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The impact of stakeholder preferences in multicriteria evaluation for the retrofitting of office buildings in Italy

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Abstract: Buildings are responsible for about 26% of the total final energy consumption in Italy. Therefore, building retrofitting represents an opportunity to achieve economic and environmental benefits. However, a challenge task is the application of robust methodologies for evaluating cost optimal retrofit measures. The paper evaluates in terms of multiple criteria based-approach several retrofitting alternatives selected for a typical office building in Italy. The alternatives are evaluated considering economic, environmental and technical requirements and are compared by means of a Stochastic Multicriteria Acceptability Analysis (SMAA) method, able to consider uncertainties in the criteria evaluation. Three different stakeholder preferences are analyzed and compared with the aim to point out the importance of preference information in multicriteria analysis. The results highlight that, when the preference is the investment cost, for the case study analyzed the most suitable solution is represented by a gas boiler and electricity withdrawn from the market. On the other hand, when the operational cost has the same or more importance than the investment cost, the best solution is represented by a micro-CHP coupled with PV plant. Lastly, the analysis highlights that the main driver of a building retrofit are of economic nature and that, depending on the actors involved, a precise study of preference information could influence the outcome of the analysis.

Keywords: Building; SMAA; Multicriteria Analysis; Retrofit;

1 Introduction

The ambitious target set by European Union to cut carbon emissions increased the attention towards the energy efficiency in buildings, that in Italy represents 26% of total final energy consumption [1]. Improving building energy performance in the urban environment could help meeting sustainability targets set by the European Union for 2020 [2]. Nowadays the replacement rate of existing buildings is limited to 1-3% per year. Considering that a large part of European building stock was built before 1960s, the potential economic and environmental savings using retrofitting measures is very high [3].

During the last years, the research focused on the development of clean technologies for micro-scale application, including micro-CHP [4] and heat pumps [5]. In particular, micro-generation proved to be effective for increasing the efficiency of production by matching thermal and electrical demand.

The complexity of the sustainability problem is increasing the need of adopting multicriteria decision analysis (MCDA) methods in the energy field [6]. MCDA has been applied to large scale energy systems [7], [8] and more recently to buildings [9], [10]. The aim of the study is to identify the most suitable retrofit alternatives for an office building, considering economic, environmental and technical criteria. Since the problem may be influenced by several parameters and assumptions, the Stochastic Multicriteria Acceptability Analysis (SMAA) method [11], was employed. This method is specifically designed to consider uncertainty related to criteria measurements.

The SMAA has been applied to several decision-making problems, including energy policy assessment [12], sustainable solution for buildings [13], heating choices for residential area [14] and integration of carbon-neutral technologies into district heating system [15]. A recent survey on the application of SMAA can be found in [16].

In detail, the paper is aimed at assessing the importance of stakeholder preferences when a retrofitting scenario analysis is performed for a typical office building. Three different preferences were analyzed and compared.

The paper is organized as follows: section 2 introduces the methods used for performing the retrofitting analysis. Then, section 3 describes the case study and highlights criteria and preference information used, while in section 4 the alternatives proposed are presented. Section 5 presents the results, while discussion and conclusion are given in section 6.

2 Methods

2.1 Simulation of energy needs and alternatives

The energy demand of an archetype of office building was evaluated by using EnergyPlus 8.0.0 [17], an open source software able to estimate thermal and electrical energy needs of the buildings. The assumptions adopted to model the system were made according to the Italian legislation and previous literature [18], [19]. A more detailed description of the model can be found in [20], [21].

The retrofit measures, described below, were simulated using Matlab [22], in order to evaluate the main input necessary for the SMAA analysis. The model was formulated to satisfy the energy demand over a full year of operation, while optimizing the energy efficiency according to different criteria.

2.2 Stochastic Multicriteria Acceptability Analysis

To evaluate and compare the alternatives proposed the SMAA method [23] was applied, in particular the JSMAA open source version was used [24]. SMAA has been developed for situations where neither criterion nor weights are precisely known.

The problem is formulated as a set of m alternatives $\{x_1, x_2, \dots, x_m\}$ to be evaluated in terms of *n* criteria. The decision makers' preference structure is represented by a value function $u(x_i, w)$. Uncertain criteria are represented by a matrix of stochastic variables ξ_{ij} with a probability density function $f(\xi)$. The value of each alternative is obtained through an additive value function:

$$u(x_i, w) = w_1 * u_{i1} + w_2 * u_{i2} + \cdots + w_n * u_{in} \tag{1}$$

Where the partial values u_{ij} are evaluated through linear scaling with respect to the best and worst outcome into the range [0,1].
Preference information provided by decision makers about weights are represented by suitable weight distribution $f(w)$ in the feasible weight space W, where weights are non-negative and normalized to 1:

$$W = \{W \in R^n \mid w \geq 0 \; and \; \sum_{j=1}^{n} w_j = 1\} \quad (2)$$

Since both criteria and weights are represented by distributions, Monte-Carlo simulation was used to analyze the problem. A value of K=10000 simulations was considered, obtaining an accuracy of around 1%. During the K simulations several statistics figures were computed, including:

- B_{ir}: the number of times alternative x_i obtained rank r;
- W_i: sum of the weight vectors that made alternative x_i most preferred.

Moreover, two descriptive measures, the rank acceptability index (b_i^r) and the central weight vector were evaluated.

The rank acceptability index b_i^r measures the probability that the alternative x_i obtains a certain rank r. The rank acceptability indices are estimated as follows:

$$b_i^r \approx \frac{B_{ir}}{K} \quad (3)$$

The rank acceptability is useful to identify the most acceptable alternative, in fact alternatives with high acceptability for the best ranks are identified as acceptable solution. On the other hand, alternatives with low or zero acceptability index for the best ranks are excluded from further analysis.

The central weight vector w_i^c is the expected center of gravity (centroid) of the favorable first rank weights of an alternative. It represents the preferences of a DM that supports that alternative and may be useful for the decision makers to understand how different weights correspond to different choices. The central weight vector is estimated as follows:

$$w_i^c \approx \frac{W_i}{B_{i1}} \quad (4)$$

3 Case study

The paper analyzes a retrofit process of an archetype of office building considering various preference information. The office building is located in Turin (45.07°N, 7.67°E) that is characterized by a humid subtropical climate and around 2500 heating degree day. In particular, the analysis considers an archetype of an office building constructed in Italy during the 1946–1970 period. According to Rollino [25], the typical office building in Italy until 1970 has a cellular plan, with no more than six floors and located in an urban environment, surrounded by lower building. For the case study here, a four-floor office building was analyzed.

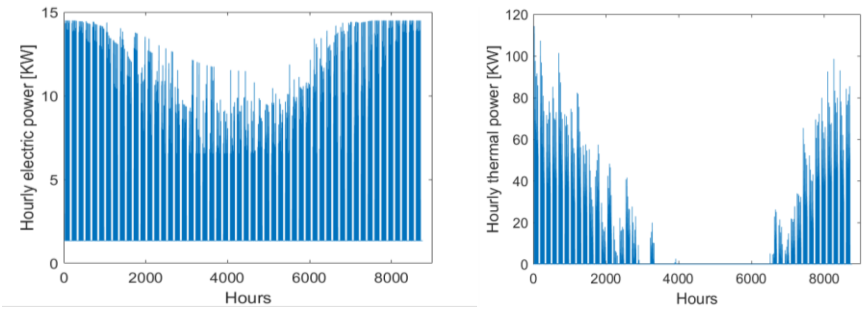


Fig. 1. Simulated electric and thermal load of the building during the year

As can be seen in **Fig. 1**, the electrical load is characterized by a constant base load and a small seasonal variation, while the heat profile has no base load and a strong seasonal variation, due to the temperature variation that influences the heat demand. Moreover, the office is used only in the weekdays, therefore during the weekend there is no heat or electrical demand.

3.1 Criteria and preference information

The multicriteria evaluation considers economic, environmental and technical criteria to analyze and compare various retrofit solutions. The criteria selected here are summarized and briefly described in **Table 1**.

Table 1. Criteria chosen for the analysis

Criteria	Description
INV Investment cost	Cost of initial investment for the alternative
OP Operational cost	Cost of the system including fuel, electricity, maintenance
CO2 emissions	The CO2 emissions during the year
FLEX Flexibility	Fast-response adjustment of production volume

Lifetime cost, that includes both investment and operational cost, is very often used in retrofit projects, however, merging two criteria could introduce dependent uncertainties and lead to a loss of information, reducing the possibility to express stakeholder preferences. Therefore, since the main goal of the analysis is the impact of stakeholder preferences, the two criteria were analyzed individually.

After the criteria selection, the methodology focuses on preference information provided by decision makers. Three scenarios were considered:

- Scenario 1: it gives priority to the investment cost. This may represent the preference of a small-medium company that analyses the possible retrofit of the building.
- Scenario 2: The priority is given both to operational and investment costs, considered of equal importance. This may represent the preferences of a medium-large company.
- Scenario 3: it gives priority to the operational cost. This scenario may represent the choice of an ESCO.

The preference information is summarized and ordered in **Table 2**.

Table 2. Decision makers' preference information

Scenarios	1		2		3		4
Scenario 1	INV	>	OP	>	CO2	~	FLEX
Scenario 2	INV	~	OP	>	CO2	>	FLEX
Scenario 3	OP	>	INV	>	CO2	>	FLEX

4 Design of the retrofit alternatives

The base case includes a gas boiler, used to satisfy the thermal demand, while the electricity is withdrawn from the market to cover the electrical demand (A1).

The retrofit solutions are based on the adoption of three technologies: solar based systems, biomass boiler and internal combustion engine (ICE) cogeneration units. The alternatives are described in the following:

- *Photovoltaic plant*: a solar power plant was integrated on the roof. Based on solar irradiance data [26], two alternatives were analyzed: A2 includes a 10 KW PV plant, sized to cover part of the electrical demand, while A3 considers a 20 KW PV plant, dimensioned to cover the demand and sell electricity surplus. Other three alternative were studied, coupling the 10 KW plant with a cogeneration unit (A6) and two different PV systems of different sizes (10 and 20 KW) with biomass boiler (A8,A9).
- *CHP unit*: two sizes of CHP unit, respectively 10 and 20 KW [27], were integrated with the gas boiler (A4,A5). The smallest size aims to partially cover the electrical demand, while the 20 KW CHP was designed to cover the electrical demand and sell the surplus.
- *Biomass boiler*: The alternative A7 replaces gas boiler with biomass (*pellet*) boiler, assessing economic and environmental benefits.

4.1 Data and assumptions

In the following, technical and economic data, such as emission factors and costs of the different technologies are introduced to evaluate each criterion. Then, the assumptions on the uncertainties of the model are briefly discussed.

As far as the technical data and assumptions are concerned, the investment costs considered for each alternative were assessed according to [28] and reduced by the incentives, taken from [29]. To evaluate the operational cost, for each alternative, the model takes into account fuel costs, electricity costs (withdrawn and sold to the grid) and other variable costs (O&M) and subsidies, taken from [30]–[33]. Looking at environmental and technical criteria, CO_2 emissions were evaluated using emission factors according to [34]. Flexibility of the plant was ranked according to the type of technology and its size, where 1 represent the best alternative and 9 the worst.

Concerning the uncertainties assumptions, the buildings energy models are affected by several type of uncertainties, including technical and demand uncertainties. To simulate the variabilities of investment cost, fuel and electricity prices, and heat and electricity demand, an uncertainty of ±10% was considered for each criterion according to [14]. Uncertainties affect costs and emissions and are represented through a uniform distribution. The flexibility was supposed to be not affected by uncertainty, since it depends only on the type of technology.

5 Results

5.1 Simulation output for different alternatives

In **Table 3**, the investment and operational costs, the emissions and the flexibility for each alternative are shown. In particular, these values are associated with the uncertainties previously discussed and used as input for SMAA simulations, coupled with preference information for each scenario. The table highlights that each alternative lead to a decreasing of operational costs and emissions with respect to the base case. Alternative A6 halves operational costs, while alternative A9 reduce significantly the emissions.

Table 3. Output of the simulation for the alternatives

Alt	INV [k€]	OP [k€]	CO2 [t/y]	FLEX
A1	0	10.5	27	8
A2	9	9	22.5	6
A3	18	8.5	20	4
A4	6.3	9.5	21	3
A5	12.6	8.5	21	2
A6	21.6	5	11	1
A7	5	10	15	9
A8	14	8.7	10	7
A9	19	8.2	8	5

5.2 SMAA results

The rank acceptability index b_i^1 is the probability that the alternative i is the most preferred considering the uncertainties information, therefore it was used as indicator to identify the best solution.

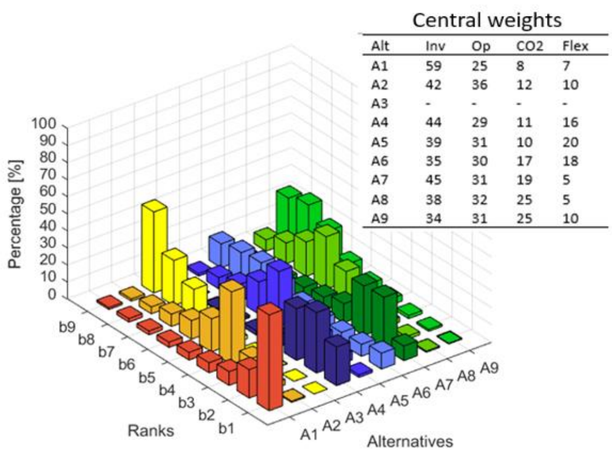
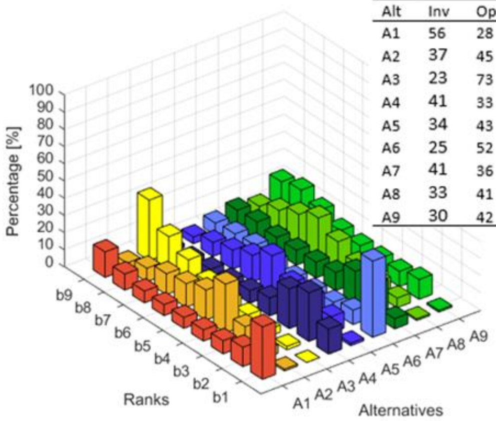


Fig. 2. Rank acceptability indices and central weights for Scenario 1 (%)

As can be seen in **Fig. 2** the most acceptable alternatives are A1 and A4, with acceptability value of 57% and 25%. These results underline how, even if there is high space for improvement, the choice of many companies is influenced by investment cost, even when incentives are provided. The most acceptable alternative excluding the base case is represented by a small CHP, able to reduce both electrical and heat costs with a limited investment cost. The central weights shown in **Fig. 2** represent typical preferences that make each alternative the most preferred. In particular, A1 is preferred if the investment cost obtains ~ 60% of weight, while A4 is preferred when the weights are more homogeneous. **Fig. 3** shows how, changing preference information, as in Scenario 2, the results of the analysis are different. In fact, in this scenario the most acceptable alternatives are A6 and A1, with 40% and 35% acceptability value respectively. Moreover, as can be seen from the weights presented in the **Fig. 3**, A6 is more preferred with respect to the previous scenario if operational costs obtains more importance from stakeholder, while A1 even with the same central weights, obtains less acceptability value.



Central weights

Alt	Inv	Op	CO2	Flex
A1	56	28	11	4
A2	37	45	13	5
A3	23	73	2	2
A4	41	33	17	9
A5	34	43	15	8
A6	25	52	15	7
A7	41	36	19	4
A8	33	41	21	5
A9	30	42	21	7

Fig. 3. Rank acceptability indices and central weights for Scenario 2 (%)

From

Fig. 4 it can be seen that the most preferred alternative for Scenario 3 is clearly A6, with an acceptability value of 74%, followed by alternative A1 and A7 with 8%. As highlighted by the central weights, A7 is the most acceptable solution if more importance is given to environmental criteria. On the other hand, if more importance is given to investment cost, then A1 is identified as most acceptable solution.

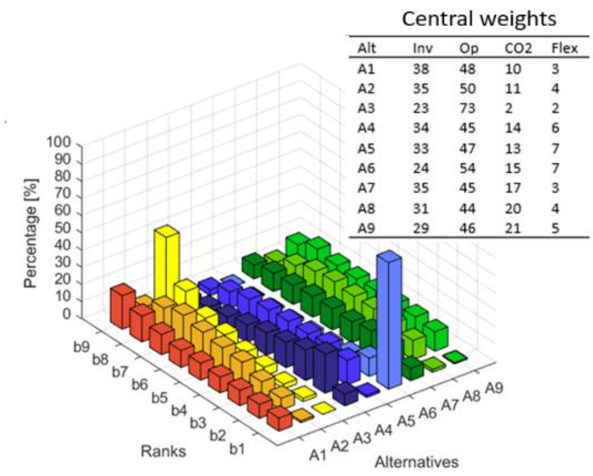


Fig. 4. Rank acceptability indices and central weights for Scenario 3 (%)

6 Discussion

The presented paper aimed at identifying the best retrofit alternative in presence of uncertainties and considering three scenarios with different preference information. SMAA method was used for its capacity to consider uncertainties, differently from other MCDA methods. The analysis is focused on the impact of stakeholder preferences, considering three scenarios. In the first scenario, the possible preferences of a small-company were considered, highlighting how even if there are profit margins for the investment, according to the high importance given to the investment cost, the use of the current heat technology and withdraw electricity from the grid is preferred. On the other hand, scenarios that emphasizes the importance of reducing operational cost suggests as best solution the coupling of a CHP and PV plant. Moreover further analyses showed that assigning a high weight on CO_2 criteria, the best solution remains the coupling of a CHP and PV plant, followed by the coupling of biomass and PV.

The previous scenario could be useful for policy makers, interested more in environmental aspects; moreover, the method is able to overcome the difficulty of assigning precise weights in MCDA method, using ordinal preference information. The use of such method could help decision makers in understanding the impact of their opinion on the analysis.

The weak point of the analysis is the uncertainties assessment that could be improved using the methodology presented in [15], or the method could be improved trying to handle partially conflicting preference information.

Future works may consider the application of the method to residential buildings, try to include other technologies to the system, as electric and thermal storage, or shifting the analysis toward environmental criteria helping policy makers in their decisions.

7 Conclusion

In this study, the stochastic Multicriteria Acceptability Analysis (SMAA) was selected for its ability to identify the best alternative in presence of uncertainties. SMAA method was used to identify sustainable alternatives to produce both electricity and heat in office buildings. Then, the study compared three scenarios consisting in three different stakeholder preferences. The analysis highlights how, even if there is an increasing interest for the environmental aspects, the main drivers of feasibility study are of economic nature, and that the investment cost is still the hardest aspect to face.

The paper highlighted the impact of stakeholder preferences for the retrofit of an office building, pointing out how different preferences can lead to different results and, consequently, how a precise study of stakeholder preferences could influence the outcome of the analysis.

References

[1] International Energy Agency IEA, "Energy Efficiency Indicators Highlights." 2016.

[2] European Commission, "Europe 2020. A European strategy for smart, sustainable and inclusive growth." 2010.

[3] "Europe's buildings under the microscope. A country-by-country review of the energy performance of buildings." .

[4] S. Murugan and B. Horàk, "A review of micro combined heat and power systems for residential applications," *Renew. Sustain. Energy Rev.*, vol. 64, pp. 144–162, 2016.

[5] A. Bagdanavicius and N. Jenkins, "Power requirements of ground source heat pumps in a residential area," *Appl. Energy*, vol. 102, pp. 591–600, 2013.

[6] J.-J. Wang, Y.-Y. Jing, C.-F. Zhang, and J.-H. Zhao, "Review on multi-criteria decision analysis aid in sustainable energy decision-making," *Renew. Sustain. Energy Rev.*, vol. 13, no. 9, pp. 2263–2278, 2009.

[7] A. Maxim, "Sustainability assessment of electricity generation technologies using weighted multi-criteria decision analysis," *Energy Policy*, vol. 65, pp. 284–297, 2014.

[8] S. Matteson, "Methods for multi-criteria sustainability and reliability assessments of power systems," *Energy*, vol. 71, pp. 130–136, 2014.

[9] D. Chinese, G. Nardin, and O. Saro, "Multi-criteria analysis for the selection of space heating systems in an industrial building," *Energy*, vol. 36, no. 1, pp. 556–565, 2011.

[10] E. Wang, "Benchmarking whole-building energy performance with multi-criteria technique for order preference by similarity to ideal solution using a selective objective-weighting approach," *Appl. Energy*, vol. 146, pp. 92–103, 2015.

[11] R. Lahdelma, J. Hokkanen, and P. Salminen, "SMAA - Stochastic multiobjective acceptability analysis," *Eur. J. Oper. Res.*, vol. 106, no. 1, pp. 137–143, 1998.

[12] M. M. Rahman, J. V Paatero, and R. Lahdelma, "Evaluation of choices for sustainable rural electrification in developing countries: A multicriteria approach," *Energy Policy*, vol. 59, pp. 589–599, 2013.

[13] O. Loikkanen, R. Lahdelma, and P. Salminen, "Multicriteria evaluation of sustainable energy solutions for Colosseum," *Sustain. Cities Soc.*, vol. 35, pp. 289–297, 2017.

[14] K. Kontu, S. Rinne, V. Olkkonen, R. Lahdelma, and P. Salminen, "Multicriteria evaluation of heating choices for a new sustainable residential area," *Energy Build.*, vol. 93, pp. 169–179, 2015.

[15] G. Pinto, E. Abdollahi, A. Capozzoli, L. Savoldi, and R. Lahdelma, "Optimization and Multicriteria Evaluation of Carbon-neutral Technologies for District Heating," *Energies*, vol. 12, no. 9, 2019.

[16] R. Pelissari, M. Oliveira, S. Ben Amor, A. Kandakoglu, and A. Helleno, "SMAA methods and their applications: a literature review and future research directions," *Ann. Oper. Res.*, 2019.

[17] D. B. Crawley *et al.*, "EnergyPlus: creating a new-generation building energy simulation program," *Energy Build.*, vol. 33, no. 4, pp. 319–331, 2001.

[18] "EN 15232:2012. Energy performance of buildings - impact of building automation, controls and building management;" .

[19] I. Ballarini and V. Corrado, "Analysis of the building energy balance to investigate the effect of thermal insulation in summer conditions," *Energy Build.*, vol. 52, pp. 168–180, 2012.

[20] Y. Cascone, A. Capozzoli, and M. Perino, "Optimisation analysis of PCM-enhanced opaque building envelope components for the energy retrofitting of office buildings in Mediterranean climates," *Appl. Energy*, vol. 211, pp. 929–953, 2018.

[21] Y. Cascone, "Optimisation of opaque building envelope components withPhase Change Materials," Politecnico di Torino, 2017.

[22] The MathWorks, "MATLAB 2016b." .

[23] R. Lahdelma, K. Miettinen, and P. Salminen, "Ordinal criteria in stochastic multicriteria acceptability analysis (SMAA)," *Eur. J. Oper. Res.*, vol. 147, no. 1, pp. 117–127, 2003.

[24] T. Tervonen, "JSMAA: open source software for SMAA computations," *Int. J. Syst. Sci.*, vol. 45, no. 1, pp. 69–81, 2014.

[25] R. Luca, "Fabbisogni energetici per edifici caratterizzanti il terziario in Italia: aspetti termici e illuminotecnici," Politecnico di Torino, 2012.

[26] PVGIS, "Photovoltaic Geographical Information System." [Online]. Available: http://re.jrc.ec.europa.eu/pvgis/. [Accessed: 29-Oct-2018].

[27] Asja Group, "TOTEM energy." [Online]. Available: http://www.totem.energy/wp-content/uploads/TOTEM_ST.pdf. [Accessed: 02-Aug-2019].

[28] M. Badami, G. Chicco, A. Portoraro, and M. Romaniello, "Micro-multigeneration prospects for residential applications in Italy," *Energy Convers. Manag.*, vol. 166, pp. 23–36, 2018.

[29] ENEA, "Ecobonus2018," 2018. [Online]. Available: https://finanziaria2018.enea.it/index.asp. [Accessed: 02-Nov-2019].

[30] AIEL, "Costo del pellet: scenario sul mercato nel 2019." [Online]. Available: http://www.aielenergia.it/public/rassegna_stampa/378_1 febbraio 2019 biomassapp.it.pdf. [Accessed: 12-Mar-2019].

[31] GSE, "Ritiro dedicato." [Online]. Available: https://www.gse.it/servizi-per-te/fotovoltaico/ritiro-dedicato. [Accessed: 03-Jan-2019].

[32] EIA, "Updated Buildings Sector Appliance and Equipment Costs and Efficiencies." .

[33] M. Badami, F. Camillieri, A. Portoraro, and E. Vigliani, "Energetic and economic assessment of cogeneration plants: A comparative design and experimental condition study," *Energy*, vol. 71, pp. 255–262, 2014.

[34] Covenant of Mayors, "The emission factors." [Online]. Available: https://www.eumayors.eu/IMG/pdf/technical_annex_en.pdf. [Accessed: 02-Apr-2019].