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Energy Audit and Multi-Criteria Decision Analysis to identify sustainable strategies in the university campuses: application to Politecnico di Torino

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Abstract. Universities play a headship role among entities that invest in technological progress and intend to increase education in sustainable culture towards a post-carbon society. With this in mind, Politecnico di Torino is a leader on the national and international scene. It has prepared sustainability lines for the next few years to translate the Sustainable Development Goals into concrete actions. The goal of this work is the evaluation of eight alternative energy efficiency scenarios resulting from the combination of different strategies for the retrofit of the University Campus of Politecnico di Torino. In the first part of the study, the alternatives are assessed in terms of energy performance. Subsequently, an economic evaluation supported by the multi-criteria TOPSIS method makes it possible to order the alternatives according to the opinion of several experts. The integrated evaluation allows considering a set of co-benefits generated by the project going behind the energy aspects. The best strategy involves covering electricity needs with renewable energy sources, adopting students' engagement policies and optimizing the set-point temperature. The results highlight how low-cost solutions such as awareness campaigns and variation of the set-point temperature can bring significant co-benefits from energy, economic, environmental and social perspectives.

Keywords: university campus, SDGs, decision support systems, TOPSIS, SWING, co-benefit.

1 Introduction

Many universities are endowing themselves with sustainability policies for the enhancement of the heritage, the planning of new initiatives and training policies to encourage research on Sustainable Development Goals (SDGs). Universities are laboratories for experimenting and testing technologies and sensitizing society on important issues in order to help society moving towards sustainable lifestyles [1, 2]. In this context, universities promote, at regional and global level, the minimization of negative effects on the environment, the growth of the economy, the improvement of the health generated by the use of their resources [3]. In 2014, Politecnico di Torino (POLITO) joined the International Sustainable Campus Network (ISCN) in order to be part of a worldwide forum that sustains institutions and universities to plan activities that contribute to sustainability. The ISCN promoted the Campus Report Charter in order to formalize all the actions within its sustainability policies and to report its progress annually in a transparent manner [4]. The POLITO working group tried to individuate these activities and divide them into five dimensions, according to the three ISCN principles. In detail, the Green Team was set up in 2015 to develop actions and activities towards sustainability, converting the university to a laboratory for promoting innovation. Members want to develop a partnership between all the students and people involved in the POLITO in order to create specific projects synergistically [5]. In particular, the team individuated 52 key initiatives involving 11 different topics, such as the reduction in primary energy consumption, improvement of insulation, encourage bicycle use, enhance the safety in campus etc. The Green Team, composed by professors and experts of the POLITO, is working to define and pursue five dimensions of sustainability; 1) Energy and buildings, 2) Mobility and transport, 3) Urban outreach, 4) Food water and waste, 5) Green procurement. In detail, this study is focused on the first dimension looking at reducing and rationalizing energy use and the related environmental impact.

The objective of this work is the evaluation of eight alternative energy efficiency scenarios for the POLITO, which involve different sustainability measures presented in the 2015 ISCN report. The alternative scenarios were evaluated through an integrated approach based on energy evaluation and multi-criteria analysis. First, an energy evaluation was led in order to understand the energy consumptions of the alternatives. Secondly, they were evaluated through the TOPSIS approach in order to consider different positive and negative co-impacts generated by the alternatives.

Next, Section 2 describes the methodological approach of the study; Section 3 includes the application to a real case study. Results and discussions of the research are summarized in Section 4. Conclusions follow.

2 Methods

2.1 Integrated framework

The aim of this work is the strategic evaluation of alternative energy efficiency scenarios for a portion of the POLITO main campus, through integrated energy and socio-economic approach [6]. The first step has been the identification of the energy efficiency measures within the ISCN report with different level of invasiveness. The scenarios evaluated in this study are the result of the combination of eight measures presented in the ISCN report. Secondly, the energy evaluation was carried out by building a simple energy model in order to identify the consumptions of the current state as baseline scenario (BASE) and to calculate the energy savings of the energy efficiency measures and their combinations, i.e. the alternative scenarios.

The scenarios were evaluated using a multi-criteria assessment model. In detail, the TOPSIS technique was conducted to rank the strategies based on their performances according to nine criteria considering the economic, technical, environmental and social aspects [7,8]. Different experts weighed the evaluation criteria according to their background by the SWING method [9]. The aim is to identify different intervention priorities according to experts' opinion and validate the robustness of the results.

2.2 Energy assessment

An energy audit of the POLITO building was conducted, using the Simplified Energy Audit Software (SEAS 3), created by ENEA (Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile - National agency for new technologies, energy and sustainable economic development) and the DESTEC (Department of Energy, Systems, Territory, and Construction Engineering) from Università di Pisa (Italy). The inputs to compile the audit are separated into four macro-groups: "Auditor/building data and geographical context"; "Usage profile and envelope characteristics"; "Heating and domestic hot water production"; "Energy billings and calibration". Starting from this input data, SEAS 3, thanks to a quasy-steady state modelling approach, is able to calculate the energy needs and the relative consumptions for space heating and cooling, domestic hot water (DHW) production, ventilation, lighting and appliances.

2.3 Multi-criteria analysis: TOPSIS method

The economic evaluation was performed deploying the TOPSIS method, developed by Hwang and Yoon in 1981. It is usually implicit in solving selection/evaluation problems in a finite number of alternatives. The main goal of this method is to reach the closest alternative to the ideal solution, using a remote Euclidean approach. Indeed, the TOPSIS approach classifies alternatives by calculating distances from the ideal positive and negative ideal solutions. The positive ideal solution and the negative ideal solution are possible alternatives that have the values of the best criteria and the values of the worst criteria, respectively.

This method could be resumed in the following seven steps.

Step 1. Determining the objective of the decision problem and identify the pertinent evaluation criteria C_j.

Step 2. Constructing the initial decision matrix based on the performance of the alternatives according to the selected criteria. Therefore, an element, x_{ij} of the decision matrix shows the performance of i-th alternative with respect to j-th criterion.

Step 3. Calculating the normalised decision matrix, n_{ij} using the following equations (1) (2):

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{1}$$

$$n_{ij} = \begin{cases} \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \text{ if } C_j \text{ is a criterion to be maximised} \\ \\ \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} \text{ if } C_j \text{ is a criterion to be minimised} \end{cases} \quad (2)$$

This step transforms performances values into non-dimensional attributes which allow comparisons across criteria. Normalised values are positive and range between 0 and 1.

Step 4. Defining the relative importance of evaluation criteria estimating the weight of the j-th criterion w_j.

Step 5. Computing the weighted normalised matrix v_{ij} as follows (3);

$$v_{ij} = w_j n_{ij} \quad (3)$$

Step 6. Obtaining the ideal positive (best) and the negative (worst) solutions. The ideal positive solution is the solution that maximises the benefit criteria and minimises the cost criteria. While the negative ideal solution maximises the cost criteria and minimises the benefit criteria.

Step 7. Calculating the separation measures of each alternative from the ideal positive and the negative solutions using traditional n-dimensional Euclidean metric.

Step 8. Ranking the preference order or select the alternative closest to 1.

The advantages of this method are ease of use and simplicity of the process. Despite a large number of alternatives and criteria, the number of passes remains the same.

3 The Case Study: Politecnico di Torino

3.1 Overview of the campus

In Torino, there are five POLITO campuses. In this study, we focused the attention on a portion of the headquarter representing the largest energy-user according to seasonal energy consumption. It is located in Corso Duca degli Abruzzi 24 in Turin, built-in 1958, with an area of 122,000 m^2. The building hosts the School of Engineering, offices, laboratories, classrooms, rector's and general director's secretary, and central library. The choice of this building derives from the fact that it includes many functions and represents the case where experimenting with replicable alternative strategies on the other university campuses of the city.

3.2 Definition of retrofit measures

The measures belonging to the "Energy and buildings" (EB) dimension have been selected in the ISCN-GULF Charter. The first measure is the increase in the production of electricity from renewable energy sources (RES). In recent years, POLITO is producing almost 25-30 MWh/year of electricity thanks to a PV system. His closest challenge is the construction of a PV system with a pick power of 400 kWp to produce almost 450 MWh per year (EB1). The PoliSAVE initiative (EB2) is the second measure chosen in this study. PoliSAVE is a software developed by the POLITO electronics department that allows users to program their PCs switched off during lunch, breaks and at night, in order to avoid waste. PoliSAVE generates an energy saving of 0.6 kWh per PC per day, which can be translated into almost € 250,000 saved per year. Every year POLITO is replacing old lamps with LEDs (EB3), a crucial low-cost measure that helps reducing energy consumption. Today about 4.5% of the total number of lamps has been replaced. POLITO is connected to DH for suppling heating to the building. The proposed measure envisages the use of DH to cover the DHW needs, thus eliminating the electric boilers distributed in the building (EB4). In 2012, POLITO launched a free water dispenser project called "to drink" in collaboration with the SMAT (Società Metropolitana Acque Torino) local water company. The goal is to reduce the usage of plastic bottles providing students with an aluminium bottle (EB5). Every year EDILOG (Construction and Logistic office) replaces some old windows with new high-performance ones (low-e, double glazing, etc.) according to the available budget (EB6). The existing windows have a transmittance value of almost U_w=5.8 W/m^{2}K. While the new ones have a value between approximately 1.3 W/m^{2}K and 1.6 W/m^{2}K. Today almost 28.5% of the windows have been replaced. POLITO promotes awareness campaigns about energy savings called “M’illumino di meno” (EB7). The activity has the goal to reduce electricity consumption and educate staff and students. The last initiative provides the set-point temperature decrease in the winter period, from 20 °C to 19 °C, in order to get energy savings (EB8). Once defined the measures, the following step was the creation of eight alternatives (Table 1) from the combination of three energy efficiency strategies at a time. They were made up, establishing the area of intervention of each measure between envelope (EB6), system (EB1, EB3, EB4), and management (EB2, EB5, EB7, EB8). In general, the composition was created combining measures that provide actions on the system, the initiative in the management field, and/or envelope improvement (A1, A2, A4, A6, A8). Three alternatives were composed considering all of the three fields (A3, A5, A7).

Table 1. Alternative retrofit scenarios and related sustainable measures.

Scenarios	A1	A2	A3	A4	A5	A6	A7	A8
Combination of measures	EB1	EB1	EB4	EB3	EB2	EB1	EB3	EB2
	EB2	EB4	EB6	EB4	EB5	EB7	EB6	EB5
	EB3	EB7	EB8	EB5	EB6	EB8	EB8	EB7

3.3 Energy performances estimation

SEAS 3 software was chosen as the tool to build a simplified energy model. Ten thermal zones were identified, and the characteristics of both the envelope and the systems’ components were defined thanks to the support of design and technical sheets provided by EDILOG. The occupation was identified with the support of standards, while lighting and appliances power was defined per each zone thanks to the knowledge acquired with visits in situ. The model so developed permitted to assess the current consumptions (BASE scenario), which were compared with the energy bills for calibration purposes. Each energy efficiency scenario was implemented in the model in order to assess the consumptions of DH and electricity related to the following final uses: heating, DHW production, lighting and appliances [10]. Then primary energy consumptions for the same final uses was evaluated. The energy performance guaranteed by the eight scenarios were evaluated as the difference with respect to the BASE scenario.

Looking at the reduction of the total primary energy consumptions, the A1 (EB1, EB2, EB3) is the most advantageous (-33%). Taking action on electricity consumption would lead to significant savings in terms of primary energy. The A7, which intervenes on the building envelope (EB6), on the lighting sector (EB3) and the regulation system of the heating system (EB8), allows achieving 30% energy savings. As expected, alternatives that involve invasive measures on the envelope lead to significant advantages compared to management actions. The estimated consumptions represent the input data in the first step of the TOPSIS methodology.

3.4 Ranking of the alternative scenarios

Criteria selection

Following the TOPSIS steps, it was necessary to identify the criteria that best described the alternatives with respect to the objective of the decision-making process. The criteria mainly refer to four areas in order to evaluate the scenarios from different points of view; environmental (En), economic (E), technical (T) and social (S). Nine criteria were identified as follows:

En1: Decrease in primary energy consumption (%/year). This criterion has the aim to quantify the percentage of primary energy saved with respect to the current state. To be maximised.

En2: Reducing in CO_{2eq} emissions (%/year). The criterion describes the percentage of CO_{2eq} saved by sustainable alternatives. It is computed knowing the energy consumptions per each energy carrier. To be maximised.

E1: Investment cost (€). The investment cost or initial cost represents the part of the economic capital that should be spent to carry out the alternatives' implementation. To be minimised.

E2: Maintenance cost (€/year). The maintenance cost or operational cost represents the costs strictly connected to the life cycle of a product. This cost includes annual expenditures for the technology managing and people implied. To be minimised.

E3: Energy savings (€/year). To calculate the annual energy savings, the difference between pre-intervention and the post-intervention final consumptions were calculated per each energy carrier and multiplied by the values of its specific cost to compute the total saving in energy bills [11]. To be maximised.

T1: Service life (years). The criterion is the maximum period of operation of a product or technology expressed in years. To be maximised.

T2: Maturity of technology (1-9). The criterion expresses the level of reliability of technologies and measures, according to a qualitative scale [12]. Low levels represent researches and practical applications, but no proofs yet, or technology under observation and validation in the laboratory and later in relevant environment. Medium levels identify technology that, passed validations, was represented by a prototype or model. High levels describe complete and qualified technologies. To be maximised.

S1: Users participation (1-5). The users' participation describes the users' attitude and involvement in a development activity or system implementation. The dimension was evaluated through a 5-points Likert scale submitted by questionnaire to 73 students, PhD and post-doc researchers in order to evaluate their agreement with the energy efficiency strategies chosen. To be maximised.

S2: Users involved (1-3). This sub-criterion wants to identify the typology of users that each retrofit strategy involves. The criterion identifies students, professors and employees as users groups. To be maximised.

The assessment of the environmental criteria is closely linked to the identified consumptions. The economic criteria were quantified thanks to the Piedmont Region pricelist [13,14], in order to acquire specific costs per each intervention. For the technical criteria, various bibliographies were used and at the same time information from the companies' technical datasheet. As stated above, the social criteria were measured through a questionnaire to evaluate the participation of students and the type of users involved. Once the criteria were identified, the performance of the alternatives was assessed (Table 2). The matrix has to be normalised, in order to turn the attributes into non-dimensional attributes which allow comparisons across criteria.

Table 2. Scenarios performance according to selected criteria.

	Criteria	En1	En2	E1	E2	E3	T1	T2	S1	S2
	Unit	%/year	%/year	€	€/year	€/year	years	1-9	1-5	1-3
	Ranking Sense	Max	Max	Min	Min	Max	Max	Max	Max	Max
Alternatives	A1	33.1	28.6	965,749	12,680	97,228	17	7	3.9	3
	A2	27.3	23.9	860,794	12,078	82,045	27	8	3.9	3
	A3	11.8	12.8	935,047	7,426	52,359	30	8	3.9	3
	A4	11.0	9.3	157,981	8,777	30,547	15	8	4	3
	A5	9.8	10.4	946,034	15,367	41,632	18	7	4.1	3
	A6	30.4	27.3	846,781	12,000	96,381	25	8	3.9	3
	A7	22.4	21.7	1,040,002	8,028	81,999	20	8	4.1	3
	A8	3.9	3.3	25,000	8,019	11,315	6	8	4	1

Weights of criteria

To assign a weight to each criterion is the crucial step of this assessment because the definition of ranking depends on it. To identify these global weights, an expert for each criteria family investigated in the MCDA was interviewed, for a total of four experts. All experts are familiar with the case study analysed as they work as researchers or in the EDILOG offices. In this study, we used the SWING method, which explicitly incorporates the attribute ranges in the elicitation through a specific questionnaire that has been submitted to each expert.

The questionnaires gave back four global weights that were used to carry out the analysis (Fig. 1). In general, all of the four experts gave high scores to the sub-criterion En1 because it is crucial in terms of savings respect to the pre-intervention audit. High scores were assigned to the social criteria, in particular to T2, because the end-users will be the real beneficiaries of a project. According to the four experts' judgements, four weighted matrices will be identified.

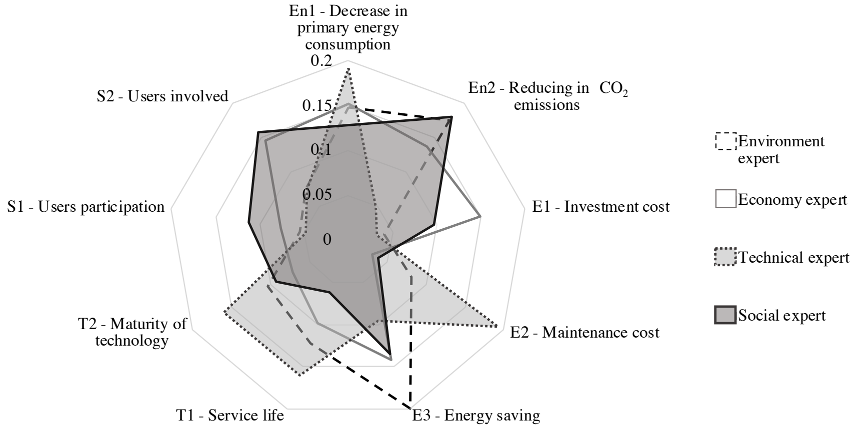

Fig. 1. Criteria global weights according to experts' point of view.

Identification of the Ideal and Negative Solutions

Starting from the four weighted matrices, the vectors of ideal solutions were defined. The best attributes values compose the vector of the positive ideal solutions according to the ranking sense, and the vector of the negative solutions made of the worst attribute values. The next step is the determination of two matrices, obtained from the multiplication of the standardized weighted matrix by the two ideal vectors. This step identifies the separation of the alternatives from the best and worst hypothesized ones.

4 Discussion of the Results

From Fig. 2, the A6, A1 and A2 are preferable for the costs and co-benefits generated. The ranking shows that the first classified scenario is the A6 for all experts. A6 is performing from different points of view. In particular, in addition to energy savings, it allows a significant reduction in environmental impacts, a lower investment cost than most alternatives, and a high level of technological safety.

Scenario A8 is the worst for most experts. The A8 is characterised by measures with low technological maturity and a few years of service life. A7 stands in the middle of the ranking. This scenario presents the values of the performing attributes in the criteria best assessed by the four experts, in particular, in En1, En2 and E3. On the other hand, it is characterised by high investment and maintenance costs that do not allow it to rank first. The scenarios A4 and A5 change position in the ranking according to expert opinion. A4 is assessed in the penultimate solution by the environmental expert as it is characterised by a low reduction in CO_{2eq} emissions (-9.3%) and low energy savings (30,547 €/year). A5 is evaluated in the last positions by the economic, technical and social expert.

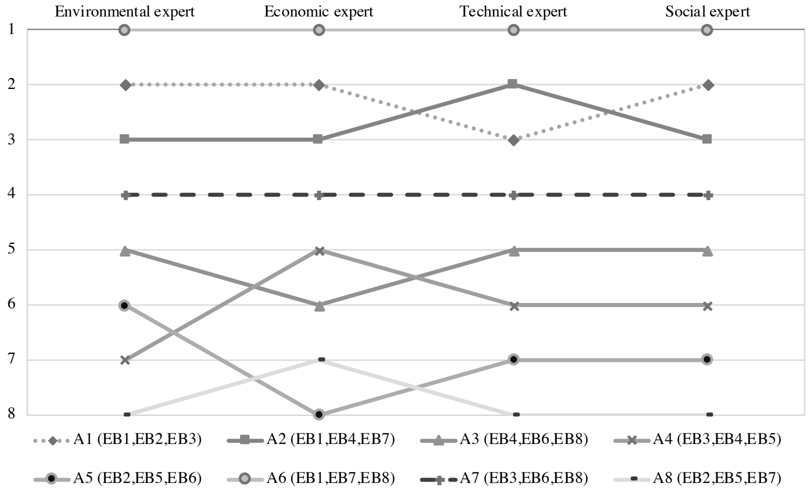

Fig. 2. Alternatives' ranking according to experts' opinion.

5 Conclusions and Future Perspectives

The integrated strategic evaluation used in this study allowed to classify a defined set of sustainable scenarios that could help the governance of Politecnico di Torino to plan some specific sustainable policies. The results of the study highlighted the need to arrange some energy efficiency strategies, described by POLITO in the ISCN report. In general, the best-classified scenarios involve simultaneously interventions at the envelope, system and management scale. While the worst alternatives plan changes mainly in the field of management since they do not have enough impact. The multi-actor analysis made it possible to highlight the potential of the alternative scenarios concerning different points of view.

Following this evaluation framework, possible future developments could be the extension of the evaluation at the scale of the entire main campus taking into account also other final uses such as space cooling and the assessments of the other POLITO campuses. Other implementations could be the involvement of different experts to develop a new ranking and make a comparison [15]. The inclusion of measures from the POLITO ISCN report referring to the mobility, waste, public awareness and food dimension in the evaluation model would lead to a complete strategic vision in an integrated sustainability perspective according to all SDGs objectives [16]. To do it, the definition of other metrics for their quantification is a needed action.

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