

An Approach to Develop the Sustainable Warehousing Assessment Model

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Abstract. The aim of the article is to present an approach to define the set of criteria applied to create the sustainable warehousing assessment model. The criteria were identified on the basis of expert analysis and the literature review including the scientific approach as well as standards applied for the purpose of assessing the level of sustainable buildings. It allowed to include in the proposed model the broad spectrum of factors, which affect the warehousing sustainability in economic, social and environmental aspect. As a solution utilized for the purpose of sustainable warehousing assessment model creation the COMET method (characteristic object method) was applied. This constitutes the basis for applying the fuzzy set theory to propose the characteristic of each criteria used for the assessment.

1 Introduction

However the problem of sustainable development was firstly discussed 300 years ago by Hans Carl von Carlowitz, the term became popular in 80-ties of the last century [1]. Firstly joined with the ecology, due to conducted research was considered taking into account its interdisciplinary character, manifesting the need for integration in key areas: economy, society and environment [2].

Nowadays, the sustainable development is more often used in logistic due to the fact that it is the human activity present and influencing at various areas of our life. In the mid-2000s, the concept was highly promoted regarding to building and modernizing warehouses and distribution centers towards environmentally-friendly solutions, reducing operating costs and creating more favorable working conditions. However the global slowdown in economic growth slightly weakened this trend, the idea to apply in warehouses the solution, which are increasing the level of sustainability is still the focus of interest for many companies [3]. More and more popular is becoming the certification of warehouses on the basis of existing building standards.

This article also considered the issue of assessing the level of sustainability in the context of warehousing and presents an approach for description of criteria that are taken into account as field of measurement.

2 Literature review

The sustainable development is today widely discussed in various areas of business activities. On the field of logistics, there are many research considered in particular the sustainable supply chain management or sustainable

transport system. There are also some studies focusing on the context of sustainable warehousing area to create a unit equipped by appropriate technological and organizational solutions, which allows to operate maintaining the high standards of work, reduce the negative impact on the environment and achieve the lower cost of its functioning [4]. This assumptions are compatible with the considerations of sustainable warehouse given by Żuchowski, which requires "a set of organizational and technological solutions whose aim is to efficiently execute warehouse processes, with the highest social standards met, with the lowest possible environmental impact and taking financial effectiveness into account" [1]. However this definition indicates different dimensions of sustainability concerning the building design, application of advanced technology to support the warehouse processes and application of social policy to ensure higher standards of work, nowadays the problem of sustainability of warehouse is measured taking into account the existing building certification standards: BREEAM (Building Research Establishment Environmental Assessment Methodology), LEED (Leadership in Energy and Environmental Design), HQE (Haute Qualité Environnementale), DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen) [5-7]. This standards require that location, design, construction, maintenance and demolition of the building should provide the effective utilization of energy, water and materials which in consequence contribute to provide benefits for owners, higher social standards, better financial effectiveness and more environmental friendly environment. The most often applied certification systems are LEED and BREEAM.

LEED [6-7] (v4 version) takes into account 9 categories with specified aspects which are the basis of

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the assessment: an integrative processes (e.g. the ability to use innovative approaches to design and construct the building, selection of a project team), location and transportation (e.g. neighborhood location, efficient transportation options), sustainable sites (e.g. minimization of pollution, naturally inclusion to ecosystem), water efficiency (e.g. reduction of water consumption, application of innovative technologies to avoid wastage of water), energy and atmosphere (e.g. use of the renewable energy sources, optimization of energy consumption, application the technological solutions to reduce energy consumption), material resources (e.g. utilization of recycled materials, use of certified materials), indoor environmental quality (e.g. ventilation system efficiency, possibility of temperature control, CO₂ monitoring), innovation in design (aspects not included in the basic criteria), regional priority (entering the regional strategy). BREEAM [6-7] distinguishes the following categories: management (e.g. overall management policy, site management, procedural issues), energy (e.g. CO₂ emission, light energy consumption), health and wellbeing (e.g. amount of daylight in rooms, temperature and air quality, acoustics), materials (e.g. use of materials obtained from legal and local sources with appropriate ecological certificates), transport (e.g. CO₂ emission, location-related factors), water (e.g. application the solutions limiting water consumption), waste (e.g. applied waste management policy), pollution (e.g. water and air pollution impact), land use and ecology (green areas management, biodiversity of flora and fauna).

The analysis of given standards lets to notice that the considered aspects affecting the sustainability are convergent in both cases. However they are focused on the construction of buildings and do not relate to specify of warehouse and the realized processes. The criteria like water and energy consumption, air quality, application of environmental friendly materials or land development are required to be the core of prepared warehouse assessment model, but the way they are measure and the given scale must refer to warehouse conditions.

As indicate [4] and [8], the concept of sustainable warehousing goes beyond the building facilities. [4] described eight sustainable warehousing constructs within which there are included elements presenting various dimensions of sustainability. It allows to propose best practice activities, that can be used as a roadmap for setting future targets and goals towards achieving higher level of sustainable development.

The above remarks were the basis to elaborate a model which assesses, from one side, the warehouse building facilities in accordance with the sustainable development needs and from the other side the way of warehouse equipment and management [9]. Such a model can be applied to compare the sustainability level between different warehouses as well as can be implemented as a tool of self-assessment of the unit aiming the improvement of various aspects of sustainable development.

3 An approach for identification and application of criteria for the purpose of

sustainable warehousing assessment model

The final aim of the conducted research is to propose a model, that allows to measure the level of sustainable warehousing. To create such a model it is necessary to indicate the dimensionality of the problem and for this purpose identify the set of criteria which will be the basis for the assessment. An attempt to construct a model has been taken and is presented in [9].

An applied method of model creation is COMET (the Characteristic Objects Method). The COMET method is a multi-criteria decision-making method (MCDM), which is an alternative approach for AHP, TOPSIS, ELECTRE or PROMETHEE methods and allows to eliminate the phenomenon of rank reversal [10]. In accordance with the COMET method 5 steps are required to be carried out [11]:

- defining the space of the problem by determining the dimensionality of the problem (set of criteria) and a set of fuzzy numbers for each of the criteria,
- generating characteristic objects on the basis of Cartesian product,
- determining the Matrix of Expert Judgment to rank and evaluation of the characteristic objects,
- conversion of each characteristic object and preference value into a fuzzy rule.
- inferencing in a fuzzy model and final ranking.

Applying the COMET method lets to create the series of individual models as a result of partial aggregation and finally the group model, which allows to inference on the given problem.

The first step of the method requires to determine the set of criteria and appropriate set of fuzzy numbers for each criteria. The set of fuzzy numbers is presented in natural language. Each fuzzy number is determined by a membership function. The membership function $\mu_A(x)$ describes the membership of the elements x of the base set X in the fuzzy set A .

The functions assigns to elements of X the values from the interval $[0,1]$. In this case the membership function is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1 [12]. It cause that fuzzy sets allow elements to belong to a given set with a certain degree. It is the role of expert to define the fuzzy numbers and appropriate membership functions. In case of sustainable warehousing assessment model this step is crucial for further analysis, because it creates the background for generating the characteristic objects and their ranking and evaluation. The experience and knowledge of experts engage in model creation, and in particular in description of the

As show [12-14], there are many types of membership functions e.g. triangular, trapezoidal, Gaussian, generalized bell, π -shaped and s-shaped membership function. However, the description of criteria applied to create the sustainable warehousing assessment model is based on the trapezoidal and triangular functions. In general, the use of a more complex function does not give increased precision, so triangular and trapezoidal

functions are commonly used and quite well adapt to such a problem.

A triangular membership function $\mu_A(x)$ is given as follows [14]:

$$\mu_A(x) = \begin{cases} \frac{x - a_1}{a_2 - a_1}, & \text{for } a_1 < x < a_2 \\ \frac{a_3 - x}{a_3 - a_2}, & \text{for } a_2 \leq x < a_3 \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

where:

$$A = (a_1, a_2, a_3) \\ x, a_1, a_2, a_3 \in R \\ a_1 < a_2 < a_3$$

A trapezoidal membership function $\mu_A(x)$ is given as follows [14]:

$$\mu_A(x) = \begin{cases} \frac{x - a_1}{a_2 - a_1}, & \text{for } a_1 < x < a_2 \\ 1, & \text{for } a_2 \leq x \leq a_3 \\ \frac{a_4 - x}{a_4 - a_3}, & \text{for } a_3 < x < a_4 \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

where:

$$A = (a_1, a_2, a_3, a_4) \\ x, a_1, a_2, a_3, a_4 \in R \\ a_1 < a_2 < a_3 < a_4$$

Application the fuzzy sets and identification the criteria using the linguistic data lets to define the space of considerations of each criteria and simultaneously reduce the dimensionality of further analysis. However, this step require the precisely description of applied measure for each criteria and a given scale as well as such assignment the linguistic values to this scale, that it will properly represent the range of applicable linguistic values.

The other issue is to guarantee the appropriate spectrum of criteria, which will allow inference about the level of sustainable warehousing. From the sustainable development point of view this criteria should include environmental, social and economic dimensions of sustainability. Considering it in case of warehousing, it is required to choose the element regarding to the building design as it is posted in standards as well as technical issues and social policy aspects, which influence on the way the warehouse processes are organized and the resources applied and consumed.

4 Results

Elaborating the model assessing the level of sustainable warehousing was made with the following steps:

- analysis the sustainability in the context of warehouse organization and realization of warehouse processes,
- selecting the set of factors (criteria) influencing the sustainable warehousing based on literature review

and expert analysis and considering their impact on economic, environmental and social aspects of sustainable development,

- indicating the measurement scale for each criteria,
- indicating the linguistic scale for each criteria,
- applying the criteria for the purpose of sustainable warehousing assessment model in accordance with COMET method.

The literature review and expert analysis let to identify 22 criteria, which should be taken into account for the purpose of model creation [9]. The spectrum of criteria is presented in Table 1.

Table 1. The range of criteria of sustainable warehouse management assessment model.

Name of the criteria	Meaning of the criteria in the model	Field of warehousing assessment
the use of energy-saving and ecological lighting	the level of certified energy-saving lighting application (eg. LED),	Building design
the use of automatic lighting control devices	the level light sensors application	Building design
the roof surface covered by skylights	the level of roof skylights installation	Building design
light transmittance in skylights	the level transparency glazing (in accordance with the requirements of stored products)	Building design
the use of renewable energy	the level of application the energy from renewable sources comparing to energy from traditional sources	Building design
the use of alternative water sources	the level of rainwater utilization in water consumption	Building design
the use of mechanisms reducing the water flow	the level of sewage points equipped with mechanisms reducing water flow	Building design
the level of building insulation	the thickness of installed insulation	Building design
the use of automatic temperature control devices	the percentage of warehouse area where the possibility of automatic temperature control is given	Building design
the use of air purification methods and tools	the level of purification systems applied in the warehouse	Building design
the use of environmental friendly materials in building structure	the level of the use of pro-ecological materials in the construction of the building	Building design
environmental friendly plot area	the level of biologically active plot area with a diverse flora with low water demand	Building design
level of automation	the level of technological advancement of devices used in the warehouse	Warehouse equipment

IT level	the level of functional complexity of IT systems used in the warehouse	Warehouse equipment
effective inventory control	the level of application the inventory management methods in planning, inbound, storing, picking, and outbound	Warehouse equipment
distance reduction during warehouse operations	the level of application the methods used to orders consolidation, picking paths optimization, picking zones creation	Warehouse equipment
employees' training regarding to recycling and sustainable development	the percentage of employees taking part in training in the field of recycling and principles of sustainable development	Human policy
employees' training regarding to material handling equipment (MHE)	the percentage of employees taking part in training in the field of MHE	Human policy
the use of low-emission moving around the warehouse	the percentage of drivers certified in low-emission driving	Human policy
recycling of packaging and returns	the level of the utilization of returns and recycled materials	Human policy
organization of the employee-friendly zones	number of employees-friendly zones/rooms	Human policy
applying health and safety policy	the level of the quality of the health and safety protection policy	Human policy

The criteria refer to both the technologies and materials used for designing and building the warehouse as well as applied equipment (advancements and application), procedures and standards to promote environmental friendly behaviors and better organization of processes and work conditions.

In accordance with characteristic object method the scale and set of fuzzy numbers was defined. On the figure 1 and figure 2 are presented two examples of the fuzzyfication of two criteria: 1. employees' training regarding to recycling and sustainable development, 2. the level of building insulation. The presented examples concern different issues of sustainability. The first one lets to assess the element of building design and construction and the second one refers to increasing the awareness of people working in warehouse and can be perceived as a part of human policy applied in the organization.

A scale was indicated for each criteria and expressed in natural language using a set of fuzzy numbers. There were three fuzzy numbers in each presented criteria. The membership functions (trapezoidal and triangular) were given in accordance with expert opinion based on his/her knowledge and experience.

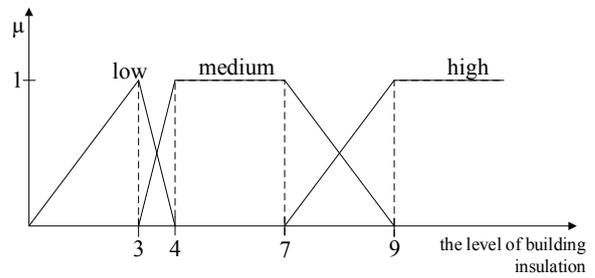


Figure 1. The criteria of level of the building isolation defined in accordance with the fuzzy sets methodology (source: own elaboration)

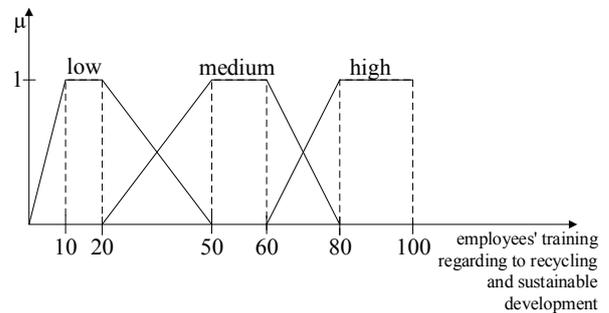


Figure 2. The criteria of employees' training regarding to recycling and sustainable development defined in accordance with the fuzzy sets (source: own elaboration).

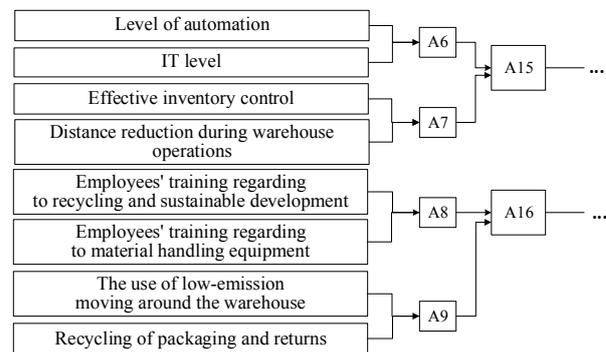


Figure 3. The fragment of aggregation of criteria applied to create the sustainable warehousing assessment model (source: own elaboration)

However the membership function, which determine the fuzzy set is subjective, it makes the foundation for further research. It is possible to verify and change the set of fuzzy numbers used for each criteria as well as the distribution of the membership functions. The changes in this step might be the source of improvement of the sustainable warehousing assessment model.

The method requires, to give the final grade of sustainable warehousing, the creation of successive aggregates built on the basis of selected criteria. The role of the expert is to judge the created object by determining the Matrix of Expert Judgment. In sustainable warehousing assessment model there were established 19 objects. The fragment of prepared aggregation is presented on figure 3.

The object A8, named environmental awareness, was built using the criteria employees' training regarding to recycling and sustainable development (presented on

figure 2) and employees' training regarding to material handling equipment. The final ranking allows to determine the level of sustainable warehousing using the 5-elements scale expressed in natural language: very low level of sustainability, low level of sustainability, medium level of sustainability, high level of sustainability, very high level of sustainability.

4 Conclusions and Future Research

The growing importance of sustainable development issues causes that in the literature there are many studies which has on aim offering the solutions helping to achieve balance between environmental, social and economic dimensions.

The article presents the original approach to apply the COMET method for the purpose of sustainable warehousing assessment model elaboration. It is indicated, how to utilize the fuzzy set theory to describe the criteria, that are the basis of the assessment and the Matrix of Expert Judgement to reduce the multifurthy of conclusions. The achieved results show that COMET method lets to provide the final model, however, because is based on the expert description of the space of the problem, it is necessary to verify the adopted assumptions of criteria description. The proposed model can be an important step towards finding the measure tool of sustainable warehousing, and the selected criteria may be utilized as indicators showing the directions of improvements implementation to achieve the higher grade of sustainability. The next step of the research is focused to check the complexity of the criteria and the established scales.

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