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Application of Cost Benefits Analysis for the Implementation of Renewable Energy and Smart Solution Technologies: A Case Study of InteGRIDy Project †

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Abstract: Cost–benefit analysis is a common evaluation method applied to assess whether an energy system is economically feasible as well as the economic viability of energy investment for the energy transition of a pre-existing energy system. This paper focuses on examining the economic costs and benefits obtained through the implementation of renewable energy and smart technology to a pre-existing energy system of two pilot sites—St. Jean and Barcelona. The evaluation process includes all relevant parameters such as investment, operating and maintenance costs, and energy prices needed to assess the economic feasibility of the investment. The results show that investing in energy system development towards a decarbonized future, can provide various benefits such as increased flexibility, and reduced emissions while being economically feasible.

Keywords: cost benefit analysis; feasibility assessment; renewable energy; smart technology; energy storage; demand response; European project

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1. Introduction

There has been an increased push for global, national, and regional efforts to intensify and boost energy system development that enables an energy transition towards a cleaner and decarbonized energy system [1–3]. This push is driven by various factors, such as resource scarcity, which impacts on the access and availability of fossil fuels, and adverse climate change impacts from fossil fuels, which requires the phasing out of burning fossil fuels in our global energy system [1–8]. Cost–benefit analysis (CBA) is one of the methods often applied to help decision-makers understand the potential economic expenditure and economic gains associated with energy development that enables the implementation of renewable energy, alternative fuel vehicles, and smart technologies to the current energy system [3,9–11]. The focus of a CBA is based around an overall assessment of investment of the proposed project, and it must consider all cost and benefit parameters. The results obtained from CBA are expressed in monetary values and provide an insight into the overall economic impact and positive as well as negative gains associated with a specific investment [9–11]. The CBA has been applied to assess and identify the costs and benefits of energy development and sustainable development. It has been used to assess the cost recovery of new energy technology development [9]. CBA has also been used to assess the economic benefits and costs of renewable energy implementation to phase out coal as well as energy efficiency improvements with the electricity grid to decrease electricity generation from coal power plants [3]. This paper aims to identify the economic gains for the integration of renewable energy, energy storage, optimization, and distribution technologies to the already existing energy system within St-Jean and Barcelona pilot sites. The work presented in this paper is part of the InteGRIDy EU Horizon 2020 project completed in September 2021.

2. Description of Pilot Sites

2.1. St Jean Pilot Site

For the St-Jean pilot site located in France, the cost–benefit analysis consists of two scenarios:

- Scenario A—Conventional Energy System grid with no Renewable Energy Technology implementation.
- Scenario B—Renewable Energy Technology Integration, Energy Flexibility and Storage capabilities.

Scenario A focuses on the energy system without renewable energy technology and is based on the assumptions that the energy supply from pre-existing energy systems is solely coming from conventional fossil energy resources without any localized energy technologies. In comparison, Scenario B is based around the introduction and implementation of renewable energy technologies and smart technology solutions to the pre-existing energy system from scenario A. The key difference between these two scenarios is that scenario A is a 100% conventional energy system based on fossil fuel. In contrast, scenario B is based on the same energy system as that in scenario A and localized renewable energy and the introduction of future renewable energy and smart technology development.

Table 1 does illustrate key cost parameters and input values used for the analysis, which were based on assumptions and derived from secondary data and discussion with locally based inteGRIDy partners.

Table 1. St Jean Key CBA parameters, assumptions, and inputs.

St Jean Pilot Site		
Energy Price per MW (PV)	€380.00	At the first year
Energy Price per MW (National Grid)	€110.74	At the first year without taxes
Centrale des Clapeys	€70.00	At the first year
Centrale de Saint Julien Montdenis	€75.70	At the first year
Centrale de la Neuvachette	€83.20	At the first year
Energy Imports Growth	1.20%	per year
Growth in RE Generation	5%	36%—until 2028
O&M cost annual increase (Hydro)	3%	of total investment
Energy Consumption growth rate	−1.50%	per year
Annual Price Decrease (PV)	6.30%	per year
Average Annual Price increase	5%	per year
Discount Rate set by France Authorities	2.8%	
Energy index tariff evolution	1.12%	
PV—Annual Investment from 2020 to 2023	€464,600.00	
PV—Annual Investment from 2023 to 2028	€920,000.00	
Hydro—Annual Investment to 2023	€965,333.33	
Hydro—Annual Investment to 2028	€2,606,400.00	
Hydropower plant Centrale Valloirette (3 MW)—2023 O&M costs	€55,000.00	Per year
Hydropower Plant 1MW—2026 O&M costs	€35,000.00	Per year
Hydropower Plant 1MW—2027 O&M costs	€35,000.00	

2.2. Barcelona Pilot Site

The Barcelona pilot, Spain, is categorised as a large-scale pilot site within the inteGRIDy project. This pilot site aims to evaluate the implementation of energy-saving measures and demand response through the installation of monitoring equipment for a building energy management system. The Barcelona pilot is also equipped with a storage solution focusing on the capability of distributed end-user energy storage facilities based on distribution Li-Lon batteries to provide increased grid penetration potential of renewable energy systems.

The cost–benefit analysis for the Barcelona pilot site consists of and considered two scenarios.

- Scenario A—Conventional energy system without the implementation of any smart solution technology.
- Scenario B—Smart solution implementation in addition to the conventional energy system.

Table 2 does illustrate key cost parameters and input values used for the analysis, which were based on assumptions, and were derived from secondary data and discussion with locally based inteGRIDy partners.

Table 2. Barcelona Key CBA parameters, assumptions, and inputs.

	Barcelona Pilot Site	
Energy Price (€/MWh) Conventional	68.45	At the first year
Energy Price (€/MWh) PV	68.45	At the first year
Gas Price (€/MWh)	45.85	At the first year
Increase in energy price (Conventional)	2.5%	Per year
Increase in energy price (PV)	3.5%	Per year
Energy Consumption Growth Rate	−0.5%	Per year
Carbon Dioxide Emission Ratio	0.331	Per kWh
Exchange rate	1.16	Pounds to Euros

The implementation of renewable and smart technologies considered for cost benefit evaluation of the Barcelona Pilot site can be characterised into two groups; the PV system with battery storage technology classified as Technology A, and the Integrated Energy Platform is classified as Technology B. Associated costs with Technology A and Technology B are summarised in Table 3a,b.

Table 3. Cost-specific information for both technologies.

(a) Technology A	
CAPEX	€54,359.57
OPEX (maintenance)	€50.25
Total Cost	€49,318.82
(b) Technology B (Integrated Energy Platform Costs)	
CAPEX	€5100.00
OPEX (periodic fee)	€3200.00

3. Data Collection and Evaluation Methodology

Data collection for the cost–benefit analysis required an array of quantitative datasets regarding the two major components.

1. The energy system such as energy consumption, energy supplied, energy production capacity, investment cost for energy system expansions, energy technologies within the system, and operation and maintenance cost of the energy system.
2. The energy market, such as energy price, market size, the share of renewable energy technology, and the shares of convectional fuel energy technologies in the market.

The methodology for the CBA evaluations was structured around three steps, which are illustrated in Figure 1. **Step one** focuses on defining the requirements and assumptions and identifying and selecting modelling parameters for the CBA assessment model. The work was based on inputs from previous work concluded by other work packages within the InteGRIDy project, alongside a high degree of engagement with local partners. One of the main requirements for CBA analysis was the timeframe of the simulation, which was 20 years and used a 3.5% discount rate in the analysis. In **Step two**, the data collection focuses on obtaining data through (i) a collaboration with relevant partners at each respective pilot site and (ii) secondary desk research based on published governmental, academic and organisational publications. In **Step three**, the analysis focused on examining the monetised costs and economic benefits for each pilot site to highlight the economic benefits obtained from implementing smart and renewable energy technologies.

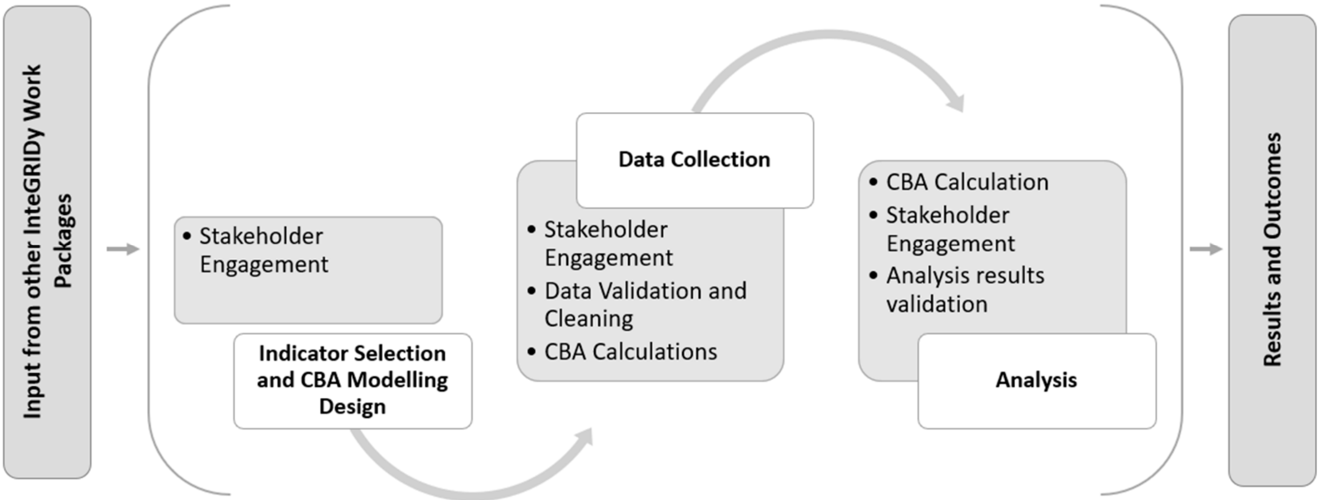

Figure 1. The Methodological process for CBA Evaluations.

4. Results

4.1. St Jean Pilot Site

The CBA evaluations for the ST Jean Pilot site highlight that implementing renewable energy technologies and smart technology is economically profitable and feasible for the local stakeholder. The energy transition provides the local DSO stakeholder economic gains of 1,127,344 million Euros over the 20-year simulated period. Table 4 provides an overview of the economic comparison between the two scenarios at the end of the simulation period, which shows that the economic gains for the DSO are achieved through the extensive increase in energy flexibility in the system associated with the implementation of renewable energy technologies. This increase in flexibility is illustrated in Figure 2 below.

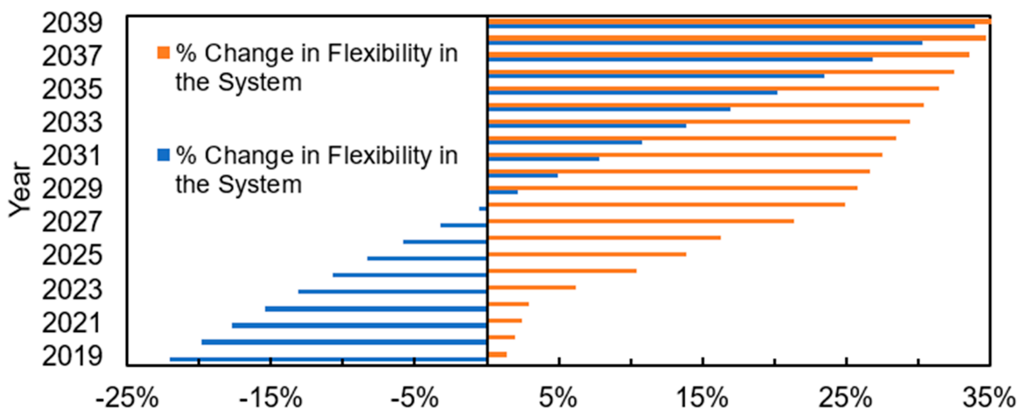

Figure 2. Comparison of System Flexibility for St Jean Pilot, Blue (Scenario A) and Orange (Scenario B).

Table 4. St Jean Economic Sensitivity Analysis.

Variables (€)	2.80% (€)	3.50% (€)
Total Investment (Scenario A)	29,681,906	29,481,159
Total Investment (Scenario B)	63,883,765	63,451,701
Flexibility − Economic benefits (Scenario A)	5,127,606	509,292
Flexibility − Economic benefits (Scenario B)	65,058,511	64,618,502
Total Income (Scenario A)	552,954,300	549,214,512
Total Income (Scenario B)	554,006,617	550,259,713

The overall results show that a transition towards the renewable energy system requires higher investment in energy infrastructure than maintaining the pre-existed energy system. However, an increase in investments can be expressed as a cost-avoided rather than a direct revenue gain, since the total financial benefits obtained from flexibility over 20 years cover the investments costs associated with infrastructure requirements that the energy transition entails. Furthermore, the results show that integration and a shift towards a full decarbonized energy system improve the energy security and stability of the energy system through an increased capability to meet volatility in energy demand within the system due to a higher degree of flexibility.

4.2. Barcelona Pilot Site

Results from the cost–benefit analysis carried out for Barcelona Pilot proves to be profitable over the 20 years considered in this work. A running cost of €5,537,348, as shown in Table 5 (A discount rate of 3.5%), is required for the baseline scenario without the implementation of any renewable technology. For Scenario B, a capital investment of €43,943 is required to procure and install the smart solution technologies and software. Similarly, an additional investment of €31,450 is required for battery replacement. A positive cash flow of over €5000 is obtained from year two to year nine just before the battery replacement. Overall, the analysis indicated that the implementation of smart solution tools for the Barcelona Pilot are economically viable with a payback time of 8.2 years. Similarly, the technologies were also able to save over 53 tonnes of carbon dioxide emissions just within the first year. Table 5 also presents additional costs associated with the Barcelona Pilot at 1, 3.5 and 5% discount rates.

Table 5. St Jean Economic Sensitivity Analysis.

Discount Rates	1%	3.5%	5%
Total Energy Costs Scenario A (€)	€5,674,411.49	€5,537,348.41	€5,458,243.43
CAPEX Scenario B (€)	€79,909.48	€77,979.29	€76,865.30
OPEX Scenario B (€)	€5,526,942.95	€5,393,441.92	€5,316,392.75
Total Cost Scenario B (€)	€5,606,852.43	€5,471,421.21	€5,393,258.05
Revenue Scenario B (€)	€317,370.78	€309,704.82	€305,280.46
NPV Scenario B (€)	€33,164.24	€32,363.17	€31,900.84

5. Conclusions

The economic analysis of St. Jean and Barcelona pilot sites carried out in this work focused on understanding the economic viability and highlighting any positive and negative economic impacts regarding the technological investment and implementation of renewable energy technologies and smart solutions technology to respective energy systems. The results from CBA evaluations highlight that the investment and implementation of the proposed technology solution are economically viable for both pilot sites over the 20-year evaluation simulation period. The economic feasibility for both pilot sites is achieved through providing low to high marginal profit to the DSO attained with the revenue gains from the flexibility and better energy utilisation or cost avoidance related to lower costs associated with grid upgrades. The knowledge obtained from the evaluation highlighted those investments in the decarbonisation of energy system which yield economic gains for stakeholders, such as the DSO, alongside resulting positive societal impacts through increasing energy security and stability of the energy system. In addition, the mitigation of greenhouse gas emissions is achieved by increasing the shares of renewable energy generation within the systems and greener energy consumption. Overall, the results from the economic evaluation of the implementation of smart solution technologies within the two inteGRIDy pilot sites (St-Jean, Barcelona) highlights that the implementation enhances the demand flexibility/Grid optimisation; reduction in energy consumption, cost optimisation, retailers' costs, and energy storage/EV, CO_2 emission reduction.

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Data Availability Statement: The data that supports the findings of this study are available from the inteGRIDy consortium through the first author, but restrictions apply to the availability of these data which were used under license for the current study and so are not publicly available.

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