A joint Multi Criteria – Cost Benefit Analysis for project selection on smart grids

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***Abstract*— Techno-economic assessment methodologies are fundamental tools both for defining strategic policies and for selecting the worthy investment options. Since smart grid transition and the increasing demand for novel decision support tools, a joined Multi Criteria – Cost Benefit Analysis (MC-CBA) is presented in this paper. The aim is to provide an assessment framework for smart grid projects which considers monetary and non-monetary impacts. The joint approach is proposed for outclassing the weaknesses of both CBA and MCA by emphasizing their strengths. The MC-CBA framework is employed for identifying the best option among a set of active network distribution planning alternatives. The monetisation of all impacts is not required; hence, the MC-CBA is suitable for assessing social and technical impacts without introducing any underlying bias. The aim of the proposed MC-CBA is to help companies and government bodies in strategic planning.**

Keywords—distribution network planning, distributed energy storage, multi-criteria analysis, decision making

I. INTRODUCTION

The electrical power system is currently experiencing the smart grid transition. Several key drivers such as environmental concerns, market liberalization, increase of distributed renewable energy are leading the transformation to an active and bidirectional network scheme. In this novel scenario, the traditional planning methodologies are no longer effective [1]. In distribution system planning, expansion plans and reinforcements activities are defined in order to meet the expected future scenario. Since the increased complexity of the power system, this process has to satisfy more goals than the cost minimisation constrained by the quality of supply. Each planning option has to achieve a satisfactory level of performances on, e.g., energy losses, hosting capacity, self-healing, cyber-security, reduced emissions, customer participation. In this context, traditional assessment approaches based on economic tools (i.e., Cost-Benefit Analysis - CBA) which aggregates all objectives into a single criterion may lead to suboptimal plans. Furthermore, not all costs and benefits produced by an expansion plan are quantifiable and/or monetizable; this kind of impact are intractable for classic CBA [2], [3]. With the aim to assess independently several conflicting criteria and include in the analysis the intractable impacts, Multi-Criteria Analysis (MCA) resorts in planning activities [1], [3]–[6]. Since CBA and MCA are complementary tools, a combined assessment framework may be devised in order to emphasize their strengths. A combined assessment approach is promoted both at an academic and regulatory level on several sectors [4], [7]–[9]. In this paper, a combined MC-CBA assessment framework is proposed. This framework is based on international recommendations and guidelines on project analysis, it allows for a systematic and simultaneous assessment of different impacts. The aim is to provide a decision-making tool which helps both system operators and regulatory bodies for smart grid projects assessment by complying with the novel context requirements. To present the MC-CBA framework, a case study focused on the decision-making problem of smart grid planning alternatives is described. More specifically, a set of different upgrading plans based on the Active Distribution Network (ADN) approach is analysed for identifying the best planning option.

II. APPROACHES FOR TECHNO-ECONOMIC ASSESSMENT

From the governance point of view, smart grids are considered as the mean for reaching several strategic objectives such as promote renewable energy sources, enhance the security of supply, foster energy efficiency, and increase the active role of customers in a liberalised energy market [10]. Smart grids will enable novel features and services in the distribution system whose impacts will cross the power system borders. To illustrate, market liberalisation, dispersed generation, smart metering, electric vehicles and flexible services such as demand response will influence the customer daily habits and will impact on the society as a whole. Since smart grids are mainly related to public sector investments, traditional tools used for project appraisal in the private sector show several fundamental shortcomings [2], [5], [9]. CBA is based on welfare economics principles [11], as underlying hypothesis assumes people as consumers and considers goods and services which are exchanged within a market. In the private sector the tangible impacts are majoritarian, and the investor target is to maximise the profits. Conversely, in public sector, people are involved as citizens and the offered goods and services do not have a market. Moreover, intangible impacts are not negligible, and the main investor goal is to maximise the efficiency and the effectiveness of investment cost. Since these fundamental differences, CBA used in the public sector is not directly applicable: the required adjustments on quantifying, monetising, and discounting techniques weaken the CBA validity.

MCA is an operation research tool for complex decision making [12]. Among MCA, Multi-Attribute Decision-Making (MADM) methods help in identifying the best option among an explicitly known set [13]. For the sake of simplicity, this paper refers only to this branch of approaches as MCA methods. MCA allows for appraising heterogenous and conflicting criteria: tangible and intangible impact can be simultaneously evaluated. Furthermore, the stakeholder point of view is directly involved in the evaluation process by means of the definition of criteria relevance [12]. These features make MCA suitable for strategic decision-making within public sector; however, no explicit rule such that benefits must exceed costs exists (Kaldon-Hicks criterion),

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hence the identified best option may not purse well-being improvement: the "doing nothing" principle might result as preferable [12].

CBA and MCA are not mutually exclusive tools, therefore a combined approach for project analysis can be devised with the aim to fill the respective gaps while preserving the respective strengths [8].

Since the relevance of techno-economic assessment in strategic decision-making, decision-support tools are widely investigated in Literature; in the following several recent research works on electricity sector are briefly described. In [14], a sequential MCA-CBA for demonstrating the effectiveness of storage in the distribution network is presented. A large number of plans involving storage devices are devised by using a multi-objective optimisation approach. Then, the economic sustainability of the alternatives belonging to the Pareto front is assessed by a CBA. The study has been promoted by the Italian regulator to define the conditions under which remunerate the DSOs which owns and operates storage for network issues. In [15], an improved CBA (CBA 2.0) is used for evaluating several case studies concerning the Italian transmission system. The approach is based on two sets of impact categories, the first is monetised as far as possible while the second is qualified. Since the aim is to find a reliable monetary value for all impacts, a monetisation technique is proposed also for the second set. In [16], a selection problem of distribution planning projects is solved by using an MCA technique (TOPSIS). The best option among the given set is identified considering 3 economic and 5 technical criteria. Three different stakeholders' perspectives are investigated, the resulting best option is different in the 3 scenarios.

III. THE MC-CBA FRAMEWORK

In this paper, an MC-CBA approach for smart grid project assessment is presented. Within the MCA framework, the economic criterion evaluates the result of a CBA focused on monetised impacts. Conversely, other tangible and the intangible impacts are appraised by means of several evaluation criteria according to MCA principles. The overall assessment of each planning option is obtained by combining the result obtained from the monetary evaluation with the result of the non-monetary one. The MC-CBA framework for smart grid planning assessment used in this paper is based on international guidelines [4], [17]. These fundamentals grant validity to the proposed approach whose novelty is the formalisation of the assessment procedure. The MADM technique implemented to compute the overall score of the alternative is based on the fundamentals of the Analytic Hierarchy Process (AHP) [18]. In this section, the key elements of the MC-CBA framework are described.

A. The hierarchy and relevance of criteria

A hierarchical structure of criteria is used for decomposing the decision-making problem. The hierarchy of criteria is organised according to the principle of abstraction. Therefore, the main goal at the head of the hierarchy is referred to the strategic objectives, the intermediate objectives placed in the first level of the hierarchy represent general goals on specific sectors related to the main goal of the decision problem. The second level hosts criteria which describe specific objectives of the sector. The last level contains the terminal criteria whose fulfillment is directly measurable by means of the performance indicators. The hierarchy is formed by three independent branches: the economic evaluation, the smart grid deployment merit evaluation, and the evaluation of externalities. The overall goal of the hierarchical tree is to identify the best project option according to the decision maker's (DM) perspective. The first branch assesses the economic performances of each alternative by evaluating the result obtained from a CBA of monetary impacts. The second branch is focused on the assessment of the contribution towards the smart grid realization given by each project option. This contribution is evaluated according to the Policy Criteria (PCs) and the related Key Performance Indicators (KPIs) proposed by the Joint Research Centre (JRC) [4], [17]. The smart grid deployment merit evaluation is output-based: the evaluation is focused on the effects produced by the infrastructure, instead of its technical features. The third branch assesses the externalities produced by the investment option. Several thematic areas can be defined to aggregate single impacts. The former is the second level criteria of the overall hierarchy, while the latter are the related terminal criteria. Once the evaluation criteria are decided, each branch is independently evaluated. The criteria relevance depends on stakeholders' perspective, the criteria weights are defined accordingly. Each criterion has a local weight (or local priority) referred to the parent criterion and defined with respect to the other criteria which belong to the same level of the hierarchy. Conversely, the global weight (or global priority) of each criterion measures its relevance with respect to the main goal at the head of the hierarchy. The global weight is computed from the local weights according to the hierarchical composition principle [19].

B. The normalised score of the alternatives

According to MCA principles, each impact has to be measured by using a quantitative or qualitative index. Together with criteria relevance, the performances of the alternatives measured by the indicators are the key elements of an MCA. Each indicator measures the fulfillment of the related terminal criterion of the hierarchy. The Performance Matrix (PM) of the decision-making problem contains, for each alternative under analysis, the values of the indicators. In general, the indicators related to different terminal criteria have different measurement unit. A normalisation procedure is necessary to combine the performance obtained on different criteria. In this paper, the automatized scoring process proposed by the authors in [5] is used. By means of an automatized pairwise comparison procedure, the used scoring process allows to obtain a normalised score for each alternative on each terminal criterion.

C. The overall score of the alternatives

Since the three branches are independent, three partial scores are computed for each alternative. For each of the three branches of the criteria hierarchy, the partial scores of the alternatives are evaluated as in (1).

$$\overline{P_b} = \underline{S} \cdot \overline{W} = \begin{bmatrix} s_{1,1} & \cdots & s_{1,h} \\ \vdots & \ddots & \vdots \\ s_{r,1} & \cdots & s_{r,h} \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ \vdots \\ w_h \end{bmatrix} \qquad (1)$$

Where $\overline{P_b}$ is the vector of the partial scores of the alternatives for the *b-th* branch. $\underline{S}$ is the matrix of the normalised scores of the alternatives with respect to each terminal criterion. $\overline{W}$ is the vector of global weights of the terminal criteria. r is the number of alternatives, while h is the number of terminal criteria. $s_{i,j}$ is the normalised score of the *i-th* alternative with respect to the *j-th* terminal criterion. w_k is the global weight of the *k-th* terminal criterion.

Similarly, the overall score of each alternative is obtained by linearly combining the three partial scores with the global relevance of each branch, as shown in (2).

$$\overline{S} = [\overline{P_1}, \dots, \overline{P_{n_b}}] \cdot \overline{V} \qquad (2)$$

Where $\overline{S}$ is the vector which contains the overall score of the alternatives, dimension $(r, 1)$. $\overline{V}$ is the vector which contains the global weight of the three branches, dimension $(n_b, 1)$, where n_b is the number of branches. $\overline{P_i}$ is the *i-th* vector which contains the partial scores of the alternatives with respect to the *i-th* branch of the hierarchy.

The alternative which achieves the highest overall score is identified as the best option by the MC-CBA framework.

IV. CASE STUDY

A. *The distribution network under analysis*

The case study presented in this paper concerns the analysis of a set of distribution grid planning alternatives. The portion of the distribution grid represents a typical rural scenario; the network is weakly meshed with emergency tie connections and radially operated [5]. As represented in Fig. 1, the network is fed by two primary substations (nodes 1 and 2) and it has 22 MV nodes. The radial structure is divided into four zones: A1, B1, B2, C1. The zone A1 is an urban area characterised by two underground feeders. The zones B1 and B2 are rural areas fed by means of overhead feeders and several distributed generators. The zone C1 is a passive rural area fed by a lateral branch. The underground feeders are 95 mm^2 MV cables, while overhead MV lines trunk feeders and lateral branches have sections of 35 mm^2 and 16 mm^2 respectively.

B. *The planning alternatives under analysis*

The planning alternatives under analysis are a set of reinforcement plans based on the ADN approach. This novel approach differs from traditional *fit and forget* since it combines *network solutions* and active management strategies with the aim to maximise the exploitation of the existing infrastructure. The active management strategies are also known as *no-network solutions,* they involve e.g., reactive power management, system reconfiguration, generator dispatch, demand-side management. In this paper, along with line and substation upgrading, the siting, sizing, and management of Distributed Energy Storage (DES) devices is provided as a *no-network solution*. The aim of this paper is to present a systematic framework for project analysis and selection, the information required by the presented MC-CBA framework is only related to the performance achieved by each planning option, at this stage the assessment does not require information about how a reinforcement plan has been devised. However, for the sake of completeness, a brief description of the process which devised the alternatives is given. Each reinforcement plan under analysis has been devised by a multi-objective planning optimisation. A Pareto front has been obtained by using the procedure described in [20]. Each plan has a time horizon of 10 years, the network topology and the number of distributed generators are fixed. A load growth rate of 3% per year is considered for each MV/LV node. Uncertainties have been introduced by modelling loads and generators with typical daily profiles and normal probabilistic distribution functions. The technical constraint violation risk is evaluated hourly by means of a probabilistic load flow. Steady state and emergency configurations are assessed. The multi-objective optimisation planning procedure considered 9 objectives: network investment, energy losses, reactive power exchange with the Transmission System Operator (TSO), quality of service in terms of number of interruptions, quality of service in terms duration of the interruptions, quality of service in terms of voltage dips, voltage profile quality, black start support, and DES investment. The DES devices considered are Li-ion batteries with 10 years of expected lifetime. Each reinforcement plan is characterised by up to 2 DES devices having a nominal power within the range 100 kW ÷ 3 MW and a nominal duration within the range 1 ÷ 10 hours. The Distribution System Operator (DSO) owns the DES devices which are used for network operation; conversely, their use for energy price arbitrage is forbidden.

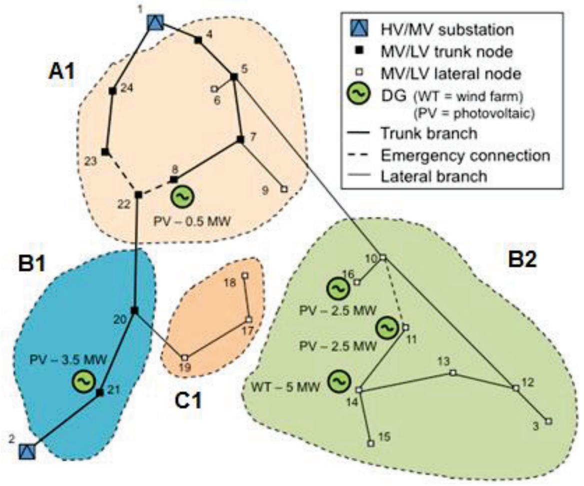

Fig. 1. Distribution network of the case study [5]

C. *The criteria hierarchy*

According to MCA principles, a set of relevant evaluation criteria has to be identified with the aim to effectively assess the alternatives. The hierarchy of evaluation criteria selected in the present case study is depicted in Fig. 2.

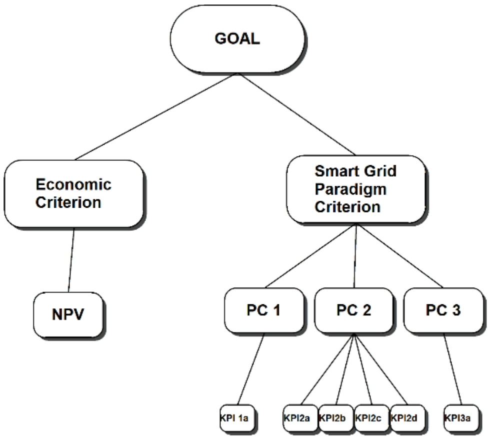

Fig. 2. Overview of the hierarchy of evaluation criteria

The decision-making problem is addressed from the utility perspective which proposes the plans, the externality impacts have been neglected due to the unavailability of data. The economic assessment is based on the performance achieved by the alternatives in terms of Net Present Value (NPV). This indicator is evaluated by means of a CBA which concerns the three monetary impacts: the investment cost of traditional network reinforcement solutions, the investment cost in DES devices, and the cost related to the reactive power exchange with the transmission grid. The smart grid deployment merit is evaluated by means of the list of criteria proposed by the JRC [4], [17]. The proposed list is general purpose for the smart grid context, therefore the most suitable subset of criteria has to be identified according to the decision-making problem at hand. The 3 PCs chosen for the present case study are: network connectivity and access to all categories of network users (PC1), security and quality of supply (PC2), and efficiency and service quality in electricity supply and grid operation (PC3). The related KPIs are: operational flexibility provided for dynamic balancing of electricity in the network (KPI_{1A}), stability of the electricity system (KPI_{2A}), duration (KPI_{2B}) and frequency (KPI_{2C}) of interruptions per customer, voltage quality in terms of voltage variations (KPI_{2D}), and level of losses in distribution networks (KPI_{3A}). The overall hierarchy is characterised by 7 terminal criteria. The performances of the alternatives on these criteria are assessed by means of quantitative indicators. The formulas for evaluating the numerical value of each indicator are described in this section.

1) NPV

The Net Present Value of each alternative is evaluated as the sum of discounted benefits and costs, as in (3).

$$NPV = C_{inv}^{T} + C_{inv}^{DES} + Q_{EXC} \tag{3}$$

Where C_{inv}^{T} is the investment cost of traditional network reinforcement solutions; C_{inv}^{DES} is the investment cost of DES devices; Q_{EXC} is the monetary value of the reactive power exchange with the transmission grid. Each term is discounted by considering a fixed discount rate of 4%. The plan which achieves the highest NPV is the best option according to the economic assessment.

2) KPI_{1A}: Operational flexibility

The KPI_{1A} evaluates the contribution in terms of flexibility given by the alternative to the operation of the grid. This contribution depends on the dispatchable resources available in the network. In the case study, DES devices are the only dispatchable units. Considering the available information on the expansion plans, the KPI_{1A} is evaluated by (4).

$$\text{KPI}_{1\text{A}} = \sum_{i=1}^{N_{DES}} \frac{(\hat{P}_{DES,i}^{(out)})_{SG} + \left|(\hat{P}_{DES,i}^{(in)})_{SG}\right|}{2} \tag{4}$$

Where N_{DES} is the number of DES devices provided by the alternative; $(\hat{P}_{DES,i}^{(out)})_{SG}$ is the expected maximum power generated by the *i-th* device in the planning horizon; $(\hat{P}_{DES,i}^{(in)})_{SG}$ is the expected maximum power adsorbed from the grid by the *i-th* device in the planning horizon. The alternative which contributes more to operational flexibility is the one which achieves the maximum value of the $\text{KPI}_{1\text{A}}$.

3) KPI_{2A}: Power system stability

The KPI_{2A} evaluates the contribution of the planning alternatives in relieving the possible sources of system instability. JRC suggests simulating the system behaviour in several extreme scenarios [17]. Since the available information on the alternatives, a different approach is used. Taking into account that DES devices can contribute to network black-start, a potential ex-post contribution to the system reliability is considered in this paper. The performance indicator for KPI_{2A} is computed by (5).

$$\text{KPI}_{2\text{A}} = P_{BS} = \sum_{i=1}^{N_{DES}} \sum_{h=1}^{N_h} \min(SoC_{h,i} \cdot \eta_{dis,i}, P_{n,i}) \tag{5}$$

Where P_{BS} is the amount of active power available for the black-start service; N_{DES} is the number of DES devices provided by the alternative; N_h is the number of time intervals of the planning period; $SoC_{h,i}$ is the state of charge of the *i-th* device in the *h-th* time interval; $\eta_{dis,i}$ is the discharging efficiency of the *i-th* device; $P_{n,i}$ is the nominal power of the *i-th* device. The planning option that achieves the highest value of $\text{KPI}_{2\text{A}}$ better performs in terms of black-start support.

4) KPI_{2B}: Duration of interruption

The KPI_{2B} evaluates the contribution of the planning alternatives in reducing the duration of the interruptions for each customer; therefore, the KPI_{2B} corresponds to the System Average Interruption Duration Index (SAIDI), it is evaluated as shown in (6).

$$KPI_{2B} = SAIDI = \frac{\sum_{i=1}^{n} U_i NC_i}{\sum_{i=1}^{n} NC_i} \tag{6}$$

Where U_i is the duration of outages for the customers in the *i-th* bus; NC_i is the number of customers in the *i-th* bus; *n* is the number of busses in the network. The planning option that achieves the lowest value of $\text{KPI}_{2\text{B}}$ better performs in terms of duration of interruptions.

5) KPI_{2C}: Frequency of interruption

The KPI_{2C} evaluates the contribution of the planning alternatives in reducing the frequency of interruptions for each customer; therefore, the KPI_{2C} corresponds to the System Average Interruption Frequency Index (SAIFI), it is evaluated as shown in (7).

$$KPI_{2C} = SAIFI = \frac{\sum_{i=1}^{n} \lambda_i NC_i}{\sum_{i=1}^{n} NC_i} \tag{7}$$

Where λ_i is the failure rate in the *i-th* bus; NC_i is the number of customers in the *i-th* bus; *n* is the number of busses in the network. The planning option that achieves the lowest value of $\text{KPI}_{2\text{C}}$ better performs in terms of frequency of interruptions.

6) KPI_{2D}: Voltage variations

The KPI_{2D} evaluates the contribution of the planning alternatives in rejecting voltage variations. DES can contribute to voltage regulation by means of the power factor management. In this paper, the KPI_{2D} is evaluated by (8).

$$KPI_{2D} = \sum_{i=1}^{n} \sum_{h=1}^{N_h} \left|V_{max.i}^{(h)} - V_{min.i}^{(h)}\right| \tag{8}$$

Where *n* is the number of busses in the network; N_h is the number of time intervals of the planning period; $V_{max.i}^{(h)}$ is the maximum voltage value in the *i-th* bus at the *h-th* interval;

$V_{min.i}^{(h)}$ is the minimum voltage value in the *i-th* bus at the *h-th* interval. The planning option that achieves the lowest value of $\mathrm{KPI}_{2\mathrm{D}}$ better performs in terms of voltage variations.

7) KPI_{3A}: Energy losses

The $\mathrm{KPI}_{3\mathrm{A}}$ evaluates the contribution of the planning alternatives in reducing the network energy losses. DES can contribute in reducing network losses by providing the peak shaving service. The $\mathrm{KPI}_{3\mathrm{A}}$ is evaluated by (9).

$$KPI_{3A} = \sum_{j=1}^{N_e} \sum_{k=1}^{N_h} E_{L_{j,k}} \tag{9}$$

Where N_e is the number of element considered for the assessment of energy losses (HV/MV transformers, lines); N_h is the number of time intervals of the planning period; $E_{L_{j,k}}$ is the energy loss of the *j-th* element in the *k-th* time interval. The planning option that achieves the lowest value of $\mathrm{KPI}_{3\mathrm{A}}$ better performs in terms of energy losses.

D. Planning alternatives and Performance Matrix

The case study presented in this paper concerns 5 planning alternatives. Each planning option provides both line and substation upgrading and DES siting and sizing. An overview of DES siting and sizing of the alternatives is given in Table I. Since the MC-CBA framework is output-based, for the sake of brevity only the data required by the assessment is reported in the paper. The alternative labeled A_1 is the baseline scenario, hence no DES devices are involved in. In addition, in Table II the PM of the alternative is shown. The values in Table II are obtained from data provided as output by the multi-objective planning optimization process which devised the alternatives. Therefore, the values are based on simulating the scenario related to each alternative for the whole planning period, as described in IV.B.

TABLE I. TOPOLOGICAL INFORMATION ON DES

Option	DES bus	DES power rate [kW]	DES energy size [kWh]
A_1	No DES	0	0
A_2	7	100	100
A_3	14	200	400
A_4	16	100	100
A_5	14	100	100

E. Local and global weights of criteria

MCA requires to define a numerical weight for each criterion according to their relevance for the DM or stakeholders. The economic branch has in its lower level a unique criterion, the local weight of the NPV criterion is equal to 1. The smart grid deployment merit branch is divided into 3 sub-branches. According to JRC recommendation, criteria belonging to the same level of the hierarchy have the same weight; therefore, the PCs are equally relevant: their local weight is 1/3. Furthermore, the local weight of $\mathrm{KPI}_{1\mathrm{A}}$ and $\mathrm{KPI}_{3\mathrm{A}}$ is 1, whereas the local weight of each KPI related to PC2 is equal to 0.25. By considering an equal relevance of the two branches, the hierarchical tree has been evaluated according to the hierarchical composition principle; the resulting global weights of the terminal criteria are shown in Table III.

TABLE III. GLOBAL WEIGHTS OF TERMINAL CRITERIA

Terminal criterion	Global weight
NPV	0.5
$\mathrm{KPI}_{1\mathrm{A}}$	0.16667
$\mathrm{KPI}_{2\mathrm{A}}$	0.04167
$\mathrm{KPI}_{2\mathrm{B}}$	0.04167
$\mathrm{KPI}_{2\mathrm{C}}$	0.04167
$\mathrm{KPI}_{2\mathrm{D}}$	0.04167
$\mathrm{KPI}_{3\mathrm{A}}$	0.16667

V. RESULTS AND DISCUSSION

The result obtained by means of the MC-CBA is shown in Table IV. The alternative which achieves the highest overall score is the A_5; therefore, A_5 is the best option according to the MC-CBA assessment made by considering the criteria relevance defined in Table III. The worst alternative is the baseline scenario (A_1). Observing the partial scores on the two branches, the alternative A_5 scores the highest in the economic branch, while the A_4 is the best alternative according to the smart deployment merit evaluation. A_4 is the more effective in satisfying the smart grid criterion, however, has an economic performance lower than A_5, hence the latter is preferred by the overall evaluation. Since both alternatives provide a same sized DES device, the difference on the economic performance depends on its management which yields to a different network investment cost and/or reactive power exchange. A_3 is similar to A_5, but the DES device installed in the bus 14 has a bigger size and the performance on the economic criterion is lower. Even if A_3 installs a bigger device than A_4, the performances on the smart grid deployment merit branch are lower than A_4; hence, topology and scheduling of storage strongly influence the benefits that a device produces, size is not the only key factor that has to be considered. In Fig. 3 the result of a sensitive analysis made by varying the relevance assigned to the two branches is depicted. Accordingly to partial scores, the alternatives A_4 and A_5 are the only options identified as best option in the criteria weight range.

TABLE II. PM OF THE DECISION-MAKING PROBLEM

Option	Economic branch	Smart Grid Branch					
	NPV [k€]	*KPI_{1A} [MW]*	*KPI_{2A} [MW]*	*KPI_{2B} [occ/y]*	*KPI_{2C} [h/y]*	*KPI_{2D} [pu]*	*$KPI3_{A}$ [MWh]*
A_1	0	0	0	2.026	0.837	11.48	11216.1
A_2	4.257	66.2	1269.2	2.017	0.751	10.68	10677.7
A_3	3.371	184.2	2903.9	2.017	0.751	10.68	10701.3
A_4	12.905	48.4	984.6	2.017	0.751	10.68	10661.3
A_5	88.587	38.2	574.1	2.017	0.751	10.69	10682.4

More specifically, the breakpoint is 0.24. If the economic branch has a local weight lower than 0.24 (hence the smart grid deployment merit branch has a local weight higher than 0.76), the best alternative according to the MC-CBA framework is A_4. Contrariwise, the best alternative is A_5.

TABLE IV. OVERALL AND PARTIAL SCORES

Option	Overall score	Partial score Economic Branch	Partial score Smart Grid Branch
A_5	0.2749	0.3204	0.2295
A_4	0.2468	0.2387	0.2549
A_3	0.2273	0.2072	0.2475
A_2	0.2242	0.2072	0.2411
A_1	0.0268	0.0265	0.0270

VI. CONCLUSIONS

In this paper, a MC-CBA framework for smart grid project assessment is presented. The proposed approach is general purpose since it can be used for assessing any smart grid asset by identifying the relevant evaluation criteria. The aim of the proposed MC-CBA framework is to help DMs of companies and government bodies in strategic planning. By identifying the best option and by analysing the sensitivity with respect to criteria weights, the DM obtains an overview of the effects produced by each alternative. The effectiveness of complex planning problem is increased since the DM is supported by a systematic framework which simplifies the analysis and rejects personal biases. The usefulness of support decision tools, as the presented MC-CBA framework, rises together with the decision-making problem dimension. As the number of criteria and/or alternatives increases, identifying the best option become extremely difficult and burdensome. Moreover, the presented MC-CBA framework does not require to convert all impacts in monetary terms, hence it is suitable for accounting social and technical impacts of power system planning without introducing any underlying bias.

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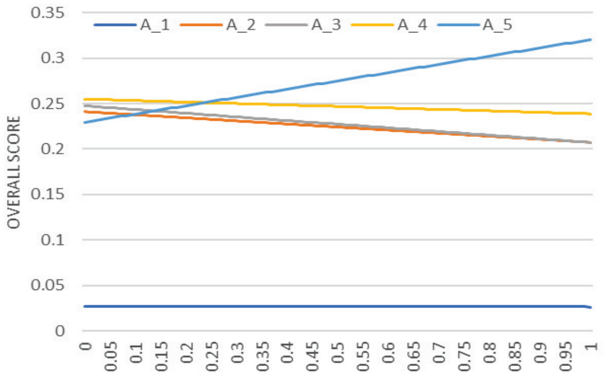

Fig. 3. Sensitivity analysis on the first level criteria weight

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