Prethodno priopćenje

ODABIR OPCIJE UPRAVLJANJA OTPADOM HRANE METODOM PROMETHEE

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Sažetak: Rješavanje problema otpada hrane u skladu sa strategijom kružnog gospodarstva je složen problem na malim otocima. Postoji nekoliko standardnih postupaka za rješavanje problema, ali i dva specifična koja je nužno uzeti u obzir. Jedan je ispuštanje usitnjenog otpada hrane u kanalizacijski sustav, a drugi je transport otpada na kopno u regionalni centar. Svaki postupak ima svoje prednosti i nedostatke u odnosu na cilj rješavanja problema. Problem se stoga mora rješavati cjelovito sustavnim pristupom, a izbor prihvatljivog rješenja primjenom višekriterijskog postupka. U ovom radu takovi postupak je primijenjen na rješavanje problema na primjeru otoka Visa. Dobiveni rezultati pokazuju da je rješenje sa ispuštanjem otpada hrane u lokalni kanalizacijski sustav najprihvatljivije te da u cijelosti zadovoljava ciljeve kružnog gospodarstva. Korištenje metode PROMETHEE za izbor optimalne opcije se pokazalo vrlo praktično i korisno.
Ključne riječi: višekriterijska analiza, PROMETHEE, gospodarenje otpadom hrane, mali otoci, kružno gospodarstvo

SELECTION OF THE FOOD WASTE MANAGEMENT OPTION BY PROMETHEE METHOD

Abstract: Food waste management performed in accordance with the EU Circular Economy Strategy principles poses a problem to small islands. There are several standard food waste management methods on islands; however, there are also two specific methods which have to be taken into consideration as well as all positive and negative impacts. These two specific methods are: food waste discharge into the city sewer system and transport to the mainland, i.e. to regional waste processing facilities. In this paper a multi-criteria decision analysis is presented to evaluate different waste management options and their applicability in small islands as it is Vis. The results of this study show that the solution in which food waste is discharged into the city sewer system and processed with wastewater through wastewater treatment turned out to be best food waste treatment option for small islands. The used PROMETHEE method has proved to be very useful tool in solving the problem.
Key words: multi-criteria decision analysis, PROMETHEE method, food waste management, small islands, Circular Economy

1. Introduction

The EU Circular Economy package [1], i.e. the Circular Economy Action Plan provides for 50% waste reduction, conversion of waste into resources, cessation of waste disposal in landfill sites by 2030, and energy recovery which includes waste-to-energy generation and the use of biofuels. The aim is to reduce food waste generation as much as possible in the entire supply process. The islands are characterised by their isolation from the mainland, sparse permanent population, and a large and rapid increase in population and in number of tourists during the summer season. In such environments a large quantities of food waste are generated during summer which must be managed. This paper presents the application of PROMETHEE method in the selection of solution for island Vis.

The generated waste should be treated and disposed of in accordance with the waste hierarchy [2]. The food waste management hierarchy is similar to the waste hierarchy for food waste defined in the Waste Framework Directive [2] (WFD), Figure 1. The food waste have to be re-used wherever possible, recycled into animal feed or recycled via composting into a new process of plant food production, recovered into energy product by using biogas from anaerobic digestion, and at the end of the hierarchy the amount of unavoidable waste should be disposed of with the use of landfill biogas. Standard food waste treatment processes are used: anaerobic digestion, composting, and the disposal of waste with the use of landfill gas. Incineration of food waste is one of the options; however, it is always performed with other combustible wastes. The mere incineration process of organic matter is not neutral due to carbon emissions and therefore it should be avoided.

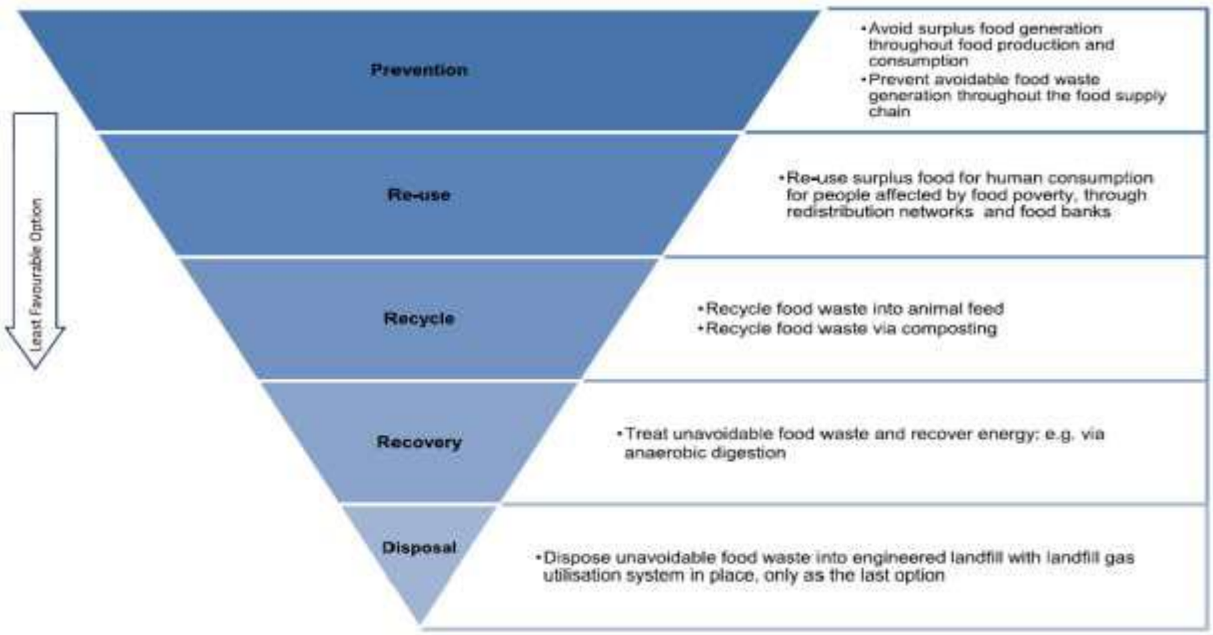


Figure 1. Interpretation of the waste hierarchy for food waste [3]

From the point of view of environmental protection, the abovementioned waste treatment processes have different impacts on climate change, the amount of nutrients and their reuse, primary energy use, the ozone layer, etc. It is therefore advisable to determine the net effect on the environment by applying the Life Cycle Assessment (LCA) methodology [4]. Likewise, the economic efficiency is significantly different, and the unit price for treated waste (euro/kg) depends heavily on the capacity of the facility. The solution of food waste storage prior to the treatment and storage of waste treatment products (compost, sludge, energy, gas, heat) has a significant effect on the overall system efficiency. These are all important technological characteristics of the process which should be taken into consideration when selecting the solution.

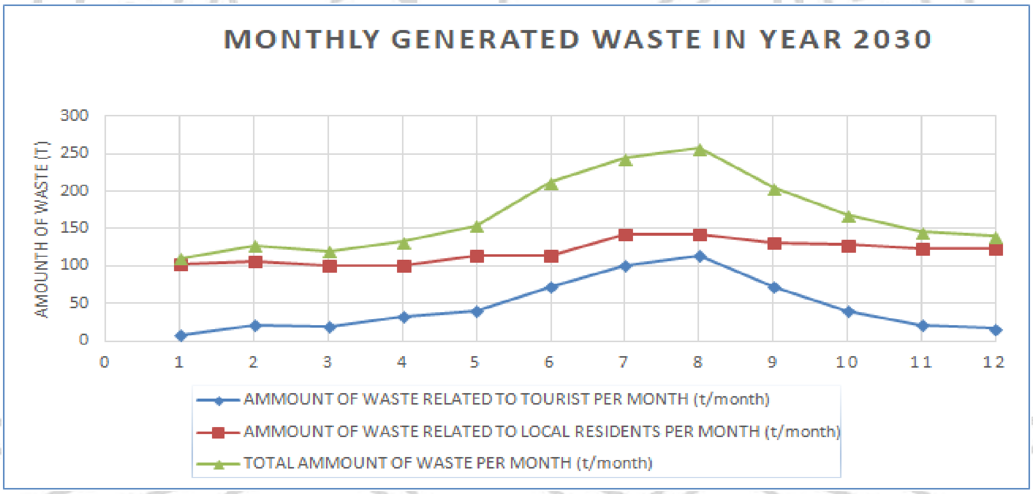
Storage, collection, transportation and transfer of wet and rapidly decomposable waste are a complex task. It is best to organise the separation of food waste at source, and to prevent wastage in the process of collection, transport and preliminary treatment. Food wastage generation results in environmental pollution, and in resource, energy and/or nutrient loss. The worst option is the mixing of organic waste with other municipal waste types, because it also reduces the value of other types of waste. In this case, the entire process is more expensive than in the case of a separate treatment.

Separate collection of organic waste makes it easier to handle, thus enhancing the potential for reuse. Storage, collection, and transportation of kitchen waste require the use of special technology, all in order to decrease adverse environmental impacts. The entire collection and transport system takes place in sealed containers in order to prevent contact with animals, and to control gas and wastewater discharge into urban environments. If waste is stored for a longer period of time in a certain location, the rate of decomposition decreases, resulting in decrease in gas production and wastewater generation; furthermore, it most often requires drying or the addition of certain substances.

In addition to these systems, a system in which grinded organic kitchen waste and food are directly discharged into the sewerage system is also used. Such a system has long been used in the USA and only to a lesser extent in the EU. Such system does not require local storage and transport and has specific advantages and drawbacks [5].

2. Waste generation and characteristics at island Vis

The amount of waste generated in 2016 is 1,658 t/a, (data from the local waste management company Gradina d.o.o.) and the planned amount of waste, which is projected for 2030, is based on the population growth rate of 0.3%, a 1% growth of overnight stays and the amount of 0.9 kg/day/capita and 1.2 kg/day/overnight stay, Figure 2. A seasonal balance is presented in Table 1.



Graph 1. The projected monthly generated waste in year 2030

Average annual quantity of food waste generated per day amounts to 2.3 (t/day); furthermore, average quantity during winter is 1.88 (t/day), and during summer 3.14 (t/day). Estimated annual quantities of waste are 828.2 t/a.
The island of Vis and other Croatian settlements since 2016 have been required to address the issue of waste in accordance with the Circular Economy and other relevant guidelines and regulations. Namely, glass, paper, cardboard, plastics, metal, clothing and footwear needs to be collected separately.

Table 1. The projected amounts of kitchen waste during high season and off-season for 2030

Types of waste	%	Total t/a	Off-season (1,102 t) (October – May)			High season (918 t) (June-September)		
			Average amount (t/day)	Average amount (t/month)	Amount (t/a off-season)	Average amount (t/day)	Average amount (t/month)	Amount (t/a high season)
Kitchen waste	41,0	828,2	1,88	56,48	451,82	3,14	94,1	376,38

These are dry components in municipal waste which can be stored in an easier manner and for a longer period of time without adverse environmental impacts. Their volume is reduced by compaction at source or after collection; in addition, they are baled/packaged for efficient storage and transport. When sufficient quantities are accumulated, the waste is transported to the mainland for further processing and sales. This is the usual procedure for managing segregated dry municipal waste. The solution is in accordance with the Circular Economy Action Plan and guidelines, thus it can be concluded that the issue of this waste has been resolved.
In the event of mixed waste generation, separation of waste on the island or transport of mixed waste to the mainland should be organised. This is, in principle, an environmentally and economically less acceptable solution than source separation of waste and is therefore not recommended. Namely, Waste management plan in Croatia recommend the source separation as the best solution [6]. Transport to the mainland is more expensive because it requires long distance transport and usage of the ferry, which results with even bigger emission of greenhouse gases and other negative impacts.

The objective of managing organic waste on the island of Vis is to achieve local, regional and global environmental protection and sustainable development, including the direct realisation of an organic waste management strategy through the most efficient, cheapest and environmentally and socially acceptable waste treatment technology.

3. Possible options and their characteristics

There are two basic strategic options: (i) local organic waste management, or (ii) organic waste management on the mainland. Option "transportation to the mainland" ™ consist of: local storage, local treatment-drying, local tanker-truck transport, transport to the mainland, transport from the port to regional centre.

Local management implies that the entire organic waste can be collected and transported on a daily basis, while regional management includes local collection, storage, and occasional ferry transport to the mainland, truck transport to the collection centre and treatment in accordance with the regional centre technology. In order to ensure organic waste is managed on the mainland it is necessary to transport it on a daily basis or occasionally. Occasional transport requires local storage whose application requires local treatment of the collected waste in order to slow down or stop the decomposition process. Transport of organic waste must be adapted for such type of cargo (wet/muddy material which decomposes and generates toxic and flammable gases). It is assumed that the treatment of organic waste on the mainland will be carried out by using probably by anaerobic technology.

Three basic alternatives for the treatment of waste have been adopted for local management on the island: (i) the classical biological process; (ii) kitchen waste disposed of via sewer(the wet process) , (iii) thermal process (incineration).

The thermal process alternative which may be carried out is not realistic. Due to a relatively small amount of waste the process is unsustainable/unprofitable on the island. In addition to the abovementioned, the elimination of bio-waste with the use of energy is considered to be the last acceptable option which is in accordance with the Circular Economy guidelines. Therefore, this alternative for the treatment of waste is excluded as to be unrealistic for the island of Vis to include in the further analysis. For further analysis following local alternatives are accepted: composting, anaerobic digestion, and the wet process.

The use of food waste disposers in kitchen sinks has several possible sub-variants of the grinded wet organic waste collection: (i) directly by sewage and wastewater to the local municipal wastewater treatment plant, (ii) by vacuum system to a certain location with the container, and afterwards by occasional transport to the nearest sewerage system and to either local or regional plant, (iii) by local collection and storage in containers from which the fluid is discharged into the sewer, and the sludge is transported by tankers to the local or regional sludge treatment plant.

The manner of collecting will depend on the development and availability of the sewerage system and plant. In the case of the island of Vis by 2023, a sewerage system and a suitable plant for the City of Vis and Komiža will be built and most of the facilities will be connected to the sewerage system. Other isolated housing units will use septic tanks or holding tank which will be adequately managed, possibly by discharging into the local municipal wastewater treatment facilities. Therefore, it is not realistic to build vacuum systems for the transportation of wet organic waste, or special plants for their collection and further transportation. It is assumed that the kitchen sink waste will be transported after grinding either from local septic tanks or municipal sewerage system by sewer to the municipal wastewater treatment plant. It is a simple and reliable solution with the least adverse environmental impact and is therefore adopted for further analysis. Kitchen bio-waste generates BOD_5 in the value of about 0.25 PE [7]. This means that the discharge of kitchen waste into the sewer will increase the capacity of the plant by 25%. The long-term capacity of the plant is about 3,000 PE. By discharging the organic solid kitchen waste, the capacity will increase by 25% (3750 PE) and will not exceed the number of 10,000 PE; hence, the construction of plant with higher level treatment will not be required (secondary level of treatment).Ultimately, organic kitchen waste will be processed with the primary sludge separated at the municipal plant. Nitrate-rich sludge, which can be used as a fertiliser in agriculture by further processing, is obtained at the treatment plant by discharging food waste into a sewerage system.

Other methods that will be evaluated as part of the local solutions are classical biological methods of anaerobic digestion and composting. Each solution, a system, consists of the following elements: (i) storage at source; (ii) storage outside the housing facilities, collection and transportation of waste including transfer stations if necessary; (iii) processing and the use of waste. For each of the alternatives all the impacts have been assessed and values of the criteria defined which are used to evaluate possible solutions. A solution which was adopted due to a small number of users and the distance from the system is: local collection in paper bags and disposal in special containers outside the residential area including waste collection on a daily basis. A facility for slowing down the decomposition process is not envisaged due to the short-term waste retention (less than 24 hours).

Only one organic waste treatment facility is envisaged for the entire island. The following technologies are taken into account: outdoor static pile composting (OC), indoor composting with forced aeration (IC), and an anaerobic digester with high solids concentration in a damp and muddy condition (AD). The characteristics, advantages and disadvantages of selected technologies have been identified, mainly with the data from literature, taking into account the local characteristics of the area, climate and the amount of waste.
In accordance with the aforementioned, five realistic options are analysed for the island of Vis. The determined values of each criterion are given in Table 2.

4. Selection of the solution

4.1. Methodology

The quality of the results is always in the function of the quality of input data. Collecting numerous data is complex, time-consuming and expensive. Therefore, the analysis is often carried out in two basic steps, as the preliminary analysis and as the final. This paper presents data related to the preliminary level of problem solving.

Four aspects of sustainability of the solution were used: technological, economic, ecological and social. The respective criteria were selected for each aspect. A total of 21 indicators were used in this example. One part of the criteria is numerically defined while the other is defined qualitatively by using the scale of 1-6, Table 2. This paper presents the selected criteria which reflect the essential characteristics of the problem being solved.

The choice of relative weight *(w)* is an important element of the multi-criteria analysis. Different stakeholder groups have different preferences in relation to individual criteria groups and it is therefore difficult to achieve consensus. Several methods can be used in order to determine weight. In this paper, a simplified approach was used in which the opinions of individual stakeholder groups and of experts were used. The final values were determined by the "Rank-order weighting method" and the process of pairwise comparison. In this method, the weights are distributed as:

$$w_1 \geq w_2 \geq w_3 \geq \ldots \geq w_n \geq 0; \quad \sum_{i=1}^{n} w_i = 1 \qquad (1)$$

Weight and weight coefficient were assigned to each individual group of criteria based on the opinions of stakeholders and experts by performing a simplified pairwise comparison.

Finally, a certain percentage of preferences were assigned to a particular set of criteria, economic 23% (0.23), environmental 25% (0.25), social and local 15% (0.15), wider/external 15% (0.15) and technical-technological 22% (0.22), which has been subsequently distributed to individual criteria according to the number of criteria of each group. These preferences are selected on the basis of expert judgment based on experience from other similar projects and consultation with local stakeholders:

$w_i^m = \frac{w_i}{m}$, where m is the number of criteria in the group w_i (2)

With regard to the sensitivity of the multi-criteria analysis process to these values, it is desirable to carry out an appropriate sensitivity analysis of the results which has been performed in this paper.

Multi-criteria problem analysis can be performed using various methods [8]. Each of them has certain advantages and disadvantages in relation to the problem being solved. The problem of ranking alternative waste management solutions does not always have all the comparable characteristics. In such cases, outranking methods are applied. The method called Preference Ranking Organisation Method for Enrichment Evaluations (PROMETHEE) is one of them [9]. The underlying basis of this method is the construction and the exploitation of outranking relations. An outranking relation S is a binary relation which is defined on the set of alternatives A such that for each pair of alternatives $(A_i, A_k) \in AxA : A_i S A_k$ if, given what is established concerning/known about the preferences of the decision-maker, the quality of evaluation of the alternatives and the nature of the problem under consideration, there are sufficient arguments to conclude that the alternative A_i is at least as good as the alternative A_k, while at the same time no strong reasons exist for rejecting this conclusion.

Based on the input data provided in Table 2. and the selection of the abovementioned function, the obtained results are shown and commented below.

Table 2. The input data

		OPTIONS						
Criteria	Indicators	Outdoor composting	Indoor composting	Anaerobic digestion	Wet process	Transportation to the mainland	Weight coefficient	min/max
THE ECONOMY ASPECT 23%	Cost authority for waste treatment €/t	45,0	60,0	55,0	45,0	55,0	6,00	min
	Costs of fuel l/t	1,5	1,5	1,5	0,0	6,0	5,00	min
	Cost for society of waste treatment €/t	45,0	60,0	80,0	55,0	85,0	6,00	min
	Cost of collection and transport	105,0	105,0	105,0	10,0	150,0	6,00	min
THE ENVIRONMENTAL ASPECT 25%	Environmental load	4,0	5,0	6,0	6,0	3,0	5,00	max
	Odor	2,0	4,0	5,0	5,0	4,0	2,50	max
	Noise	4,0	5,0	4,0	4,0	3,0	2,50	max
	Traffic	3,0	4,0	3,0	4,0	3,0	2,50	max
	Visual and landscape impact	1,0	2,0	3,0	4,0	3,0	4,00	max
	Time/space for home waste	5,0	5,0	5,0	6,0	5,0	2,00	max
	% work force hired locally	90,0	80,0	80,0	30,0	30,0	2,00	max
	CO_2/t emission of processed waste	600,0	400,0	100,0	100,0	100,0	4,50	min
THE LOCAL SOCIAL ASPECT 15%	Accident rate of workplace	1,0	1,0	2,0	1,0	2,0	5,50	min
	Occupational risks	3,0	2,0	3,0	5,0	3,0	5,50	max
	Labor intensity	2,0	3,0	4,0	5,0	4,0	4,0	max
THE WIDER SOCIAL ASPECT 15%	Green job per € invested	2,0	2,0	3,0	4,0	4,0	7,50	max
	Tech innovation in treatment over time	3,0	5,0	1,0	4,0	1,0	7,50	max
THE TECHNOLOGICAL ASPECT 22%	Efficiency	3,0	3,5	5,0	5,0	4,5	6,00	max
	Safety	5,0	5,0	3,0	5,0	3,0	7,00	max
	Reliability	5,0	5,0	4,5	5,0	3,0	6,00	max
	Maturity	5,5	5,0	4,5	4,5	3,5	3,00	max

4.2. Results

PROMETHEE Flow Table

The positive flow Phi+, the so-called outgoing flow, indicates how many preferences are there in comparison with other actions. It represents the global measure of the "power" of the action, and the higher the flow, the superior the action is, i.e. the higher the Phi+ a certain activity is more dominant over the other activities.

The negative flow Phi-, the so-called incoming flow, indicates how many preferences are there in comparison with the observed action. The higher the negative value, the lower the power of the observed action.

The balance between positive and negative flows is the so-called "net preference flow". This flow unites both the "power" and the "weakness" of an action into one value, which can be either positive or negative. The result is shown in Table 3. The most acceptable solution is the wet process followed by indoor composting, outdoor composting, anaerobic digestion, and ultimately transportation to the mainland. The wet process is clearly the most acceptable while "the transportation to the mainland" is the least acceptable. Other alternatives were narrowly grouped together and thus were rank-ordered. Obviously, criteria values and weight clearly defined a firm rank-order of alternatives.

Table 3. The results obtained - PROMETHEE Flow Table

Rank	TECHNOLOGY	Phi	Phi+	Phi-
1	WET PROCESS	0.6763	0.7312	0.0550
2	INDOOR COMPOSTING	-0.0563	0.3688	0.4250
3	OUTDOOR COMPOSTING	-0.1025	0.3275	0.4300
4	ANAEROBIC DIGESTION	-0.1650	0.2863	0.4512
5	TRANSPORTATION TO THE MAINLAND	-0.3525	0.2412	0.5938

Sensitivity analysis is an essential technique used to determine the robustness of the results.The program package has a built-in program “Walking weights” that changes the order as a result of weight changes can be directly monitored.It helps to make decisions and to accept solutions.Results will show how different relative weights in the criteria level of the hierarchy will influence the final choice.In this regard, a multi-criteria analysis which includes different percentage values of the preferences was performed. The solution is analysed by using the same percentage value of the preferences for all criteria, furthermore; the percentage increases in the amount of 100% for a certain group in comparison to all other groups having the same percentage (4x11.5% + 1x34%). A total of 6 preference value groups were analysed. The results of the analysis are shown in Table 4.

Table 4. The analysis of the impact weightings on the ranking of alternatives (Phi result PROMETHEE Flow Table)

Rank of alterna.	Aspects of emphasised preferences – the importance of the impacts (Phi)						
	The initial assessment	The same for all	The economy aspect	The environmental aspect	The local social aspect	The wider social aspect	The technological aspect
1	WP (0.676)	WP (0.680)	WP (0.706)	WP (0.687)	WP (0.708)	WP (0.673)	WP (0.640)
2	IC (-0.056)	IC (-0.070)	OC (-0.045)	IC (-0.072)	IC (-0.108)	IC (-0.030)	IC (-0.002)
3	OC (-0.103)	OC (-0.122)	IC (-0.114)	AD (-0.130)	OC (-0.119)	OC (-0.150)	OC (-0.057)
4	AD (-0.165)	AD (-0.187)	AD (-0.221)	OC (-0,194)	AD (-0.217)	AD (-0.234)	AD (-0.206)
5	TM (-0.353)	TM (-0.302)	TM (-0.366)	TM (-0.290)	TM (-0.262)	TM (-0.259)	TM (-0.375)

It is obvious that the order obtained is quite stable. The best choice is "the wet process" while the worst option is "the transport to the mainland" in all the combinations of the preferences. In case of emphasising the economic and environmental criteria the order is changed from the second to the fourth rank. It can be concluded with great certainty that "the wet procedure" option has been rated to be the best. In all combinations, the positive net flow of this alternative is significantly higher than the following alternative; therefore, the domination is obvious.

5. Conclusions

In the presented study, the multi-criteria decision-making approach is identified as a useful means for evaluation of the suitable food waste management options. The result obtained is justified for small islands such as the island of Vis based on technical, economic, environmental and social criteria. The PROMETHEE method proved to be very useful in solving this problem.The method and the available software package enable equitable treatment of numerically measurable and non-measurable criteria. Graphical presentation of results to all participants in the decision-making process clearly indicates differences between options and causes of differences. In particular, it should be emphasized the possibility of direct graphical interpretation of results as a function of change of preference.That's why stakeholders have the ability to test their preferences and track the consequences of changes to the overall rank of options.

The results have shown that the application of "the wet process" can be good solution for food waste management at islands. Integration of food waste with wastewater system is very practical solution at small islands lacking knowledge, equipment and manpower. Everything takes place in a closed system with small-scale environmental impact on the household and the settlement. Furthermore, it is an excellent solution for overcoming seasonal variation of waste generation and for the treatment of sludge from the wastewater treatment plant. It is a first choice when the storage, collection, transport costs and associated environmental impacts, as well as recirculation of nutrients and weight volume reduction, are considered. The overall problem of wet organic waste on the island is solved by the treatment of organic waste conveyed by the sewer, using anaerobic digestion or the process of composting. Furthermore, the preconditions are made for returning nutrients into the food chain. This will contribute to fulfilment the objectives of the Circular Economy. Cities should become the main circular bioeconomy center. The production of renewable biological resources is recommended and converting these resources into products with added value, such as food, animal feed, products that are based on biological basis as well as bioenergy.

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