>4</sub>  | 1                            | 0.6601                 | 1                                      | 0.6601                 | 1                               | 0.6601                 | 1                   | 0.6561                 | 1                                      | 0.6561                 | 1                               | 0.6561                 |
| DMU <sub>5</sub>  | 1                            | 0.6847                 | 1                                      | 0.6847                 | 1                               | 0.6592                 | 1                   | 0.6740                 | 1                                      | 0.6740                 | 1                               | 0.6740                 |
| DMU <sub>6</sub>  | 1                            | 0.6642                 | 1                                      | 0.9442                 | 1                               | 0.8862                 | 1                   | 0.9277                 | 1                                      | 0.9278                 | 1                               | 0.9278                 |
| DMU <sub>7</sub>  | 1                            | 0.6618                 | 1                                      | 0.6642                 | 1                               | 0.6326                 | 1                   | 0.6642                 | 1                                      | 0.6642                 | 1                               | 0.6642                 |
| DMU <sub>8</sub>  | 1                            | 0.4428                 | 1                                      | 0.6618                 | 1                               | 0.6618                 | 1                   | 0.6515                 | 1                                      | 0.6515                 | 1                               | 0.6515                 |
| DMU <sub>9</sub>  | 1                            | 0.6601                 | 1                                      | 0.4428                 | 1                               | 0.3909                 | 1                   | 0.4428                 | 1                                      | 0.4428                 | 1                               | 0.4428                 |
| DMU <sub>10</sub> | 1.1429                       | -                      | 1.0390                                 | -                      | 1.2                             | -                      | 1.1429              | -                      | 1.0390                                 | -                      | 1.2457                          | -                      |
| DMU <sub>11</sub> | 1.28                         | -                      | 1.28                                   | -                      | 1                               | 0.8559                 | 1.28                | -                      | 1.28                                   | -                      | 1.1636                          | -                      |
| DMU <sub>12</sub> | 1                            | 0.2897                 | 1                                      | 0.2897                 | 1.0858                          | -                      | 1                   | 0.2897                 | 1                                      | 0.2897                 | 1                               | 0.2897                 |
| DMU <sub>13</sub> | 1                            | 0.6882                 | 1                                      | 0.6882                 | 1                               | 0.6882                 | 1                   | 0.6873                 | 1                                      | 0.6873                 | 1                               | 0.6873                 |
| DMU <sub>14</sub> | 1                            | 0.3268                 | 1                                      | 0.3319                 | 1                               | 0.4167                 | 1                   | 0.3268                 | 1                                      | 0.3319                 | 1                               | 0.3268                 |
| DMU <sub>15</sub> | 1.1130                       | -                      | 1.0119                                 | -                      | 1.113043                        | -                      | 1.1130              | -                      | 1.0119                                 | -                      | 1.1130                          | -                      |
| DMU <sub>16</sub> | 1                            | 0.8426                 | 1                                      | 0.8426                 | 1                               | 0.4959                 | 1                   | 0.8426                 | 1                                      | 0.8426                 | 1                               | 0.8426                 |
| DMU <sub>17</sub> | 1                            | 1                      | 1                                      | 1                      | 1                               | 1                      | 1                   | 0.9999                 | 1                                      | 1                      | 1                               | 1                      |
| DMU <sub>18</sub> | 1                            | 0.3747                 | 1                                      | 0.3747                 | 1                               | 0.3747                 | 1                   | 0.3202                 | 1                                      | 0.3335                 | 1                               | 0.3202                 |
| DMU <sub>19</sub> | 1                            | 0.7092                 | 1                                      | 0.7092                 | 1                               | 0.5799                 | 1                   | 0.6894                 | 1                                      | 0.6894                 | 1                               | 0.6894                 |
| DMU <sub>20</sub> | 1                            | 0.75                   | 1                                      | 0.75                   | 1                               | 0.6515                 | 1                   | 0.75                   | 1                                      | 0.75                   | 1                               | 0.75                   |
| DMU <sub>21</sub> | 1.1132                       | -                      | 1.0120                                 | -                      | 1.0487                          | -                      | 1.1132              | -                      | 1.0120                                 | -                      | 1.0861                          | -                      |
| DMU <sub>22</sub> | 1.1198                       | -                      | 1.1198                                 | -                      | 1.2196                          | -                      | 1.1198              | -                      | 1.1198                                 | -                      | 1.2001                          | -                      |
| DMU <sub>23</sub> | 1                            | 0.6524                 | 1                                      | 0.6524                 | 1                               | 0.6410                 | 1                   | 0.6524                 | 1                                      | 0.6524                 | 1                               | 0.6524                 |
| DMU <sub>24</sub> | 1                            | 0.4                    | 1                                      | 0.4                    | 1                               | 0.4                    | 1                   | 0.4                    | 1                                      | 0.4                    | 1                               | 0.4                    |

\* Decision-making unit (DMU).



The results in Table 5 show that if only the opinion of the municipalities were taken into account in the selection, DMU<sub>1</sub> would have the best chances of winning the tender. In case the view of users is highlighted, then only DMU<sub>2</sub> is competitive. If a municipality prefers only its needs and requirements, a provider that would not meet the needs of the end-user can be selected. Municipalities, as e-BSS investors, very often choose a provider that is affordable but not necessarily environmentally and user-friendly. However, they do not consider that in the long run, the e-BSS system is cost-effective if users use it. Users, however, use the e-BSS system if it is user friendly. If it is not, then the e-BSS system will not benefit the users or the municipalities. Our approach does not allow the selection of the most cost-effective, nor the most environmentally or socially efficient provider, but a compromise of all three sustainable domains. It provides win-win results to all key target groups.

It should be emphasised that DMU assessment does not differ significantly among different target groups in case of a 10% increase in environmental criteria. Significant differences in the ranking of DMUs occur between the target groups in the case of an increase in social criteria by 10%.

In Table 6, a detailed analysis of real DMUs evaluation and ranking is presented. In case a real DMU is not optimal, the associated optimal peers are listed. Peers suggest the most closely related optimal competitor. It is possible to note, from Table 6, that DMU<sub>14</sub> and DMU<sub>18</sub> most frequently appear as optimal peers.

**Table 6.** Comparison of results between the real and the best three ranked DMUs.

| Target Group: Municipalities |                 |                         |  |      |                                 | Target Group: Users |      |  |      |                                 |                |      |                         |
|------------------------------|-----------------|-------------------------|--|------|---------------------------------|---------------------|------|--|------|---------------------------------|----------------|------|-------------------------|
| Rating                       | Original Values |                         | Increase in Environmental Criteria 10% |      | Increase in Social Criteria 10% | Original Values     |      | Increase in Environmental Criteria 10% |      | Increase in Social Criteria 10% |                |      |                         |
| 1.                           | DMU * 17        |                         | DMU17                                  |      | DMU17-DMU1                      | DMU17               |      | DMU17                                  |      | DMU17                           |                |      |                         |
| 2.                           | DMU2            |                         | DMU6                                   |      | DMU17-DMU1                      | DMU6                |      | DMU3                                   |      | DMU6                            |                |      |                         |
| 3.                           | DMU16           |                         | DMU3                                   |      | DMU3                            | DMU16               |      | DMU6                                   |      | DMU16                           |                |      |                         |
|                              | DMU1            | DMU3                    | DMU1                                   | DMU2 | DMU2                            | DMU1                | DMU2 | DMU3                                   | DMU1 | DMU2                            | DMU1           | DMU2 | DMU3                    |
| Rating                       | Not opt.        | Not opt.                | 4.                                     | 5.   | 6.                              | Not opt.            | 4.   | Not opt.                               | 4.   | 6.                              | Not opt.       | 4.   | Not opt.                |
| Opt. Peers                   | DMU14<br>DMU18  | DMU14<br>DMU18<br>DMU24 | -                                      | -    | -                               | DMU14<br>DMU18      | -    | DMU14<br>DMU18<br>DMU24                | -    | -                               | DMU14<br>DMU18 | -    | DMU14<br>DMU18<br>DMU24 |

\* Decision Making Unit (DMU).

The fictional DMU<sub>17</sub> is the best in all simulations, although its characteristics are not the best in all domains of sustainability. This fact leads us to suppose that in this situation, the right balance between the desirable and undesirable characteristics is optimal; the increase in value in only one dimension of sustainability is not rewarded. From the municipality's point of view, DMU<sub>3</sub> has characteristics to reach third place in case of an increase in social or environmental criteria. If the municipality selects the provider only according to its own needs and environmental requirements or recommendations of the Slovene state or the European community, then DMU<sub>3</sub> has the best predispositions for the future. This is a very likely scenario, at least in the near future.

Surprisingly, from the point of view of e-BSS users, only DMU<sub>17</sub> manages to maintain the first place. DMU<sub>3</sub> advances by one place in case of an increase in environmental criteria by 10%. When social criteria are increased by 10%, however, it falls out of the game. This fact again confirms our prediction that DMU<sub>3</sub> has most probably the best opportunities in the future, despite entirely different requirements of users.

## 6. Conclusions

The sustainability of e-BSS depends to a large extent on the requirements of the investor and the implementer of the system, which have to be reconciled with the needs of key stakeholders of the e-BSS system (government agencies, e-bike users, etc.). However, this poses a major challenge for investors, as there is neither a set of e-BSS features expected by the main stakeholders, nor a methodology to select a sustainable provider able to meet most of the requirements of all stakeholders.

Therefore, the authors of this paper first presented a complete set of e-BSS characteristics, consisting of 22 criteria from all three domains of sustainability (social, environmental, and economic). Using a new methodology—DAHP—the weights of the criteria were calculated separately for two groups of stakeholders directly from the survey statistics rather than from pairwise comparisons. A survey revealed that the needs of e-bike users are quite different from the needs of municipalities. Environmental criteria are especially important for municipalities, but not for e-bike users. In their opinions, economic criteria are much more important, followed by environmental criteria. However, both groups believe that social criteria are the least important. Even within one dimension of sustainability, the importance of criteria differs between the two groups of stakeholders. These results correspond to RQ1, and to some extent also to RQ2, and also illustrate that when selecting a provider, the needs of all stakeholders involved should be taken into account to ensure a sustainable e-BSS.

To answer RQ2 overall, an SBM DEA and a super-efficiency measure were proposed for three reasons: (1) SBM DEA has greater discriminatory power and also detects more sources of inefficiency compared to other DEA radial models; (2) the method allows the division of outputs into desirable and undesirable without assuming a connection between them; (3) a super-efficiency measure allows the classification of efficient DMUs. However, the main added value of the method is the ability to adapt it to the needs of predefined groups of stakeholders using slack variables.

The first contribution of the paper is a comprehensive criteria system for the evaluation of the e-BSS provider. The criteria system considers all three pillars of sustainability and reflects the essential needs and requirements of the different groups of e-BSS stakeholders. These are the most important extensions and improvements of the criteria system presented in this article with the only two currently available lists of criteria proposed by Tian et al. (2018) [32] and Liu et al. (2020) [30].

A novel DAHP model is the second contribution of a paper. The proposed method is very close to VAHP. However, DAHP maintains the AHP maximum eigenvalue consistency check and also eliminates time-consuming pairwise comparisons. The DAHP model enables separated criteria ranking for different groups of stakeholders, comparing weights of criteria and taking into account the needs of all stakeholders as inputs and outputs of SBM DEA, which also includes super-efficiency measures. The slack-based DEA is not a new method, but this paper will first address practical issues of local authorities who are not normally familiar with very complex MCDM calculations. The method is also forward-looking. It integrates sustainability issues such as unwanted and imprecise data. The model is flexible and allows for the addition of additional criteria and stakeholder groups.

A multi-method approach presented in this paper allows the selection of a provider to make such an e-BSS system available for the benefit of all stakeholders. Such a win-win approach thus increases the sustainability of e-BSS. Indeed, the model presented provides suggestions for e-BSS providers to improve their efficiency and performance for all stakeholders involved (see Table 6).

A system of criteria will benefit not only municipalities but also policymakers to calibrate such measures that help to minimise the negative impacts and maximise the use of e-bikes activities and their positive effects on the neighbourhood and e-bike users.

However, despite the added value of the article, future improvements would be useful in the following directions. First, the scope of this study was limited to e-BSS providers, e-bike users, and municipalities in Slovenia (see Table 5). Therefore, the results cannot be generalised and need to be tested in other countries with different requirements and stakeholders. However, the list of criteria for the selection of the provider is based on an extensive literature search of exclusively international publications (see Table 1). Otherwise, the already significant number of articles we found with phrases presented in Section 3.1 could perhaps be further increased by using additional phrases, e.g., sustainability criteria instead of sustainable criteria. Furthermore, the methodology presented in this article

could be used in any future studies that refer to a sharing system or other provider selection problem, generally involving several stakeholders.

Secondly, the proposed approach highlights and compares the requirements of the two groups of stakeholders but does not lead the investor or implementer of e-BSS to a final decision on the most suitable provider (see Table 5). This means that the balancing of the different criteria and weights remains the responsibility of the investor. In the future, it would be necessary to improve a tool that guides the investor to a balanced final solution.

Thirdly, the comprehensiveness of the sustainable criteria set for selecting an e-BSS provider can be further enhanced by the use of all STEEP's domains and also by the use of two additional analytical frameworks (SDG and MONET).

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