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Cost and environmental benefit analysis: An assessment of renewable energy integration and smart solution technologies in the InteGRIDy project

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ABSTRACT

The emphasis and focus on energy transition towards a renewable energy-based energy system has increased, alongside the need to understand the economic feasibility of energy system development built around adaptation and implementation of renewable energy resources and smart technologies to a pre-existing energy system. Likewise comes the importance of evaluating and understanding the positive social and environmental impact obtained through energy transition towards a greener and cleaner energy system. This paper applies the cost-benefit analysis method to assess the economic feasibility of implementing renewable energy resources and smart energy technologies in a pre-existing energy system in two pilot sites (St-Jean, France and Barcelona, Spain). The evaluation process encompasses all relevant parameters such as investment, operating and maintenance costs, energy prices, energy demand, energy supply and energy technologies characteristics needed to carry out an economic feasibility assessment of investments and implementation projects. In addition, the evaluation process allows assessing the environmental benefits obtained through implementation by calculating the estimated emission reduction achieved through energy system retrofitting and transition, alongside identifying the society's economic gains attained from the emission reduction. The results show that investing in energy transition and system development toward renewable energy-based energy systems is economically viable since the analysis highlights a considerable low payback period with 8.2 years for the Barcelona pilot, and 2.8 years for St. Jean pilot. Likewise provides significant economic benefits to energy system operators and stakeholders, which is demonstrated with a 22% increase in revenue in the case of the St. Jean pilot and 4% decrease in overall costs at the Barcelona Pilot. The results highlight that energy transition offers various other benefits, such as increasing energy system flexibility with the St Jean pilot experiencing a 21% average increase in energy flexibility in the system through implementation of the energy system development. Also, this includes other benefits such as emission reduction of 23.5% for St. Jean pilot and 4% for the Barcelona pilot, which can help improve public health.

1. Introduction

The efforts and policies that enable and support energy system development and hence facilitate an energy transition to a cleaner and decarbonised energy system have become an integral part of energy policy design at all levels, global, national, and regional (Shih and Tseng 2014; IRENA 2021; IEA 2021; IPCC 2021). This pressure is being fuelled by several causes, including depletion of natural resources (Rosales Carreón and Worrell 2018), which influences the access and supply of fossil fuels, making society vulnerable due to high dependence on fossil fuels in most current national and local energy systems (Pizarro-Alonso et al., 2019). In addition, to the predicted growth in carbon emission linked to growing global energy demand and urbanization (Keirstead et al., 2012; Lund et al., 2015), which accelerates the detrimental impacts

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Abbreviations: AHU, Air-Handling Unit; APS, Autonomous Power Stations; BIPV-T, Building-Integrated Photovoltaics with Thermal Energy Recovery; CBA, Cost benefit Analysis; CO_2, Carbon Dioxide; EERA, European Energy Research Alliance; ESS, Energy Storage System; tCO_2, Tonnes equivalent of Carbon Dioxide Emission; DSO, Distribution system operators; IEP, Integrated Energy Platform; IRR, Internal Rate of Return; LCA, Life Cycle Assessment; kWh, Kilo-watt Hours; MWh, Megawatt Hours; NPV, Net Present Values; PV, Photovoltaics; RES, Renewable Energy Source; STES, Seasonal Thermal Energy Storage; UNSDG, United Nation Sustainable Development Goal; HOMER, Hybrid Optimization Model for Electric Renewable.

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of fossil fuels on climate change, these causes necessitate the phase-out of fossil fuel combustion in our global energy system (IRENA 2021; IEA 2021; IPCC 2021). Renewable energy technologies provide one of the leading solutions to these problems, which have been highlighted in recent years, especially with the introduction of the United Nations Sustainable Development Goals (UNSDG) in 2015. Similarly, UNSDG 7 (Affordable and Clean Energy), UNSDG 9 (Industry, Innovation, and Infrastructure) and UNSDG 13 (Climate Action) emphasise the focus on the development and transiting towards a cleaner, greener, and resilient energy system infrastructure with the focus on combating the climate crisis brought through the emission of greenhouse gas to the atmosphere (UN 2015). Hence, providing affordable, clean, and reliable energy to all (UNSDG 7), through an energy transition focused on mitigation of environmental and climate degradation caused by energy production through decreasing fossil fuel dependencies within the energy system and, to a significant extent phasing out fossil fuel from future energy system (UNSDG 11 and 13) (UN 2015). Thereby providing an energy system built on renewable and clean energy sources (UN 2015).

Renewable energy refers to energy generated from a diverse range of resources, all of which are self-renewing (IRENA, 2021; IEA 2021; IPCC 2021). This includes sunlight (Keirstead et al., 2012; Lund et al., 2015), wind (Keirstead et al., 2012; Lund et al., 2015), rivers (Bull 2001), geothermal (Bull 2001), and biomass such as energy crops, agricultural, industrial waste, and municipal waste (Bull 2001; Pizarro-Alonso et al., 2019). Renewable technologies deployed to harness renewable energy provide clean sources of energy, and their optimal use minimises environmental consequences, produces minimal secondary waste, and are economically and socially sustainable in the long run (Panwar et al., 2011; Li et al., 2015; Pizarro-Alonso et al., 2019; IRENA 2021). The diversity of renewable energy technologies and resources is one of its most striking characteristics. There is little doubt that the final scale of the renewable energy resource is substantial and has the potential to contribute significantly to global energy demand. (Gross et al., 2003; Shih and Tseng 2014). As highlighted above the transition from fossil driven energy system towards clean and greener energy system is a crucial task that is required in order to mitigate climate change. The transition, however, is faced with a plethora of challenges and uncertainties related to economic viability, societal factors such as population growth and urbanisation, technology development and environmental factors (Rosales Carreón and Worrell 2018; Pizarro-Alonso et al., 2019; IEA 2021).

Consequently, cost-benefit analysis (CBA) method is a frequently used to assit decision-makers in understanding the potential economic costs and benefits of energy development, which enables the integration of renewable energy, alternative fuel vehicles, and intelligent technologies into the current energy system (Mathioulakis et al., 2013; Shih and Tseng 2014; UN 2015; Dehdarian 2018; Ahmadian et al., 2018; Chahrour et al., 2021). A CBA's primary objective is to conduct an overall assessment of the proposed project's investment, considering all cost and benefit factors. CBA results are reported in monetary terms and provide insight into the total economic impact and both positive and negative gains linked with a particular investment (Mathioulakis et al., 2013; UN 2015; Dehdarian 2018; Ahmadian et al., 2018; Chahrour et al., 2021). CBA-based approaches have, over the recent years, been applied to assess the economic viability of energy system development and planning strategies toward greener and cleaner energy systems through the adaptation of renewable energy and smart energy technologies. Kennedy (2007) applies CBA to carry out an economic assessment of the feasibility of building new nuclear power plants in the United Kingdom. The evaluation was carried out through comparative and scenario analysis between the costs and benefits of the nuclear power plant, conventional gas-fired power plants and low carbon energy technologies. The results provide a supportive viewpoint that supports the enabling of the building of new nuclear power plants in the context of the energy market, since benefits of nuclear are highlighted in the enhancement of energy security and its impact on gas prices and carbon prices.

Kaldellis et al. (2009) carried out a study to investigate the financial viability of an integrated electrification solution based on photovoltaic (PV) generators coupled with an energy storage system (ESS). The aim was to provide an integrated methodology to ascertain the optimal PV-ESS configurations for the energy system of small remote islands. The study analysed birth mature and emerging technologies as well as the impact of crucial aspects such as solar irradiation levels and the local economy's key features. From the obtained results, the energy generation cost of the suggested solution is, in the majority of cases, much less than the marginal production cost of the existing autonomous power stations (APS), reaching 0.18 €/kWh, or 42% less than the equivalent value for the APS operation. Variations in sun irradiation values and regional economic conditions contribute to significant variations in outcomes. For the conditions studied, it is believed that the proposed photovoltaic-energy storage combination is a cost-effective energy system capable of resolving the pressing issue of electrifying the numerous small, inaccessible islands. They concluded that in addition to the anticipated financial gains, it is important to consider the greater security of supply, the reduction of air pollution, and the macroeconomic costs associated with imported oil. As part of European Energy Research Alliance (EERA) funded projects, Parissis et al. (2011) conducted a twenty-year cost-benefit analysis for the integration of wind and hydrogen technologies in the power system of Corvo Island in Portugal. The technologies considered include a wind turbine, thermal generator, fuel cell, electrolyser, and hydrogen storage tank. The financial viability of these systems was determined based on Net Present Values (NPV) and Internal Rate of Return (IRR) indicators. The findings from this work identified the introduction of wind as an energy source and hydrogen as a storage method to be attractive and profitable for Corvo island, resulting in a reduction of about 43% cost associated with power generation. In addition, this clean energy would be able to meet 80% of the island's energy demands, thus significantly decreasing dependencies on imported fuel and carbon footprint.

Mudasser et al. (2015) applied the Hybrid Optimization Model for Electric Renewable (HOMER) decision tool to conduct a feasibility assessment, including a CBA assessment to assess the economic viability and incentives related to community feed-in tariff schemes for wind-biogas hybrid energy production. The analysis points out that without a governmental policy incentive like the community feed-in tariff schemes, a hybrid wind-biogas energy system is not economically viable. Whereas the introduction of governmental incentives, which has a guaranteed energy price, provides higher energy prices to producers and enables energy producers to obtain economic benefits from the system.

Delisle and Kummert (2016) investigated the cost-benefit of building-integrated photovoltaics with thermal energy recovery (BIPV-T) with a focus on technologies that utilise air as heat recovery fluid incorporated into fully electric energy efficient residential buildings. Break-even cost, defined in the study as the highest incremental cost required to transform a BIPV system into a BIPV-T system, was used as an indicator. Data in the form of equivalent energy production of BIPV, BIPV-T and PV+*T* systems were obtained from six energy-efficient residential buildings across Canada. Four distinct heat management scenarios that include; air preheating, hot water preheating using air to water heat exchanger, hot water and space heating using air to water heat pump, and domestic hot water heating using a heat pump water heater were considered. Results showed that BIPV-T systems consistently produce more useable energy than BIPV systems. Hence, the break-even cost relative to a BIPV system was shown to be consistently positive and up to $2700 CAD for a medium-sized, two-story residence. The break-even cost of a BIPV-T system compared to a PV + T system was calculated to be $4200 CAD for the same house, assuming the price of BIPV to be comparable to that of normal roof-mounted PV modules. Nonetheless, if the price of BIPV were to decrease by 10% relative to PV, this break-even cost might grow to $6400 CAD.

Conti et al. (2019) applied dynamic modelling simulation with CBA integrated into the modelling approach to assess the economic benefits alongside energy and resources utilisation and demand change and emission trends concerning the implementation of hybrid photovoltaic and solar thermal collectors into buildings. The performance of these technologies proves to be economically viable and provides a reduction in total cost in comparison to other technology solutions, which leads to economic savings for the user. Thus resulting to improvements in resources utilisation and reduction in energy consumption from non-renewable energy sources, which enable the buildings to reach zero-energy building threshold.

Xiang et al. (2020), applies the CBA approach to assess the economic benefits, as well as the environmental benefits, obtained through an energy planning strategy that focuses on integrating demand response technologies such as smart meters. Based on the results, improving the communication between suppliers and consumers of energy enables improvements in energy utilisation. It increases energy storage potential within the system while simultaneously providing economic benefits to suppliers and consumers and reducing emissions. Sofia et al. (2020) applied CBA techniques to assess the economic and social benefits of the decarbonisation scenario applied in Italy to the year 2030. The CBA was used to quantify the economic costs and associated social benefits attained from implementing decarbonisation strategies across different sectors in Italy.

The results highlight that implementing decarbonisation strategies provides economic and social benefits and significantly reduces emissions across the various sectors. In a previous work by the current authors, Gudlaugsson et al. (2021), a CBA study was carried out to identify the key economic benefits of two inteGRIDy pilot sites (St Jean, France and Barcelona, Spain) concerning the implementation of RES and smart technologies solution to the pre-existing energy system. The results point out that initial and total investments increase significantly due to the implementation of RES and intelligent technologies. However, even though investment costs increase, the results highlight that it is economically beneficial for energy system operators and other stakeholders to implement RES and smart technologies since it will increase the energy system flexibility, enhance energy security and enable energy storage potentials. Thereby leading to an increase in revenue and economic savings in terms of energy production and cost of purchasing energy for the energy system operators and other stakeholders. The extension to the previous paper and contribution of the current paper is to extend the assessment to evaluate the benefits attained concerning the environmental and social dimension and further extend on the assessment and presentation of the economic benefits obtained from the implementation of RES and smart energy technologies.

The work presented in this paper is part of the InteGRIDy EU Horizon 2020 project, which integrated *"cutting-edge technologies, solutions and mechanisms in a Framework of replicable tools to connect existing energy networks with diverse stakeholders, facilitating the optimal and dynamic operation of the Distribution Grid (DG), fostering the stability and coordination of distributed energy resources, and enabling collaborative storage schemes within an increasing share of renewables"* (InteGRIDy 2019).

The purpose of this research is to present the finding from a CBA analysis conducted as a part of the InteGRIDy project and through extensive engagement with project partners and stakeholders. The CBA analysis focus on quantifying the economic benefits obtained through integrating renewable energy, energy storage, optimisation, and distribution technologies into the existing energy system at St. Jean and Barcelona pilot sites. In addition, this study presents the environmental and economic gains attained for the local communities through implementing these renewable energy and technology solutions in the form of emission reduction and costs avoided concerning emission reduction.

The novelty of this work is that it draws on the definition of the Barcelona and St. Jean pilot sites and scopes set forward in the InteGRIDy project which focus on delivering insight and results that enable decisions and policy making at the regional level (St Jean) and city level (Barcelona) to foster the energy transition. Furthermore, limited energy system transition research has been carried out, focusing on the St. Jean region in France and the city of Barcelona in Spain, especially in relation to energy technology integration into the current energy system. Thus, the work presented in this paper contributes to knowledge generation on energy transition through technology implementation at regional and city levels. As such, contributing to the discourse on economic feasibility and social and environmentally positive benefits associated with the energy system transition from fossil fuel-based energy systems toward cleaner renewable energy-based energy systems.

The remainder of the paper is structured as follows. **Section two**, describes the two pilot sites considered for this work. **Section three** comprises the data collection and evaluation methodology employed. **Section four** delivers the results of the cost-benefit and environmental analysis for the two pilot sites. **Section five** provides a discussion of the results finding from this study with relevant academic work. Finally, **section six** presents the conclusion.

2. Background – description of case study sites

The cost benefit and environmental case studies used for this study, are set in two location, St. Jean in France, and Barcelona in Spain. The scope and boundaries of the analysis when it comes the renewable energy technologies and solution implemented into those local energy system are set by the InteGRIDy project and local stakeholder participating in the InteGRIDy project (Dawood et al., 2021a, 2021b). The input data for this study is based on primary data obtain through engagement with the local InteGRIDy partners and stakeholders, are presented in detail in the following section.

2.1. St Jean pilot site

The St Jean pilot site is classified as a larger-scale pilot site within the InteGRIDy project (Drakopoulos et al., 2017; Lindrup et al. 2017; Dawood et al., 2021a, 2021b). The objective of the assessment for St Jean was to identify the economic benefits gained from implementing RES technologies and smart energy technologies alongside other societal and environmental benefits. In addition, to assess if implementing these technologies would allow the energy system operators to improve and optimise their ability to meet consumers' demands and provide energy storage abilities within the energy system.

For the CBA assessment carried out, two scenarios were designed:

- **Scenario A** represents the energy system and actual energy consumption without implementing smart energy technologies solutions and RES technology. The only energy supply for the system is from traditional energy generation, which is energy imports for the national grid. The focus of this scenario was to understand the energy system's abilities to meet the energy demand with only limited energy supply and identify energy system flexibility and energy storage ability. A simplified illustration of the St Jean energy system for this scenario is presented in Fig. 1.
- **Scenario B** represents a scenario in which the RES technologies are accounted for and implemented into the energy mix of the St Jean energy system as can be seen in Fig. 2. Therefore, the focus of this scenario is to capture and understand energy abilities to meet the energy demand and identify energy system flexibility and energy storage potential gained through the implementation of renewable energy technologies in the energy system. In scenario two, RES technologies added to the energy system are hydropower and solar photovoltaic.

Defining these two scenarios allows for comparative assessment to be carried out to identify and understand the benefits obtained from the implementation of RES and smart technologies to an energy system in connection to energy system flexibility gains, energy storage ability, revenue gains, cost energy production, and emissions between the scenarios.

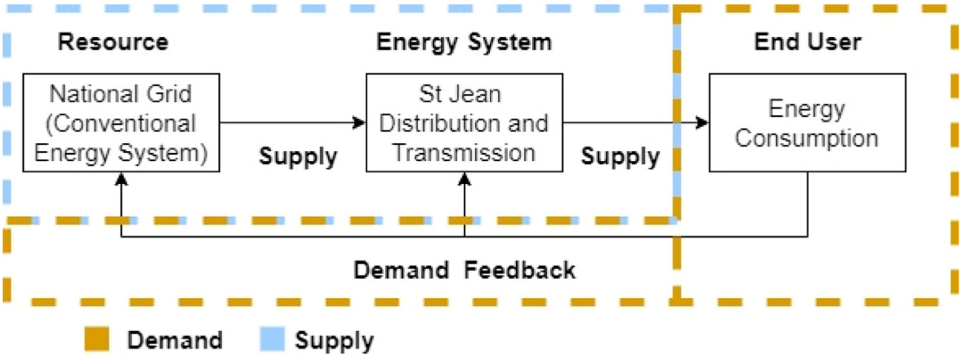

Fig. 1. Simplified Illustration of the St Jean Energy System for Scenario A.

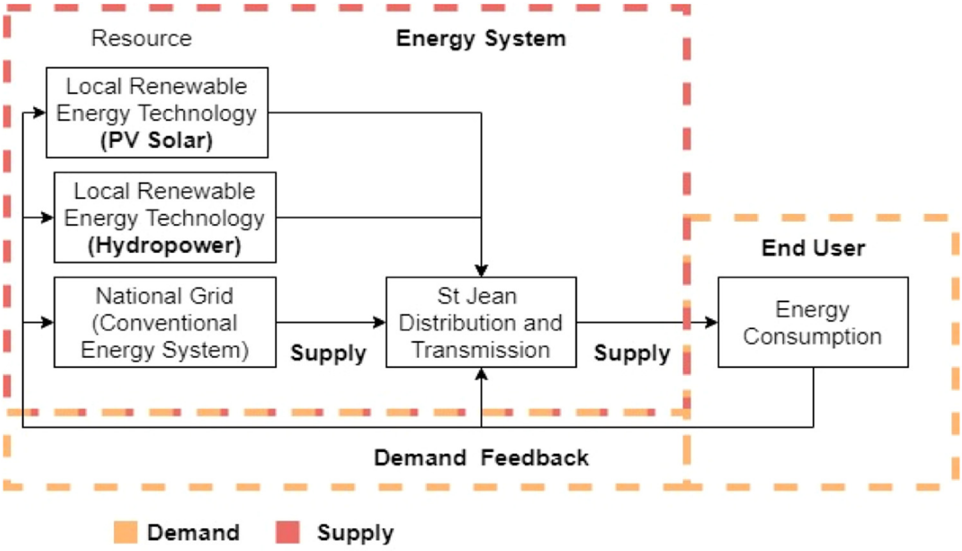

Fig. 2. Simplified Illustration of the St Jean Energy System for Scenario B.

2.2. Barcelona pilot site

The Barcelona pilot refers to the Rambla de Celler sports centre in Barcelona, Spain, which features a large pool adjacent to a smaller pool, a spa area, and numerous rooms dedicated to guided training, cycling, and other fitness activities (Drakopoulos et al., 2017; Lindrup et al. 2017; Dawood et al., 2021a, 2021b). However, the scope of this work is limited to the main swimming pool, as it has been identified as the primary consumer, requiring multiple elements to operate, including an Air-Handling Unit (AHU), a combination of a Seasonal Thermal Energy Storage (STES), and a heat pump to maintain comfortable swimming pool conditions.

This facility initially consumes electricity and natural gas from the grid and generates its energy via a hybrid solar-thermal system with a capacity of around 25kWp. As part of the inteGRIDy project, the Barcelona pilot site aimed to evaluate the deployment of energy-saving measures and demand response by installing monitoring equipment for a building energy management system. Furthermore, this pilot site was outfitted with a storage solution centred on the capabilities of distributed end-user energy storage facilities based on distribution Li-Ion batteries to boost the grid penetration potential of RES. Two scenarios were also considered for the Barcelona pilot evaluation.

- **Scenario A** – This is the baseline scenario based on conventional energy systems without implementing any smart technology or renewable energy.
- **Scenario B** – This comprises of the implementation of smart solution technologies together with the conventional energy systems. For this scenario, two groups of technologies were implemented for this pilot. Technology A – comprises of PV systems with Battery storage system technologies. Technology B – comprises of Integrated Energy Platform (IEP), which is a public cloud-based software framework that supports the several functions such as: demand response, local optimisation and forecasting, market integration, renewable production, electrical and thermal storage, grid outage protection, and grid flexibility services. The IEP is an attractive solution for ESCOs and other potential electricity market stakeholders who wish to boost energy efficiency while at the same time generating new revenue streams through the provision of robust and efficient grid services.

3. Data collection and research process

3.1. Data collection

For the CBA analysis, qualitative data collection approaches were applied to ensure the reliability of the data collection and validation of the analysis. A qualitative data collection approach was used through stakeholder engagement with internal InteGRIDy project partners and external stakeholders. The stakeholder engagement focuses firstly on the data collection from DSO and other relevant stakeholders at the beginning of the CBA analysis. In the later stage of CBA analysis, stakeholder engagement was used to validate and assess the CBA calculations through receiving feedback from the stakeholders involved. The CBA analysis for the St. Jean Pilot focuses on the flexibility potential, flexibility costs, and integration of RES technology into the energy system. For Barcelona Pilot, CBA is mainly based on optimising self-consumption of PV systems and minimising operating costs while ensuring comfort.

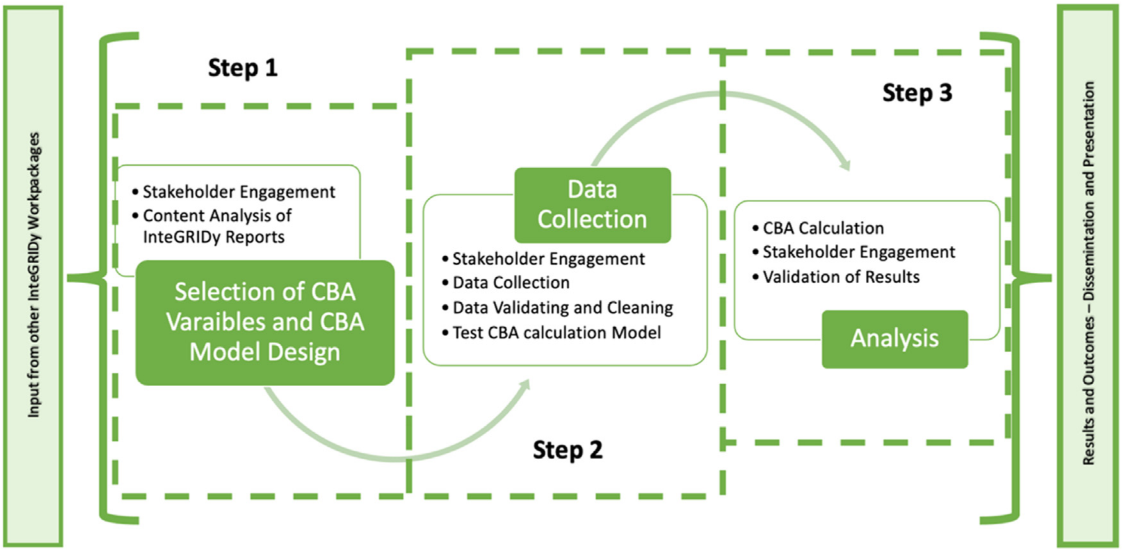

Fig. 3. Three-Step Research Process.

The data required for costs and benefits for both pilot sites can be grouped into two major components.

- **Energy system** - energy consumption, demand and supply, production capacity, investment costs for energy system expansions, energy technologies integrated into the system, and energy system operation and maintenance costs.
- **The energy market** - price of energy, the market size, the share of renewable energy technologies, and the market share of conventional fuel energy technologies.

Data for both energy system and energy market were obtained from a wide variety of sources such as published literature like international organisations and national government reports, academic research papers, alongside building automation systems, building management systems, conventional and intelligent meters, battery management systems, utility bills, other InteGRIDy work packages.

3.2. Research process

The CBA approach in this study focuses on assessing and identifying the key benefits attained through implementing RES technologies and intelligent energy technologies into an energy system. Thus, emphasising on the economic gains for the energy system stakeholders within both pilot sites presented in this study. The research process for the CBA evaluations was structured around three steps, illustrated in Fig. 3.

Step one focuses on defining the requirements, clearly defining the assumptions used, and identifying and selecting modelling parameters for the CBA calculations. The inputs were derived from previously completed work packages within the InteGRIDy project (Drakopoulos et al., 2017; Lindrup et al. 2017), alongside a high degree of engagement with local partners. Table A.1 in the appendix illustrates the key variables and assumptions for both pilots.

Step two focused on the data collection where the focal point was on acquiring data through (i) a collaboration and engagement with relevant partners at each respective pilot site and (ii) secondary desk research based on published governmental, academic, and organisational publications.

Step three focused on the calculation with the focal point on the analysis and examining the monetised costs and economic benefits for each pilot site to highlight the benefits obtained from implementing smart and renewable energy technologies. 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 (Drakopoulos et al., 2017; Lindrup et al. 2017). The following equations are applied for the calculation to assess the economic viability and identify the economic benefits obtained from the implementation of RES technologies and smart technologies.

Eq. (1) presents the NPV formula used in this study. The Net Cashflow per year is the total revenue per year, and in the case of this study, it is the revenue obtained each year in the simulations. The previous work packages defined the discount rate for this study to be 3.5%; however, for the St Jean pilot site, the discount rate of 2.8% was also applied based on the national discount. The initial investment is the investment made by the energy system stakeholders per year over the 20-year simulation period. Furthermore, Eqs. (2) and (3) were used to determine the payback time for the implementation and return of investment of RES technologies and smart technologies.

$$Net\ Present\ Value = \sum_{year=0}^{n} \frac{Net\ Cashflow_{year}}{(1 + Discount\ Rate)^{Year}} - Initial\ Investment \tag{1}$$

$$Payback = \frac{Total\ Investments}{(Total\ Costs - Total\ Revenue)} \tag{2}$$

$$Return\ of\ Investment\ = \frac{Total\ Revenue}{Total\ Investment} \tag{3}$$

Environmental and social benefits were evaluated using the assessment of avoided costs as a result of the reduction in emissions brought about by the implementation of RES technologies and smart energy technologies. Eqs. (4) and (5) were employed for this, and a social cost per tCO2 eq. value of 175 euros was utilised in the St. Jean Pilot site assessment. The reasoning for selecting that monetised price for the social cost of emission was based on the broad range of values used for the social cost of emission in literature (Tseng and Hung, 2014; Metcalf and Stock, 2020; Rennert et al., 2021), so in this case for the St. Jean analysis, the medium point was selected. For the Barcelona Pilot site assessment, the value per tCO_2 eq. was 16.05 euros (BEIS, 2019). The social cost of emission refers to the economic costs associated with the damages done by emitting one additional tonne of CO_2 into the atmosphere (Tseng and Hung, 2014; EU, 2020; EEA, 2021; Löffler, 2021). The emission factor represents the total emission from the generation of electricity within a country, and the emission factor tCO_2 eq. per kWh for the calculation was obtained through engagement with InteGRIDy internal partners.

$$Social\ Cost\ of\ Emissions\ = Emissions\left(\frac{tCO2\ eq.}{kWh}\right) \times Social\ Cost\ (Euro\ per\ tCO2\ eq) \tag{4}$$

$$Emissions = Supply\ of\ Energy\ from\ Fuel(\ kWh) \times Emission\ Factor\left(\frac{tCO2\ eq.}{kWh}\right) \tag{5}$$

4. Results

This section is divided into two sections to demonstrate the results of CBA and the overall assessment of the implementation of renewable energy and smart technology solutions for the St Jean pilot site and Barcelona pilot site. Furthermore, the CBA carried out in this paper is used to identify the economic benefits obtained by implementing RES and smart energy technologies and validate energy systems upgrading towards cleaner and greener energy systems. The first section focuses on the assessment analysis of the St. Jean pilot site. It presents the overarching economic benefits gained from the implementation of RES technology, highlighting the energy system and social and environmental benefits obtained through the implementation of RES technology to the St Jean energy system. The second section focuses on the assessment analysis of the Barcelona pilot site. It presents the economic benefits gained from the implementation of RES and Smart technology, highlighting the energy system and social and environmental benefits obtained through the implementation.

4.1. Assessment analysis of st. jean pilot site

Economic (Economic viability): Tables 1 and 2 present the economic results of CBA for the St. Jean pilot site. Table 1 highlights that the RES technology implementation is economically feasible and beneficial for the St. Jean energy system operator and stakeholders. Since the implementation provides overall economic gains of 104 million euros over the total 20-year simulation period, the critical economic gains obtained from the implementation are achieved by increasing system flexibility, which can be considered an avoided cost rather than a direct increase in revenue for the energy system stakeholder, like DSO. Since the increased revenue obtained from the enhanced flexibility over the 20 years covers the required investment costs for implementing the RES energy technology.

Furthermore, the results from CBA highlight that implementation of RES technology is economic feasibly in the case of the St Jean pilot since the analysis shows the return of investment for energy system stakeholders is 0.5 over the 20-year simulations period, which is considered a highly attractive return of investment for investors. Besides the high return of investment ratio for the investors, is economically viability of implementation of RES technology in the St. Jean energy system is emphasised with the expected payback period for scenario B to 2.86 years, respectively, in comparison to the payback period for scenario A to be 6.81 years, which is also considered to economically variable payback period.

Table 2
St Jean Economic Feasibility Analysis.

Scenarios	Payback	ROI
Scenario A	6.81 Years	0.58
Scenario B	2.86 Years	0.5

System (System Flexibility): Above, it has been pointed out that one of the critical factors for the economic viability of implementing the RES technologies in the St Jean energy system is the increased flexibility obtained through the technology implementation. Fig. 4 below illustrates the flexibility gains between the two scenarios.

In both cases, the energy demand is expected to decrease by 1.50% annually. For this scenario A, is the sole energy supply coming from the national grid or energy imports of 99,502 MWh at the start of the simulation, which grows annually by an expected 1.20% leading to 126,311 MWh of energy supply capacity. As illustrated in Fig. 5, the energy supply in scenario A is unable to meet the energy demand for the first ten years of the simulation, thereby creating an energy shortage and negative economic impact for the stakeholder since it will require additional costs brought on by the need to purchase more units of energy to meet the energy demand. Moreover, the average energy flexibility for scenario A is 4% annually, and the total economic gains energy system stakeholders obtain from the change in energy system flexibility over the 20-year period in scenario A is 5 million euros.

In contrast to scenario A, scenario B energy supply comprise of energy from the national grid and /or energy imports alongside the implementation and development of the RES technologies to the energy system: **A)** Photovoltaic plants with a start energy production capacity of 2000 MWh and estimated annual capacity growth of 5 percentage, which enables growth to 5580 MWh capacity at the end of 20 years simulation period. **B)** Hydroelectric power plants start with an energy production capacity of 27,000 MWh; however, throughout the 20-year simulation period, the capacity will grow to 48,900 MWh.

As presented in the right figure in Fig. 5, this system development and retrofitting energy system is capable of meeting the energy demand in the system from year one in scenario B. In contrast, in scenario A, the energy system cannot meet energy demand until year 10 in simulation, therefore, relying on energy imports to meet the energy demand in the system. Fig. 4 highlights that the system development and retrofitting towards greener and low-carbon energy technologies enhance the energy security and stability of the energy system as the consequences of the improved flexibility obtained through the implementation of the RES technologies allow the system to meet the volatility in energy demand. Furthermore, Fig. 4 highlights correlation between increase flexibility and that energy system stakeholders started receiving economic gains at the start of RES implementation since the energy system does attain

Table 1
St Jean Economic Sensitivity Analysis.

Variables (€)	(€)	2.80% (€)	3.50% (€)
Initial Investment (Scenario A)	1453,000.00	1413,424.12	1403,864.73
Initial Investment (Scenario B)	2886,910.66	2808,278.86	2789,285.67
Total Investment (Scenario A)	30,513,000	29,681,906	29,481,159
Total Investment (Scenario B)	65,672,510	63,883,765	63,451,701
Flexibility – Economic benefits (Scenario A)	5271,179	5127,606	5092,927
Flexibility – Economic benefits (Scenario B)	66,880,150	65,058,511	64,618,502
Total Income (Scenario A)	491,705,005	478,312,261	475,077,299
Total Income (Scenario B)	569,518,803	554,006,617	550,259,713
Total Economic Gains (Scenario A)	466,463,188	453,757,961	450,689,067
Total Economic Gains (Scenario B)	570,726,442	555,181,364	551,426,514
Total Economic Gains from RES Implementation*	**104,263,257**	**101,423,402**	**100,737,447**

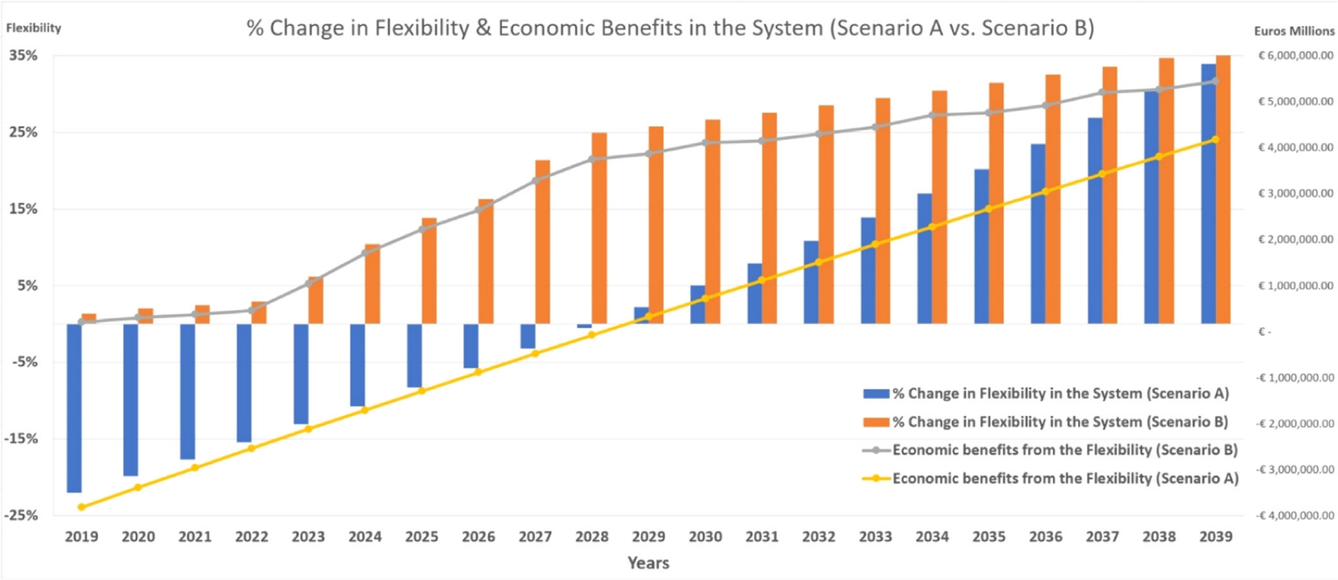

Fig. 4. Comparison of Flexibility and Economic Benefits for St Jean Pilot, Blue (Scenario A) and Orange (Scenario B).

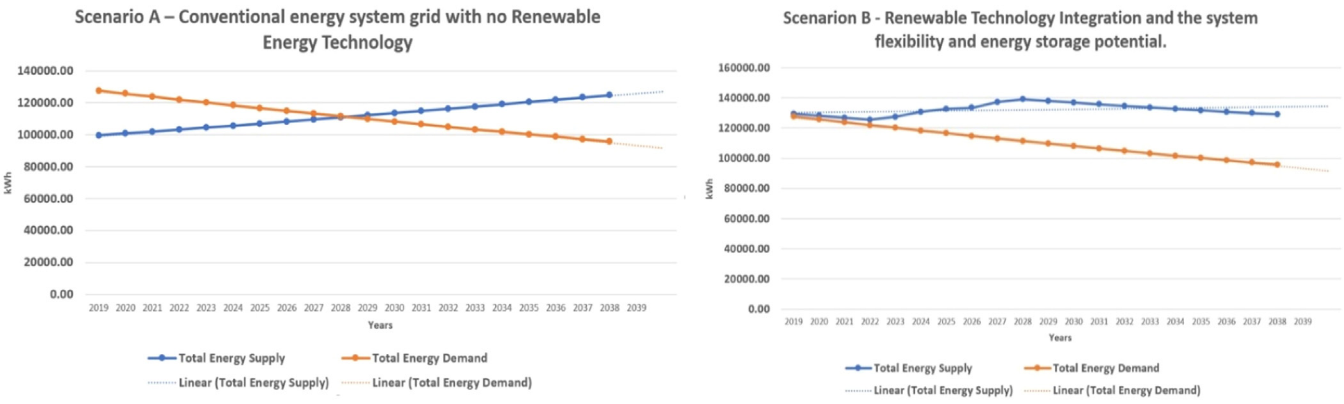

Fig. 5. Energy Demand vs Energy Supply Relationships, Left Scenario A and Right Scenario B.

Table 3
Emission Avoid/Reduction for St Jean Pilot.

Scenarios	Unit	Total Emissions
Scenario A	tCO_2	321,017.27
Scenario B	tCO_2	245,341.16
Emissions Avoid	**tCO_2**	**−75,675.10**

energy system flexibility of 1% in the first years, and the average energy flexibility for scenario B is 21%. The total economic gains the energy system stakeholders will obtain from the energy system flexibility over the 20-year period is 66 million euros.

Environment and Society (CO_2 Emissions and Social Cost of Emissions): Fig. 5 exhibits the evaluation of CO_2 emissions between the two scenarios and a reduction in emissions achieved through the implementation of RES technologies to the St Jean energy system for each year of the 20-year simulation period Fig. 6.

As Fig. 7 illustrates, that the implementation of RES technologies has a meaningful impact on the emission of CO_2 from the St Jean energy system. Table 3 highlights the impact RES technology implementation has when it comes to reducing CO_2 emissions from the energy system concerning energy production associated with energy supply. To estimate the emission from energy production, the carbon factor 0.000136 tCO_2 per kWh of energy produced was used in the calculation for both St Jean pilot site scenarios. In scenario A, the total CO_2 emission for the 20-year period was 321,017.27 tCO_2 eq. In contrast, it was 245,341.16 tCO_2 eq. for scenario B, which leads to a reduction of 75,675.10 tCO_2 eq. of emission to the atmosphere due to the implementation of RES technologies in the St. Jean energy system, thereby decreasing the St Jean energy system's direct impact on the global climate change crisis by 23%.

Moreover, the results highlight that implementing RES technologies in the St. Jean energy system is economically viable for the energy system stakeholders, alongside headlining that implementation of RES technologies into conventional fossil fuel energy systems is mutually beneficial for the investors, society, and the environment. In addition, by the reducing emissions from the energy system, society avoids any additional ecological harm caused by the emissions connected to energy production. Hence, decreasing the potential economic burden on the society associated with climate change and ecological decrease, since the implementation of RES technologies and the energy transition leads to approx. 13 million euros savings connected to avoided economic impacts associated with emitting an additional ton of CO_2 over the 20-year simulations period. Further, to monetize and calculate the social cost of emissions, the social costs factor of 175 € per Tonne of CO_2 was applied in both St Jean pilot site scenarios. Table 4 illustrates the avoid costs concerning the economic impacts of emitting an additional ton of CO_2 from the St-Jean energy system.

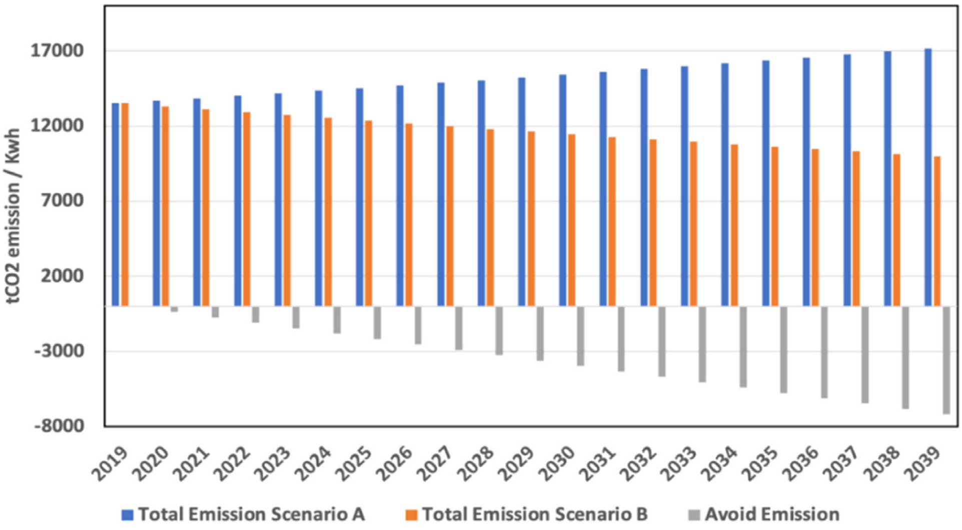

Fig. 6. Energy System Emissions and Achieved Avoid Emissions.

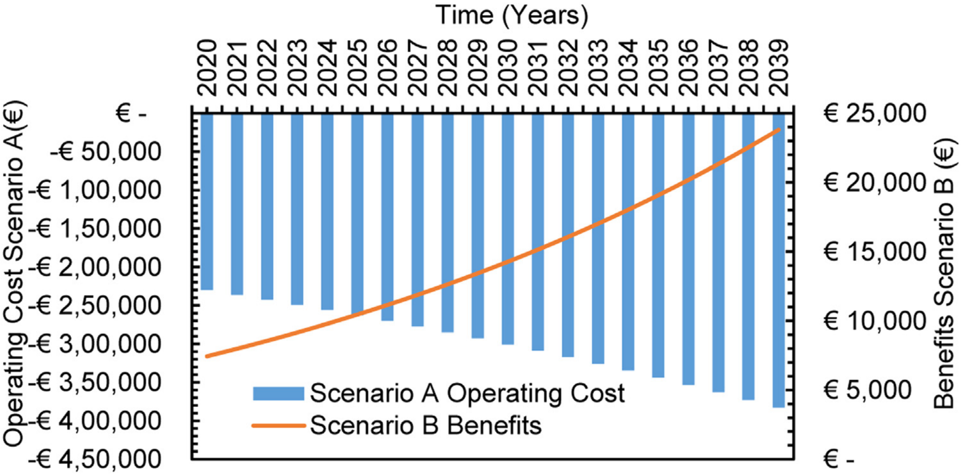

Fig. 7. Operating cost for Scenario A and Benefits for Scenario B for Barcelona Pilot.

Table 4
Social Cost of Emissions for St. Jean Pilot.

		Social Cost of Emissions		
Scenarios	Unit	(€)	2.80% (€)	3.50% (€)
Scenario A	€	56,178,022	54,647,881	54,278,282
Scenario B	€	42,934,704	41,765,276	41,428,806
Costs Avoid	**€**	**13,243,318**	**12,882,605**	**12,795,476**

Table 5
Energy Demand for Barcelona Pilot.

Variables	Scenario A	Scenario B
Electricity Demand (KWh)	49,969,639	49,998,617
Electricity Cost (€)	4366,889	4369,421
Gas Demand (KWh)	25,269,143	20,886,253
Gas Cost (€)	1637,298	1344,847
Total Energy Demand (KWh)	75,238,782	70,884,871
Total Cost (€)	**6004,187**	**5714,268**

4.2. *Assessment analysis of barcelona pilot site*

Economic Viability: Unlike the St Jean pilot, which considers the capital investment for the baseline scenario, the analysis of the Barcelona pilot focuses on the operating cost of the Baseline scenario and the total cost, i.e. capital and operating cost for scenario B. Since no additional investment is required in terms of expansion for the baseline case. Table 5 present the energy demand for the Barcelona Pilot. Over the 20-year period considered for this evaluation, a baseline energy demand of 75,238 MWh is required consisting of about 50,000 MWh of electricity and 25,238 MWh of gas. This amounts to a total cost of €6004,187 for scenario A, in contrast to €5714,268 for scenario B. This difference in total costs between the two scenarios can be associated with a decrease in electricity cost and gas costs as is illustrated in Table 5.

The costs associated with the Technologies implemented for scenario B are presented in Table 6 for both Technology A and Technology B.

Table 6
Cost of Technologies A and B Implemented for Scenario B at Barcelona Pilot.

	Technology A (PV Solar & Battery Storage)	Technology B (Software Solution for Energy Optimization) *
CAPEX	€49,268.57	€5100.00
OPEX (maintenance)	€50.25	€3200.00
Total Cost	**€49,318.57**	**€8300.00**

* Assumed that stakeholder that owns and runs the sports acquires the Software Solution for Energy Optimization.

The capital costs for Technology A includes costs associated with the purchases of the PV panels, and associated component's such as structure, inverter, and switches, installation, connection, system start-up, shipping, legalization and building license costs, monitoring devices,

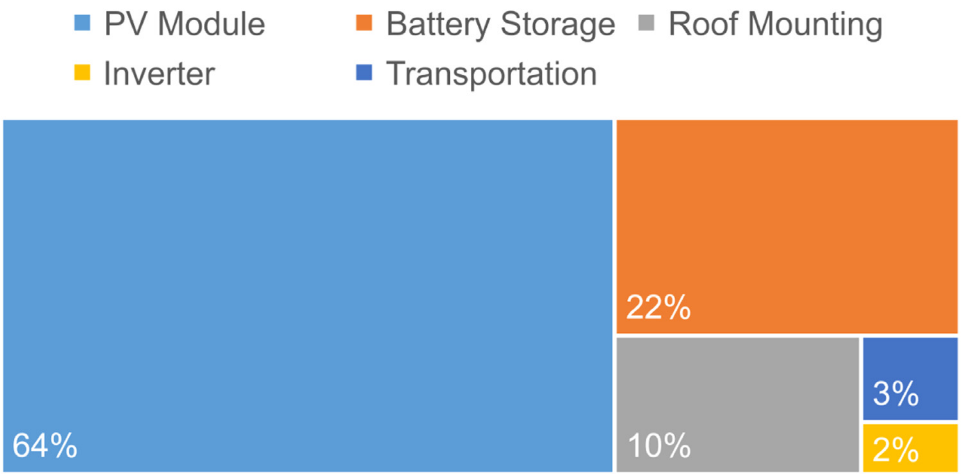

Fig. 8. LCA Result for Scenario B for Barcelona Pilot (derived from Dawood et al., 2021b).

Table 7
Sensitivity analysis of Barcelona Pilot Site.

Discount Rates	1%	3.5%	5%
Total Energy Costs Scenario A (€)	€ 5674,411.49	€ 5537,348.41	€ 5458,243.43
CAPEX Scenario B (€)*	€ 79,909.48	€ 77,979.29	€ 76,865.30
OPEX Scenario B (€)	€ 5526,942.95	€ 5393,441.92	€ 5316,392.75
Total Cost Scenario B (€)	€ 5606,852.43	€ 5471,421.21	€ 5393,258.05
Revenue Scenario B (€)	€ 317,370.78	€ 309,704.82	€ 305,280.46
NPV Scenario B (€)	€ 33,164.24	€ 32,363.17	€ 31,900.84

* This cost includes the initial cost in year 0 and the cost of battery replacement after ten years.

Table 8
Emission Avoided/Reduced for Barcelona Pilot.

Scenarios	Unit	Total Emissions
Scenario A	tCO_2	19,261.13
Scenario B	tCO_2	18,430.92
Emissions Avoid	$\mathbf{tCO_2}$	−830.206

installation and connection and battery bank (installation included). A value-added tax of 21% is also included. Note that the battery lifespan is ten years, hence costs associated with purchasing new batteries was considered in the analysis.

As seen from Fig. 8, an optimum energy demand of about 70,000 MWh comprising 50,000 MWh of electricity and 20,000 MWh of gas is required for scenario B. It is clear from this result that the electricity demand for both scenarios is very similar. However, implementing smart solution technologies resulted in a decreased demand for gas of over 5000 MWh. The incorporation of smart solution technologies implemented in scenario B also results in the additional income generated through the services provided to the grid because of the participation in Demand Response events. This amount, however, is low, which is a consequence of the electricity market framework that does not render favourable conditions to attract stakeholders. Sensitivity analysis for 1%, 3.5% and 5% discount rates for the results of the Barcelona Pilot are presented in Table 7. Overall, the analysis of the Barcelona Pilot indicated that the implementation of smart solution tools is economically viable with a payback time of 8.2 years.

Carbon Emissions: A Life cycle assessment (LCA) was carried out for a 5 kWp comprising of 15 PV modules covering a total area of about 30m^2 with the aim to understand the environmental impacts associated with the implementation of scenario B for this Pilot site. The analysis as presented in Fig. 8 indicated that the PV module account for about 64% of the total GHG emission followed by the battery storage system which accounts for over 20% (Dawood et al., 2021b).

To account for the reduction in carbon emission due to the implementation of smart solution technologies in Scenario B, a carbon factor of 331 kg for every megawatt hour of energy produced is used. The total carbon emissions for both scenarios are presented in Table 8. A total of 19,261.13 tonnes of carbon dioxide was obtained for Scenario A and 18,430.92 tonnes for scenario B, reducing emissions by 830.206 tonnes. To monetise this emission and identify the avoid social costs of emissions, an appraisal carbon value of €16.05 per tonne was used to calculate the social cost of emission. Hence highlighting that implementing RES technology results in societal economic savings of € 13,324.80 due to carbon emission reduction attained from the RES implementation.

5. Discussion

This paper presents work which is part of a larger European Research Project that focuses on energy systems and grid upgrading. The scope of work presented in this paper includes i) the implementation of smart energy technologies and solutions such as demand response and grid optimisation, ii) enhancing and enabling energy storage opportunities and capabilities, and iii) increasing penetration of renewable energy technologies into the energy market. It is important to look at the results from this study in relation to academic papers, which look at the energy system development and energy transition to renewable energy systems, to contextualise the contribution and support the findings of this study. CBA approach has been applied to carry out assessments of the economic benefits and feasibility of energy projects that focus on the implementation of RES technologies and smart energy technologies (Mudasser et al., 2015; Astiaso Garcia et al. 2016; Dehdarian 2018; Ahmadian et al., 2018; Conti et al., 2019; Xiang et al., 2020; Sofia et al., 2020). The findings of this study support the conclusion that the transition towards a greener and cleaner energy system through the adaptation of RES technologies and smart energy technologies provides considerable economic benefits for energy system operators and other stakeholders. Not only are these energy transitions economically viable, but they also result in long-term environmental and social benefits. The analysis captures that integration of greener and low carbon technologies provides emission reduction for both pilot sites, with Barcelona attaining 830.2 tCO_2 reduction in emission, and St Jean attaining 75,675 tCO_2 reduction in emissions. These findings align with research carried out in recent years in the context of the energy transition, energy system development, and energy planning (Tseng and Hung 2014; Dehdarian 2018; Ahmadian et al., 2018; Conti et al., 2019; Metcalf and Stock 2020; Xiang et al., 2020; Sofia et al., 2020; Rennert et al., 2021).

Xiang et al. (2020) highlight that implementing smart technologies for demand response into an energy system is economically viable. Even though implementation of demand response technologies increases investments. At the same time, the implementation leads to a decrease in operating costs, resulting from better optimisation and control of demand and supply in the energy system, which leads to lower costs in relation to energy demand and purchasing energy. Similarly, Xiang et al. (2020) present that through the implementation of demand response, energy storage capabilities increased in the energy system and that energy price fluctuation has a significant impact on energy storage capacity and operation costs of energy systems. This correlation between the increase investment costs, and increased optimization and control of demand and supply related to the energy storage and flexibility attained through energy system implementation of RES and smart technology solutions that Xiang et al. (2020) points out, is captured in the analysis, and presented as co-economic benefits for energy system stakeholders. This includes increased revenue for stakeholders in the St Jean pilot in scenario B in comparisons with scenario A, which is attained through increased energy system flexibility and decreased dependency on imported energy to meet energy needs in the system. Thus, allowing the system to become an energy exporter of excess energy instead of an energy importer. Besides, the analysis captures that integration of sustainable and smart energy technology solutions such as demand response and thermal storage enables functions such as energy usage optimization leading to decrease in overall energy demand 4353,911 kWh over the 20-period between two Barcelona scenarios. Hence, resulting to economic benefits attained through the lower overall costs for both the consumers, and DSO.

Mudasser et al. (2015) points out that implementing policy mechanisms focused on price control can improve the economic feasibility of technology implementation. Xiang et al. (2020) highlighted that energy price volatility does impact the economic benefits attained from implementing energy storage technologies and smart solutions. In this study, this linkage between energy price fluctuation and price control mechanism concerning the impact on economic benefits and viability of energy system development is explored through the changes in energy price between different technologies along with price change overtime during the simulation. Therefore, even though the scope of the study was not specifically looking at role that cost of energy and energy prices play in relation to economic aspects of decision, making, these elements and the behaviour patterns are crucial factors when comes to determining and deciding on investing in energy transition planning and development. This is illustrated with the increased revenue obtained for the St Jean pilot site due to improvements in energy flexibility at condition with stable energy prices. As Mudasser et al. (2015) highlights that even project located with higher energy price in relation to other location with lower energy prices might not be at one project location the considered economically viable for implementing the proposed renewable technology. Along with Xiang et al. (2020) volatile in energy prices and cost of energy can have significant impact on energy system storage capacity and operation costs to uncertainties caused by fluctuation in energy prices.

Sofia et al. (2020) present that implementing decarbonisation policies provide economic, social, and environmental benefits. Implementing decarbonisation policies lead to a reduction in greenhouse gas emissions from energy production facilities and transportation as well as other parts of the energy system. In the same way, the results of the analysis presented above highlight the reduction of emissions and positive economic benefits as a result of RES and smart technology implementation. This was done through illustrating the economic benefits and savings for energy system stakeholders in the form of lower operating and capital costs when looking at the Barcelona pilot and financial gains associated with the increased energy system flexibility when looking at the St. Jean pilot. Alongside highlighting the economic savings and benefits attained through emission reduction through avoided social costs associated with each tonne of CO_2 not emitted through the implementation of RES and smart technology solutions. Hence, both emphasise the beneficial factors related to the investment and implementation of the RES and/or smart technologies solutions to a current energy system.

However, Mudasser et al. (2015) highlight that geographical location, national and local policies, and technological and energy market factors play a considerable role in the economic viability of technological adoption and upgrading of an energy system. In that study, only one of the three locations provided economic benefits for implementing local policy to support hybrid wind-biogas energy production. Another consideration important for policymaking is the timeframe period set for the economic assessment of benefits and feasibility (Sofia et al., 2020; Barroso et al., 2021).

As with many empirical studies, this study suffers from limitations. The main limitation of the study presented in paper is that the research carried out is part of a research project, which has predefined case study boundaries set by pilot sites linked to the project. These boundaries are linked to components such as energy technologies, data availability, and the simulation timeframe of the analysis. For example, in this study, the period for CBA analysis was 20 years. In addition to each pilot site, having different energy system characteristics concerning technologies in the system and type of technologies introduced to the system, Barcelona is looking at the integration of small-scale PV solar and energy storage, and St. Jean is looking at increased hydro capacity and large-scale PV integration. The predefined nature of the research set by InteGRIDy research boundaries impacts the flexibility of the research in terms of carrying out other sets of analyses concerning introducing different types of energy technologies other than those defined within the boundaries of InteGRIDy pilot sites. Based on the analysis, the limitation concerning the predefined nature of case studies set by the InteGRIDy has a considerably low impact on the research since the results manage to provide a good frame of reference concerning the economic, social and environmental benefits attained from green energy system development. The 20-year period selected to conduct economic assessment allows the analysis to capture reasonably long-term benefits of the implementation of RES and smart energy technologies. Furthermore, this study presents results from two different geographical locations. Both pilot sites have different technological specifications for RES and smart energy technologies implemented and different values for energy market and energy system variables. These timeframe and location considerations enabled the study to capture and assess long-term economic, environmental, and social benefits attained by implementing RES and smart energy technologies. The results from this study highlight the importance of energy transition as a major factor in combating climate change and decreasing any further climate crises associated with greenhouse gas emissions.

Furthermore, considering the finding of this study and the discussion above, those investments that enable the implementation of RES and smart energy technology into the energy system are more likely to deliver a positive economic benefit to the energy system operators and other stakeholders. Besides providing environmental and social benefits with a reduction in emissions associated with energy production, the results supported that implementation of RES technologies and smart energy technologies are amongst critical actions that need to be taken to achieve the international objectives set forward in recent years, such as the UNSDG7 and UNSDG13 (UN 2015; IPCC 2021). This study presents a supportive and comprehensive assessment of the positive elements of the energy transition. It enhances further understanding and knowledge that energy transition towards a RES and smart technological-based energy system is crucial in combating climate change. However, it is essential to remember economic and feasibility studies should be revisited and updated regularly before any significant policy decision-making is done since economic assessment involves an enormous number of variables that are impacted by technological innovation, geopolitical stability, and energy market stability.

6. Conclusion

This paper has presented the overall assessment of the economic, social, and environmental benefits attained through the implementation of RES and smart energy technologies to St Jean and Barcelona pilot sites of the InteGRIDy EU Horizon project. The results show that implementing RES and smart technologies is economically viable for pilot sites. The obtained results highlight that for the St-Jean pilot site, it is economically beneficial for energy system operators and other stakeholders to invest in energy system upgrading focused on adopting RES technologies into the system. The overall economic gains obtained over the 20-year simulation period are approximately one hundred million euros and the payback period of 2.86 years. These significant economic gains are associated with increased flexibility in the energy system, which improves the revenue for energy system operators since it provides energy storage opportunities and decreases associate costs concerning energy purchasing to meet fluctuation in the energy system. Furthermore, the results for Barcelona indicate that the implementation of RES and smart energy technologies are economically viable with a payback period of 8.2 years. However, results illustrate that the Barcelona pilot site yields significantly lower economic benefits to energy system operators and other stakeholders over the 20 years simulation period due to the low income generated through DR events participation, a consequence of the electricity market framework which at the time of evaluation does not provide favourable conditions to attract stakeholders.

Moreover, the results emphasize the positive environmental benefits associated with the implementation of RES and smart energy technologies to an energy system, in terms of the St-Jean pilot site, leads to an overall reduction of 75,657 tCO_2 eq of emission. For the Barcelona pilot site, the implementation of RES and smart technologies leads to an overall reduction of 830.206 tCO_2 eq. of emission. Therefore, the results from this study highlight that a significant amount of carbon emissions can be reduced through the transition toward a greener and cleaner energy system. Lastly, in the case of the St Jean pilot site, this reduction translates to economic savings in the long term of approx. 13 million euros attained through the avoidance of economic impacts associated with emitting an additional tonne of CO_2 to the atmosphere over the 20-year simulation period.

The findings of this study provide valuable insight into the positive impacts of energy transition of urban energy systems concerning all crucial fabrics of society and emphasise the need for comprehensive and systematic economic assessments based on short and long-term perspectives to be carried out before any decision-making is taken concerning the selection of energy transitions policies and pathways.

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Data availability statement

The data that support 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.

Declaration of Competing Interest

The authors declare no conflict of interest

CRediT authorship contribution statement

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Appendix A

Table A1

Table A.1
Key Variables and Assumptions.[1]

Variable	Unit	St Jean Pilot	Barcelona Pilot	Value	Reference Point
Discount Rate	dml	x	x	a) 2,8% (set by the France NECP, submitted to the EU) b) 3.5% (set by the InteGRIDy project)	InteGRIDy, Literature
Supply of Energy (Imports)	MWh	x	x	The supply of energy from the imports is the energy coming from the national grid.	InteGRIDy Partner, Stakeholder
Supply of Energy (RES)	MWh	x	x	The supply of energy from renewable energy sources, comes from the implementation of; a) PV and Hydroelectric power stations, it was considered to be energy supplied by RES in the scenario B in the St Jean Pilot. b) PV only for Barcelona	InteGRIDy Partner, Stakeholder
Demand of Energy	MWh	x	x	The total energy demand from the first year of the calculation time period.	InteGRIDy Partner, Stakeholder
Investment Costs	€	x	x	The investment costs made by the DSO, and other energy stakeholder To cover costs, and expense of the energy infrastructure. Referred to as capital cost for Barcelona Pilot	InteGRIDy Partner, Stakeholder

(continued on next page)

Table A.1 (*continued*)

Variable	Unit	St Jean Pilot	Barcelona Pilot	Value	Reference Point
Operation and Maintenance Costs	€	x	x	The operation and maintenance costs made by the DSO, and other energy stakeholder to cover a) costs, and expense of the energy infrastructure for St Jean Pilot b) Cost of energy demands from conventional resources for Barcelona Pilot	InteGRIDy Partner, Stakeholder
Energy Consumption Growth Rate	%	x		−1.50 per year	InteGRIDy Partner, Stakeholder
Energy Supply Growth Rate	%	x	x	1.2 per year	InteGRIDy Partner, Stakeholder
Renewable Technologies	No. of Technologies	x	x	Photovoltaic & Hydroelectric Power Stations	InteGRIDy Partner, Stakeholder
Energy Price	€	x	x	Energy price for St Jean Pilot: National Grid: 110.74 PV: 380.00 Hydro: a) 70.00 b) 75.75 c) 83.20 d) 80.00 Energy price for Barcelona Pilot: National Grid: 0.00685 Gas: 0.04585	InteGRIDy Partner, Stakeholder
Energy Tariff	%	x	x	1.12	InteGRIDy Partner, Stakeholder
Growth Rate of Energy Produced by RES	%	x	x	5%	Literature
Emissions from Energy Production	tCO_2/KWh	x	x	0.000136 (St. Jean) 0.3 (Barcelona)	InteGRIDy Partner, Stakeholder
Social Cost of Emission	€ per Ton of CO_2	x		175 (For St Jean) 16.05 (For Barcelona)	Literature

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