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Methodology for the decision-making process in Social District Heating implementation

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Abstract

District heating is a centralized energetic system, capable of providing heat to different structures. This technology helps achieving energetic efficiency with a high fuel flexibility, enabling the use of various renewable sources, which will lead to a lower pollution potential. Beside the environmental perspective, these systems show a great ability concerning the social context. Benefits such as, tackling fuel poverty, increasing employment and population in areas suffering from desertification, along with forest fire prevention, lead to the social perspective as the primary motivation for the implementation of these systems, creating the concept of Social District Heating (SDH). Therefore, this paper developed a decision support tool to prioritize locations in the most need of an SHD, with the necessary features to include this technology in its area. A methodology intended to assess quantitative and qualitative variables is presented, step by step, evaluating each location relatively to community aspects, background context and council power criteria. The results presented enhance more than one location, however one appears as the most appropriate for the SDH implementation.

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Keywords: Social District Heating; Forest waste - biomass; Decision support tool; Pairwise comparison

1. Main text

District Heating (DH) consists in a central facility designed for heat production, with a pipe network that is responsible for its distribution for the different structures and services [1]. The growing popularity of this systems is a result of its sustainable characteristics, ensuring lower pollution potential comparatively to conventional heating options, due to energetic efficiency and possibility of renewable sources usage, contributing to higher fossil fuels independency and lower greenhouse gases emissions [2]. The DH system can generate heat through any type of sources, among them, fossil fuels, not used energy generated in industrial processes, nuclear energy and renewable energy [3].

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Social District Heating (SDH) is an unused term that depicts the social role in a DH system. Social benefits of this system have been mentioned in literature and are becoming, in fact, the primary motivation to implement DH systems [4–8]. The implementation of a system like this provides environmental, economic and social benefits. Socially, the activities related to wood residues, namely collection, treatment, transport, forest management and to DH functioning and administrative roles have a great potential of increasing job opportunities in the area [9]. Three aspects are responsible for fuel poverty: low income, low energetic efficiency and high fuel costs, and as such, DH has the potential to mitigate all these conditions [10]. Employment growth along with local economy stimulation, higher energetic efficiency relatively to conventional systems and operation with fuels available at lower costs are the system features allowing to overcome fuel poverty. Forest fires prevention is another significant benefit, given their serious consequences to the environment, society and economics. The coordination of DH system activities with a correct forest management by collecting forest residues, to be used as a fuel, is considered an effective tool to prevent fires [11]. Areas appropriate to include a DH system fed by biomass, as a rule, must be covered by a large forest area, meaning that they are more exposed to these types of catastrophes, requiring this type of initiatives.

A decisive phase that influences the systems functioning throughout its life, is the planning stage, however the lack of tools to support the selection of an appropriate location to implement the SDH system is a considerable limitation. From the existing methods, GIS (Geographic Information System) is the most frequently used by enhancing opportunity zones and prioritizing the most suited locations to implement a heat system project, Scotland Heat Map being one example [12]. Another tool, Leeds Heat Planning Tool, is a quantitative technique that by calculations determines locations scores [4]. Both tools identify heat opportunities and the locations in most need of these type of initiatives. Nevertheless, the idealized tool in this study required the social component as an important criterion and the evaluation of the locations according to its rural context, which is a key factor to fulfil these project primary goals. Also, the idea is to process quantitative and qualitative criteria, reflecting the need of complementing different methods. In addition, the implementation studied concerns a DH system fed by wood forest residues, a type of biomass which is comprised in renewable energies. Case studies found of existent DH systems do not provide extended or detailed information concerning the planning stage. Centralized heating systems in Llanwddyn, a small community in Wales, and Tralee, in Ireland, are examples of implemented DH systems, however in both cases the location selection step did not required any strategy, since the primary motivation was the development of these locations, defining, at first, its positioning. The Llanwddyn DH system first objective was to stimulate local economy through local forest wood and, during the planning stage, retaining attention to some conditions, which were: wood forest prices, dimension and flexibility of the system, lower and fixed heating price depending on the amount of heat consumed and local employment, among others. Also, the need of thoroughly considering certain aspects during the planning and implementation stage was underlined, including emissions, ash disposal, boiler features, traffic contributions and visual impacts since permissions may depend on these. Additionally, the main concern throughout the planning and installation was the community involvement, in order to construct a thriving wood based community heating system [7]. In Tralee, the DH system main motivation was to overturn the lack of businesses in the area, along with low competitiveness and high heating prices. Consequently, a strategy was developed to transform Tralee in a self-sustainable region relying on energy efficiency, through increasement of local employment and boosting living conditions [8]. Taking into account these circumstances, a district heating system fed by biomass was the chosen strategy.

Therefore, a new tool that meets the project goals for the system to be studied, framing the social role directly, among other important aspects, was developed. For this reason, in this work was developed a methodology to prioritize locations to implement an SDH system using as an energy source wood forest residues.

2. Methodology

This paper aims to create a tool capable of prioritizing appropriate locations for an SDH system implementation, where a series of steps are required to successfully achieve the results. Fig. 1 presents an overview of the procedure with a total of four steps organized by order.

The definition of macro variables and variables is step number one to the definition of the criteria responsible for evaluating each location in study, its characteristics and possible strengths and weaknesses when integrating an SDH is made. The need to target more detailed information related to the variables to be established to evaluate the locations, led to the need of defining variables.

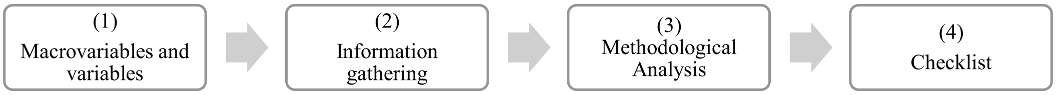

Fig. 1. Methodology ordered by steps.

Three macro variables were established: community (C), background (B) and council power (CP) and each one is divided into other variables. Community (C) refers to the social characteristics of each location and reflects the primary focus of the implementation, reporting the social features of each location and assisting on detect the locations with higher social needs and appropriate social aspects. Background reflects the context where the location is inserted to and its ability to include an SDH system in its area. Also, analyses the existence or nonexistence of means in each one of them, as well as certain local characteristics to implement the project. Council power concerns its support on the project and available resources from their part to assist and facilitate the procedure. Numerous decisions are of council responsibility, and they can provide most of the necessary information and knowledge concerning the respective location. Table 1 presents the variables considered.

Table 1. Variables considered in this work.

Population density	C	FIA[a]	B
Unemployment rate	C	FMP[b]	B
Aging index	C	Forest producers	B
Forest occupation	B	Medium temperatures	B
Softwoods occupation	B	Forest department	CP

[a]Forest intervention areas.
[b]Forest management plans.

After the establishment of variables and variables, there is the information gathering that concerns the collection of information. It is preferred to obtain the maximum data using reliable sources besides local councils. Sometimes, authorities take time providing the information and this aspect must be taken into account, especially, if the locations under evaluation are numerous, since the probability of taking longer to get answers increases with the number of local councils to contact. Also, if the information is made available online it is unnecessary to inquire the authorities about that same information. Useful data bases, as, national statistics census, council official websites, national environmental agencies, global/national temperature databases, tourism portals, among others, can be consulted to extract the maximum information needed, as long as, it is confirmed the credibility of the sources. The methodological analysis comprises the various procedures developed to determine the best location, applying them to the information gathered. Through this analysis, the results consist in a score to each location. Four steps are included in the methodological analysis, as explained below, namely normalization, pairwise comparison, ranking and sensitivity analysis. In normalization, the previously collected data are put within the same range. To fulfil this normalization is applied to the quantitative data converting into a new scale. In pairwise comparison a weight is established for each variable by applying the pairwise comparison technique. Beside addressing different aspects, the variables also differ in its relevance to the selection of the location. Therefore, pairwise comparison was applied to determine each variable weight in the final decision by calculating a percentage to each variable. This method is applied starting by indicating all the variables in analysis, as well as a fictional factor. Each variable is compared to the others, pair by pair, along with the fictional factor, assigning a point to the most relevant between the two parameters. Finally, each variable has points assigned that must be summed, resulting in a characteristic punctuation to each variable. Afterwards, this punctuation is divided by the total number of points, all the variable points summed, having, at last, the percentage of each variable. This percentage reflects the weight of each variable in the location selection and will be involved in the next steps to achieve the most appropriate locations for the SDH system implementation [13]. In the ranking stage, the locations are ranked considering the variables weight determined in pairwise comparison and the value of variables for each location. For determining the ranking value (RV) the values relative to the variables (vi) for each location were multiplied by the percentage obtained through pairwise comparison (pi), to each variable. Therefore, when summing these values, it is possible to determine each location final punctuation as shown by Eq. (1) [13]:

$$RV = \sum_{i=1}^{N} v_i * p_i \tag{1}$$

The utility of sensitivity analysis lies on the suppression of results subjectivity by determining the weight in pairwise comparison. In this case, equal weight was considered to verify if the modifications were significant or maintain the results in the previous calculation. Following the quantitative analysis, a checklist was chosen as a method to analyse the qualitative criteria, complementing the previous assessment. Checklists, include diverse criteria, where the existence, inexistence or lack of information relatively to certain features is analysed referring to the study locations. The final results and conclusions will be a reflection of quantitative analysis reinforced with the qualitative method.

3. Methodology validation

In order to validate the procedure described in the previous chapter, it is fundamental to apply it in a real context, therefore a district in Portugal was chosen to apply the methodology. For the purpose of using biomass as a fuel for the system and take advantage of the benefits it holds, as creation of local jobs and struggle population desertification, it is essential that the chosen district has a vast area of forest to collect the fuel. Viseu is a district located in the interior and centre of Portugal that has been increasing its data related to population desertification, since in 2011 the resident population was 266 207 and in 2019 this number fell to 251 628 in the region of Viseu Dão Lafões [14]. The lack of employment opportunities is the principal driver and Viseu needs initiatives to enhance its development and dynamic, which can start with the implementation of the SDH system. Concerning the biomass availability issue, the centre of Portugal, where the district of Viseu is inserted, is the second region with more forest area in the country when compared to the remaining [14]. This proves that Viseu holds a vast area of forest, being capable of supplying the system with forest residues, without causing negative impacts in the environment. This aspect allied to the fact that this region lost a considerable forest area since 1995 owing it, especially, to forest fires makes it is essential to implement forest management activities to protect the forest and prevent fires deflagration [14]. The intermunicipal community (CIM) of Viseu Dão Lafões, integrates 13 counties from Viseu and has its mission, perspective and values defined. These principles are in accordance with SDH system objectives, since its mission is about turning Viseu a more innovative, enterprising, attractive and competitive region by providing a sustainable growth with an economic and social cohesion [15]. Consequently, the support from this organization towards the system implementation is almost guaranteed, given that its goals can be successfully achieved implementing measures and systems with benefits aligned to SDH.

4. Results and discussion

This chapter will present the result achieved by applying the methodology developed to the collected data regarding the variables and locations. The weights obtained after applying pairwise comparison technique, are presented in Table 2. The minimum weight obtained was 3,6% for population density and FMP and the maximum was for forest producers with 16,4%. Forest occupation was also a low weight (5,5%) as well as unemployment rate (7,3%).

The value obtained by each county after ranking are presented in Table 3. Additionally, the table presents the results achieved by the sensitivity analysis, where the only difference to the ordering tool are the weights assigned to the variables which, in this case, was 10% to all of them (obtained dividing 100% by the number of variables).

Regarding the ranking tool, the three counties that hold the highest scores are, by order, Vouzela, S. Pedro do Sul and Sátão. When comparing both results, is evident the disparity in the obtained results. This indicates that the modification in the variables weights has an influence when selecting the most appropriate location to implement an SDH system. In the sensitivity analysis 4 counties maintain the same position, 5 change by one position or two, 3 by three positions and 1 present significant change. The verification of this difference denotes the attention needed when determining these weights since to successfully fulfil this step it is crucial the knowledge held concerning the project in hand and its main targets. The qualitative criteria, local individual characteristic, was evaluated through the checklist, as explained previously. Therefore, Fig. 2 presents the existence or nonexistence of different features capable of allying to the SDH and enhance the location interest and impact.

Table 2. Results obtained by pairwise comparison.

Population density					1				1																																																	2	3,6%
Unemployment rate	1											1			1				1																																						4	7,3%
Aging index		1									1								1		1	1			1	1																														7	12,7%
Forest occupation			1																															1	1																						3	5,5%
Softwoods occupation				1									1								1							1							1	1			1	1															8	14,5%
FIA					1									1															1													1		1	1	1												7	12,7%
FMP																														1																		1								2	3,6%
Forest producers							1								1								1							1						1				1				1				1		1			9	16,4%
Medium temperatures								1								1								1							1						1										1						1		7	12,7%
Forest department									1								1																													1			1		1		1	6	10,9%
Fictional																																																								0	0,0%
Total																																																								55	100,0%

Table 3. Results obtained by the ranking tool and sensitive analysis.

Counties	Ordering tool	Rank	Sensitivity analysis	Rank
CARREGAL DO SAL	46,88	13	38,88	13
CASTRO DAIRE	47,97	12	39,46	12
MANGUALDE	54,46	6	51,36	6
NELAS	55,60	4	51,96	3
OLIVEIRA DE FRADES	51,81	8	52,44	2
PENALVA DO CASTELO	53,14	7	45,36	9
SANTA COMBA DÃO	49,53	10	43,94	10
S. PEDRO DO SUL	60,60	2	51,54	5
SÁTÃO	58,95	3	54,15	1
TONDELA	55,08	5	48,36	7
VILA NOVA DE PAIVA	50,08	9	41,47	11
VISEU	49,14	11	47,57	8
VOUZELA	61,53	1	51,72	4

	Gastronomic Products	Monuments and Heritage	Prehistoric Monuments	Recreation	Museums	Dão Wine Producers
Carregal Do Sal	✗	✓	✓	✗	✓	✓
Castro Daire	✓	✗	✓	✓	✓	✗
Mangualde	✓	✓	✓	✓	✗	✓
Nelas	✗	✓	✓	✗	✗	✓
Oliveira De Frades	✓	✗	✓	✓	✓	✗
Penalva Do Castelo	✓	✓	✓	✗	✗	✓
Santa Comba Dão	✓	✓	✓	✓	✗	✓
S. Pedro Do Sul	✓	✓	✗	✓	✗	✗
Sátão	✓	✓	✓	✗	✓	✓
Tondela	✓	✗	✓	✓	✓	✓
Vila Nova De Paiva	✓	✗	✓	✗	✓	✗
Viseu	✓	✓	✓	✓	✓	✓
Vouzela	✓	✓	✗	✓	✓	✗

Fig. 2. Counties local characteristics evaluation.

According to the elaborated table, the counties that hold the strongest local characteristics are: Mangualde, Santa Comba Dão, Sátão, Tondela and Viseu. In consideration of the results achieved through the methodological approach and the local characteristics was recognize the potential of Sátão to include an SDH system, since this county was among the three counties holding the highest score. This checklist also indicates Tondela as a promising county, given that stands in fifth place in the ranking with practically same score of the county standing in fourth. In order to evaluate some more variables, the following step is to send a questionnaire to the City Council and then take into consideration the answers obtained that which can motivate alterations in the final results. Afterwards, the next step lies on the community areas that will be analysed according to the same criteria and, subsequently, the most appropriate will be selected to implement the SDH system.

5. Conclusion

Energy efficiency systems involve high potential technologies capable of providing not only environmental benefits, but also social and economic ones. Therefore, this work aimed at developing a tool, for the planning stage, to prioritize locations with higher social needs and appropriate features for the implementation of an SDH system. This decision support tool included a quantitative and qualitative approach. A quantitative methodology was developed that considered several steps, such as normalization, application of pairwise comparison, ranking method and a sensitivity analysis. This methodology was applied to a real case in Portugal, where all those steps were carried out. The quantitative results presented three potential locations: Vouzela, S. Pedro do Sul and Sátão, while the qualitative results enhanced Mangualde, Santa Comba Dão, Tondela, Sátão e Viseu. Combining both approaches Sátão has a high potential and, also Tondela is a promising location. The comparison of the original analysis to the sensitivity one, presented disparity in the obtained results, what demonstrates the thorough attention and precaution required when determining weights to the parameters. Future work will consider the surveys to the different councils that will be carried out, in order to collect all the necessary information to finalize the evaluation process and, therefore, select the final location. Once the location is decided, the exact same methodology should be applied to other community areas to select which one will benefit from the implementation of the SDH system. The developed methodology takes a step towards a well-organized and thoroughly considered system implementation allowing the inclusion of different variables with different natures. The replication in various projects is assured, regardless of the primary motivations, living it to the criteria of the individual applying it the parameters to include and weights to assign, enabling its use in multiple situations.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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