Renewable Energy 95 (2016) 337–355

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Life cycle assessment (LCA) and life cycle cost (LCC) analysis model for a stand-alone hybrid renewable energy system

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ARTICLE INFO

Article history:
Received 18 August 2015
Received in revised form
10 April 2016
Accepted 14 April 2016
Available online 22 April 2016

Keywords:
Renewable energy systems
LCA
LCC
MCDA
AHP

ABSTRACT

Nowadays the biggest challenge for most organizations is a real and substantial application of sustainability through the measurement and comparability of results in order to satisfy the principles of sustainability of all the stakeholders. Definitively, it is necessary to pursue sustainability through the *measurements of specific indicators* and control the variables that influence the state of the economic, social and environmental issues. The aim of this paper is to contribute to the development of a comprehensive, yet practical and reliable tool for a *systematic sustainability assessment*, based on the Life Cycle Assessment (LCA) and the Analytic Hierarchy Process (AHP) to support decision makers in complex decision problems in the field of environmental sustainability. The results are applied to a novel compressed air *energy storage system* proposed as a suitable technology for the energy storage in a small scale stand-alone renewable energy power plant (photovoltaic power plant) that is designed to satisfy the energy demand of a radio base station for mobile telecommunications. The outcome is a dynamic analysis and iterative integrated sustainability assessment of corporate performance.

1. Introduction

Energy is a necessity for human beings, but existing energy resources are exspected to be limited in the coming years due to destructive consequence to the environment. The "*key word*" is to diversify the power supply including more and more renewable energy sources in order to ensure sustainability for future generations [34,43,52]. The renewable energy systems, which combine renewable and conventional energy sources, are considered optimal solutions for off-grid power supply options in remote places or rural areas. Because of the random behavior of the renewable sources, the advantages of these energy systems, in terms of fuel saving, efficiency, emissions and costs, can be reached if energy storage systems are integrated in power supply units [32]. Renewable energy is emerging as energy of the future [47]. However, with the increasing public consciousness on environmental issues, the process to design renewable energy requires simultaneous satisfaction of the *environmental* and *economical* requirements. In order to fulfill the two conflicting requirements, a systematic and integrated approach based on life cycle approach and multi criteria decision-making method is proposed in this work. A well known multicriteria method, the Analytical Hierarchy Process (AHP), developed by Saaty [45,46] is adopted in a trade-off consideration of both technical economical evaluation and environmental impact assessment. In detail, in this study, AHP is used to derive a single criterion score by analyzing the environmental impact and the life cycle cost of a product, [10]. The "essence" of the AHP process is a decomposition of a complex problem into a hierarchy with the goal (objective) at the top of the hierarchy, criteria and sub-criteria at levels and sub-levels, and alternative decisions at the bottom of the hierarchy, respectively. AHP is an operational evaluation and decision support system that is suitable for addressing complex problems featuring high uncertainty, conflicting objectives, and different forms of data and information.

Sustainable energy management using AHP has long been widely applied to economic, social, and industrial systems [58] and has attracted the attention of decision makers for a long time as the method can provide reliable solutions to complex problems [11].

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http://dx.doi.org/10.1016/j.renene.2016.04.027
0960-1481/

Some interesting researches were proposed by the following authors. Qian et al. [42] proposed an AHP model to derive a single criterion score by analyzing the environmental impact and life cycle cost of a product, respectively. While, a model, based on AHP, was proposed by Huang and Huang [26] to evaluate the external environmental cost into the whole life cycle cost (LCC) for the electric power generation. Moreover, to reduce environmental damage Huang and Ma [27] proposed a quantitative method based on LCA and AHP. Furthermore, Ren at al. [44], developed an MCDM (AHP and VIKOR) and LCSA methodology for sustainability decision-making by studying three alternative pathways for the bioethanol production in China. On the other hand, Shi et al. [50], suggested an environmental feasibility analysis in which the life cycle assessment (LCA) methodology was introduced to evaluate the environmental impact and the weight of each index is determined via the AHP method. Additionally, the environmental impact of biomass combustion power generation (BCP) was evaluated from three perspectives (global, regional and local) based on the LCA and AHP by Bu et al. [6].

The use of AHP results to be much stronger than the traditional single criteria decision making approach as the latter generally aim to the maximization of benefits with the minimization of costs. Whereas, AHP not only provides a better understanding of inherent features of decision problems but also promotes the role of participants in the decision making processes [41]. In fact, renewable energy management is a complex, multi-dimensional issue, that cannot be fully covered by the existing portfolio based on reductive and oriented tools. A new generation of modelling tools is necessary in order to assess the triple dimensions of sustainable development, in terms of environmental, economic and social issues [22]. The need for an integrated methodological framework for renewable energy management has been widely discussed due to increasing complex environmental system problems [23,24].

Renewable energy management impacts on many aspects of our lives, therefore it is necessary to evaluate multiple aspects when evaluating alternatives energy. This work introduces a “spectrum” of tools to assess multiple aspects of alternative energy evaluation [29,36]. The urgency in developing these integration tools and methods to support policies, regulations and practices for sustainable development, both at national and international levels have been stressed in various sustainability-related studies [25].

Based on the three dimensions of sustainability, this study aims to develop an *integrated* and *systematic* methodology. The proposed framework included life cycle thinking methods - Life Cycle Assessment (LCA) [30]; [31], Life Cycle Cost (LCC), and Social Life Cycle Assessment (SLCA) - stakeholder analysis supported by multi-criteria decision analysis (MCDA) and dynamic system modelling [2,15]. In order to assist decision-makers in determining which actions should or should not taken in an attempt to make society more sustainable, the final purpose of the proposed method is to provide a tool enabling the holistic evaluation of society system. Therefore, it is necessary to assess carefully the environmental, social and economic impacts before deciding whether and what technologies, policies and investment strategies should be pursued.

The novelty of the proposed research is twofold. Firstly, a new integrated method based on AHP and LCA is proposed for a stand-alone hybrid renewable energy system, designed to cover the energy demand of a radio station for mobile telecommunications. Secondly, a **Relative Sustainability Index (RSI)** is proposed to measure the sustainability performance of the system in different scenarios. The outcome is a dynamic analysis and iterative integrated sustainability assessment of corporate performances. The scenario under study is relevant since there are approximately 5 million radio base station sites in the global telecommunication network, with a growing number each year as the network expands [14]. The traditional way to power all off-grid applications means a very high economical expenses for the mobile operators [5]. One solution is to promote more sustainable mobile networks and more sustainable systems. Furthermore, it is important to note that the state of art literature did not revealed evidence of previous studies on the aim proposed in this research.

The rest of the manuscript is structured as follows. Section 2 introduces the rationale. Section 3 analyzes the scenario and the plant configuration. Section 4 presents a real case study. Section 5 presents the results of the study. Finally, section 6 analyzes conclusion and future developments.

2. The rationale

The main novelty of the proposed model is its combined use of different multi-stakeholders point of views. Different stakeholders have their own respective environmental, social and economic criteria and interests of the developing a renewable energy system [1]. In order to understand the complexity of developing sustainable systems it is necessary to consider the triple dimensions of sustainability that are environment (LCA), social (SLCA) and economy (LCC) dimensions:

- *Environmental Dimension of Sustainability (LCA):* The proliferation of carbon/greenhouse gas accounting and water footprinting methods for assessing environmental performance of companies‘ products are considered insufficient to understand the dynamic interrelationships between the environmental and ecological impacts as well as their implications for resource consumptions [16]. A better understanding of the human health and environmental impacts of products, processes, and activities is possible through an LCA approach. In fact, LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by: compiling an inventory of relevant energy and material inputs and environmental releases; evaluating the potential environmental impacts associated with identified inputs and releases, and interpreting the results to help making a more informed decisions.
- *Social Dimension of Sustainability (SLCA):* The social life cycle assessment (SLCA) is the second dimension which accounts for the impact of an organization, product or system on society. The social benefits can be estimated by analyzing the effects of the stakeholders at local, national and global levels. The majority of social indicators measures the degree of societal values and to what extend life's goals can be achieved. However, many social issues are not easily quantifiable in performance measurements [55]. In contrast to environmental and economic aspects of sustainability assessment, social assessment still lacks of a broad consensus on adequate indicators or standardized methods.
- *Economic Dimension of Sustainability (LCC):* The third pillar of sustainability is the prosperity/profitability aspect. There has been a wide range of existing and established tools for estimating costs and revenues [19]. Economic dimension, based on Life Cycle Costing (LCC) approach, is an assessment of all costs associated with the life cycle of a product system that are directly covered by one or more actors in the product life cycle with the inclusion of externalities that are anticipated to be internalized in future decision making.

In fact, to guarantee a renewable energy system, sustainable development is not feasible by only addressing the risks and challenges of any dimension in a singular fashion [48]. Environmental, social, and economic opportunities, when combined, can have mutually reinforcing outcomes for sustainable developments.

Solution oriented targets can better capture an integrated vision and at the same time may be actionable. The targets and indicators should be scientifically credible, verifiable, measurable, and based on the best available information and evidence. However, targets and indicators should also match the level of ambition.

Thus, the purpose of this study is to develop a tool which can be applied by companies or individual sectors to carry out an overall environmental assessment requiring less detailed data, time and expert knowledge, but still providing a comprehensive analysis. In order to achieve the above result, the prospects of combining the three above-mentioned dimensions with AHP are explored in the present research.

AHP for decision making uses mathematical objectives to process the inescapably, subjective and personal preferences of an individual or a group making a decision. In the AHP process, firstly the hierarchy is defined. Secondly, judgments on pairs of elements with respect to a controlling element are expressed in order to derive ratio scales that are then synthesized throughout the structure used to select the best alternative. The modelling process can be divided into different phases, to provide a better understanding of the main phases they are described as follows:

1) *Pairwise comparison and relative weight estimation.* Pairwise comparisons of the elements in each level are conducted with respect to their relative importance towards their control criteria. Saaty suggested a scale of 1–9 when comparing two components. For example, a sore of 9 represents an extreme importance over another element, while a score of 8 represents an intermediate importance between *"very strong important"* and *"extreme importance"* over another element. For a general AHP application, we can consider that $A_1, A_2, \ldots, A_m$ denote a set of elements, while a_{ij} represents a quantified judgment on a pair of A_i, A_j. Through the 9-value scale for pairwise comparisons, this yields a $[m \times m]$ matrix A as follows:

$$A = a_{ij} = \begin{array}{c} \\ A_1 \\ A_2 \\ \ldots \\ A_m \end{array} \left| \begin{array}{cccc} A_1 & A_2 & \ldots & A_m \\ 1 & a_{12} & \ldots & a_{1m} \\ 1/a_{12} & 1 & \ldots & a_{2m} \\ \ldots & \ldots & \ldots & \ldots \\ 1/a_{1m} & 1/a_{2m} & \ldots & 1 \end{array} \right|$$

Where $a_{ij} > 0$ (i, j = 1, 2,...,m), $a_{ii} = 1$ (i = 1, 2, …,m), and $a_{ij} = 1/a_{ji}$ (1; 2; …,m). A is a positive reciprocal matrix. The result of the comparison is the so-called **dominance coefficient** a_{ij} that represents the relative importance of the component on row (i) over the component on column (j), i.e., $a_{ij} = w_i/w_j$. The pairwise comparisons can be represented in the form of a matrix. The score of 1 represents equal importance of two components and 9 represents extreme importance of the component i over the component j. However, in matrix A, there is a problem in assigning to the m elements $A_1, A_2, \ldots, A_m$ a set of numerical weights $w_1, w_2, \ldots, w_m$ that reflects the recorded judgments. If A is a consistency matrix, the relations between weights w_i, w_j and judgments a_{ij} are simply given by $a_{ij} = w_i/w_j$ (for i,j = 1, 2, …, m) and

$$A = \begin{array}{c} A_1 \\ A_2 \\ \ldots \\ A_m \end{array} \left| \begin{array}{cccc} w_1/w_1 & w_1/w_2 & & w_1/w_m \\ w_2/w_1 & w_2/w_2 & & w_2/w_m \\ \ldots & \ldots & \ldots & \ldots \\ w_m/w_1 & w_m/w_2 & \ldots & w_m/w_m \end{array} \right|$$

If matrix w is a non-zero vector, there is a λ_{max} of $Aw = \lambda_{max}w$, which is the largest eigenvalue of the matrix A. If matrix A is perfectly consistent, then $\lambda_{max}w = m$. But given that a_{ij} denotes the subjective judgment of decision-makers, who give a comparison and appraisal, with the actual value (w_i/w_j) having a certain degree of variation. $Aw = \lambda_{max}w$ cannot be set up. Therefore, the consistency of the traditional AHP judgmental matrix always needs to be revised in regard to its consistency.

2) *Priority vector.* After all pairwise comparisons are completed, the priority weight vector (w) is computed as the unique solution of Aw = λmaxw, where λ_{max} is the largest eigenvalue of the matrix A.
3) *Consistency index estimation.* Saaty proposed the consistency index (CI) to verify the consistency of the comparison matrix. The consistency index (CI) of the derived weights could then be calculated by: $CI = (\lambda_{max}-n)/n-1$. In general, if CI is less than 0.10, the satisfaction of the judgments may be derived.

The proposed methodology consists of *three main phases* as shown in Fig. 1.

The three main phases are: analytical phase, modelling phase and assessment phase, which are detailed as follows.

Phase #1: Analytical. The aim of this phase is the scenario definition. Therefore, the phase is performed following two steps:

- *Initial analysis:* The aim is to carry out a preliminary study in order to identify a possible scenario for the implementation of the model.
- *Characterization:* The aim is to identify the best indicators to carry out a deep investigation to develop a "kit" of performance indicators that are correlated to the scenario.

Phase #2: Modelling. In the current phase the collection and classification of information are conducted to inventory the necessary information (quantitative or qualitative) of the selected indicators. Therefore, the phase is performed following three steps:

- *Environmental Analysis* (Life Cycle Assessment): the aim is to analyze the typical stages of classification, characterization and, standardization/evaluation that characterize the LCA approach.
- *Economic Analysis* (Life Cycle Cost): The analysis is performed via surveys and market analysis for the calculation of operating costs (fuel consumption, maintenance, etc.).
- *Social Analysis:* the analysis is conducted through international reports and interviews. The social analysis is directly connected with phase #3.

Phase #3: Assessment. The aim of this phase is to evaluate data collected in previous phases. This phase is very complex as it takes into account all the constraints of social, environmental and economic aspects. Therefore, the phase is performed as follows:

- *Multicriteria analysis:* the aim of the multicriteria analysis is to build the AHP model in which each pillar of sustainability represents a strategic criteria aiming to determine the relative weight (index of compatibility).
- *Analysis of Flexibility:* the aim of the analysis of flexibility is to evaluate the **Relative Sustainability Index.** This index is extremely useful for a decision maker to improve and to measure the sustainability performance of a system.
- *Sustainability assessment:* The final stage of the model includes the sustainability analysis of the three solutions and the identification of possible opportunities for improvement.

3. Scenario definitions: plant configurations

As an illustrative case study, the methodological approach was applied to a stand-alone hybrid renewable power generation

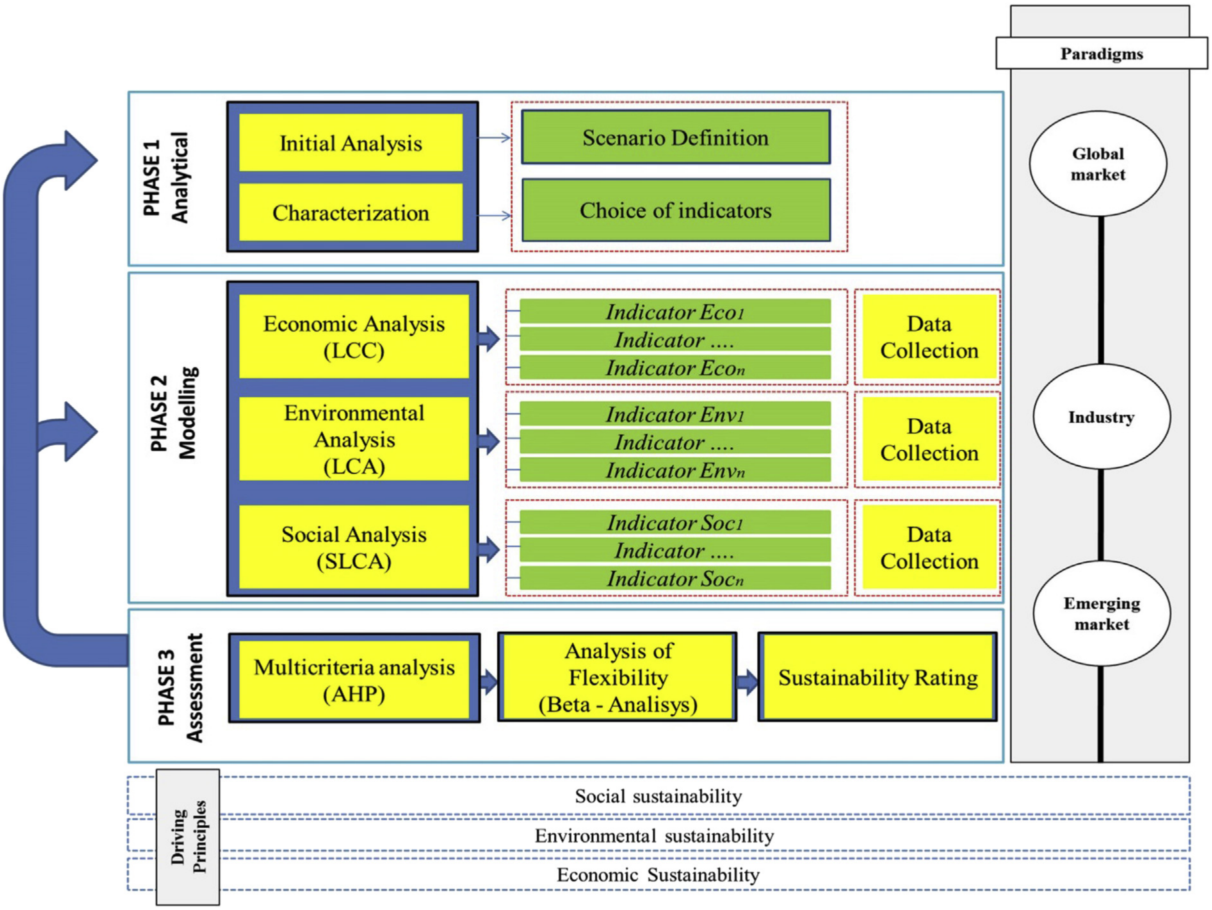

Fig. 1. Methodological approach.

system, designed to cover the energy demand of a radio station for mobile telecommunications. It is important to note that for mobile phone large base stations the transmission technology is focused on a container constructed for this purpose or on shelters.

In Fig. 2, a typical layout of a radio base station for telecommunication is shown.

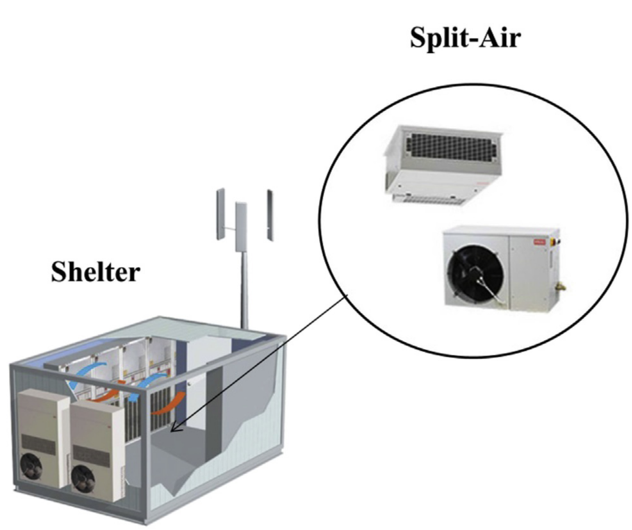

Fig. 2. Layout of a typical shelter containing the equipment for telecommunication radio base station.

The devices convert almost all the electrical energy into heat. But if the heat inside gets too high, the devices can suffer breakdowns. For this reason, in the interior of the shelter some conditioners may be installed.

A typical electric demand profile, for this kind of application, is shown in Fig. 3.

In order to appreciate the influence of solar energy availability on the hybrid plants sizing, this study was carried out considering to install the plant near the tropics, at Kharga (25°26'N latitude and 30°33'E longitude) in Egypt, where the maximum and minimum horizontal irradiations are 8370 and 4080 Wh/m^2/day.

The main data on the site are summarized in Table 1.

The installation zone of radio base station is shown in Fig. 4.

The traditional system to supply electricity in a stand-alone radio base station is composed of a diesel generator. This configuration is illustrated in Fig. 5.

In addition to the traditional solution, two alternative solutions integrated with the use of renewable energy were analyzed. The first integrated system (Plant configuration) that was proposed in this study was composed of a renewable electricity production plant, in particular of a photovoltaic plant and, a storage system composed by an electrolyzer producing hydrogen that, subsequently, was stored in a metal hydrides tank and after utilized in a fuel cell. This system is schematized, reporting its main components, in Fig. 6.

The second and last innovative system proposed (Plant configuration C) was partially composed of the same components of the previous one. The main difference was that the system presented

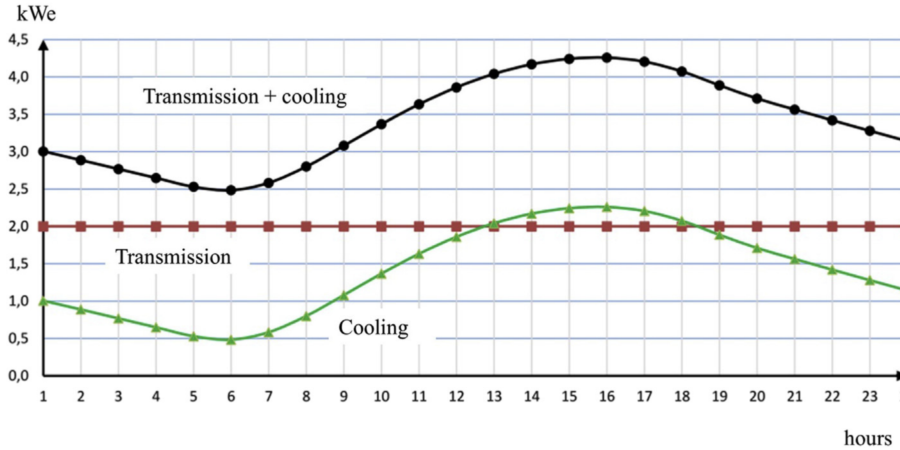

Fig. 3. Typical trend of electric demand for a telecommunication radio base station (Egypt summer period).

Table 1
Site data.

Location	Kharga (Egypt)	
Latitude	25°26′56″ N	
Longitude	30°32′24″ E	
Altitude	64 m	
Number of heating degree-days	341	
Average minimum temperature	°C	16.8
Average maximum temperature	°C	33.2
Monthly irradiation on horizontal plane (max)	Wh/m^2/day	8370
Monthly irradiation on horizontal plane (min)	Wh/m^2/day	4080

some concerns about storage system. However, the aim was not to accumulate the excess energy produced by the panel. The configuration plant is shown in Fig. 7.

4. Case study: proposal of an integrated framework for renewable energy system

The case study analysis aimed to test and validate the proposed approach. The purpose of this case study was to illustrate the use of the proposed model into a real scenario. The implementation of the integrated approach relied heavily on available quality databases. The integrated framework was performed, by a group of experts, composed by: one Energy Manager; one LCA Expert; one AHP Expert; one Mechanical Engineering; one Information and communications Technology Expert.

4.1. Phase 1: analytical

Firstly, *the Initial Analysis* was carried out to define the scenario under study. The methodological approach was applied to the analysis of a new hybrid power system, designed to meet the energy demand of a radio station for mobile telecommunications, as described in section 3.

Secondly, *the Characterization Analysis* was delineated in order to choose the indicators. An important phase of the assessment methodology was the correct definition of the indicators within each of the three sustainability dimensions: *economic*; *environmental* and *social indicators*. In fact, in the construction of the model, the criteria selection was very essential for the reliability and the rationality of the assessment results. Many environmental indices are available in the literature to evaluate the environmental performances of products [39].

In fact, according to the existing literature [12,40,57] there is an established classification of the *environmental impact indicators* in line with the impact categories (Eco-indicator 99, EDIP, EPS, etc.): Impact category, Climate change, Photo-oxidant formation, Cumulative energy demand, Acidification, Eutrophication, Stratospheric ozone depletion, Noise, Human toxicity, Ecotoxicity, Impacts of land use, Depletion of biotic resources, etc.

Moreover, regarding the *economic and social indicators*, there are a multiplicity of considerable variables in the existing literature.

However, in our opinion an interesting analysis was carried out by Basurko and Mesbahi [4]; who represented the economic sustainability as a dependent variable of environmental variables or technological attributes in order to create a linkage to sustainability dimensions.

Furthermore, recognizing the need for the integration of social criteria into LCA, in 2009 the UNEP/SETAC Life Cycle Initiative published the Guidelines for Social Life Cycle Assessment (S-LCA) of Products [53]. The UNEP/SETAC guidelines propose that SLCA conforms to the ISO 14040 framework – however, with some adaptations. Social hot spots were found in each stage of the product life cycle [54]. According to [7] an important step in determining the ability of a tool assisting as a sustainability assessment is to check which sustainability issues are addressed by specific parameters. The majority of the social impact assessment tools is based upon subjective assumptions. In fact, this can make the final outcome difficult to interpret, especially when compared with other sustainability outcome results.

For this reason, a comprehensive list of relevant sustainability issues was compiled, based on the sustainability requirements mentioned in the literature. Moreover, through the review of the existing literature, different sustainability areas covered by the different indicators were also identified as shown in Tables 2 and 3.

According to the above consideration, the most significant indicators were selected, in order to:

- Measure all the aspects considered most significant in terms of sustainability;
- Address the policies of business improvement;
- Synthesize and simultaneously embrace the complexity of the investigation to be pursued.

Definitely we selected (as shown in Table 4):

- 4 indicators of environmental sustainability;
- 4 indicators of economic sustainability;
- 4 indicators of social sustainability.

Fig. 4. Shelter installation zone: Kharga (Egypt).

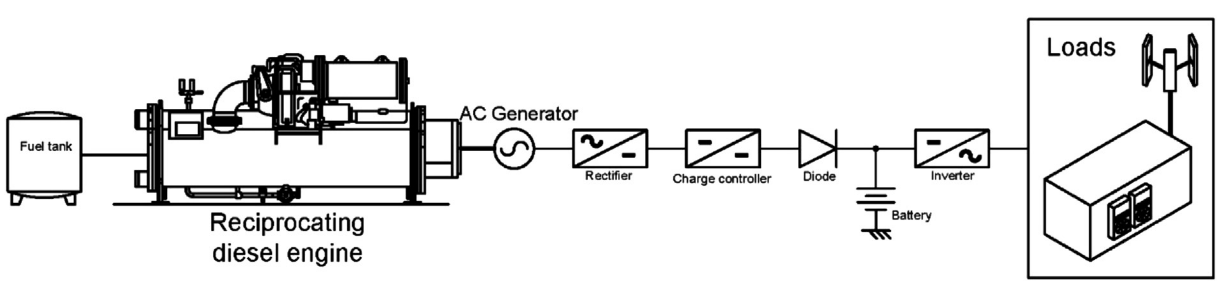

Fig. 5. Plant configuration A: traditional solution with a diesel reciprocating engine and electric generator to supply the load.

The selected indicators characterized the present case study. Thus, the type of indicators can be modified depending on the scenario.

4.2. Phase 2: modelling

During the Modelling phase, the *Environmental Analysis (LCA)* was carried out. The aim of this analysis was to quantify the environmental impact of the fuel system of a radio station for mobile telecommunications. In the current case study, three solutions (motor, motor + PV + accumulation, motor + PV) were analyzed. The three solutions allowed to meet the energy needs without the use of the electricity grid. The description of the main features characterizing the Environmental Analysis (LCA) are reported as follows:

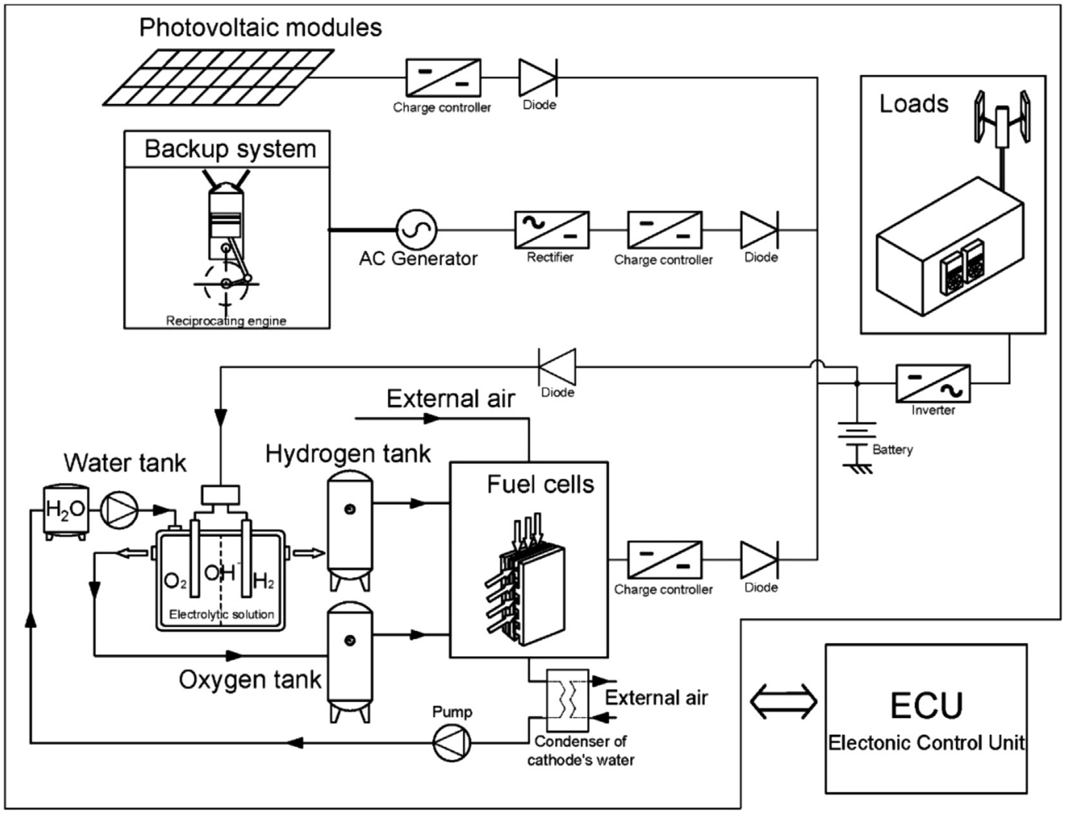

Fig. 6. Plant configuration B: energy storage by means a system with the electrolyzer for hydrogen production, energy storage in metal hybrids and fuel cell to produce electric power.

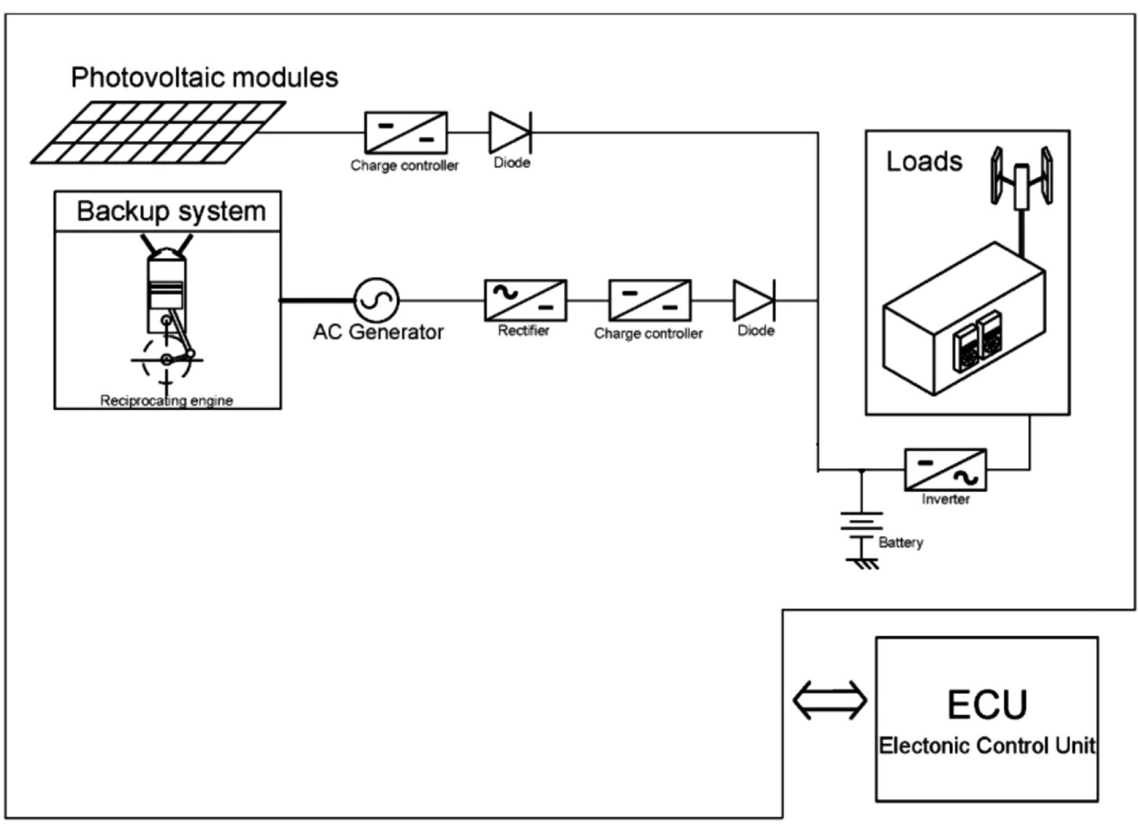

Fig. 7. Plant configuration C: Photovoltaic without accumulation.

Table 2
Economic indicators.

Economic indicators	Literature source		
	[54]	[4]	[7]
Wages costs	X		
Material costs (operational costs)	X		
Energy costs (operational costs)	X		
Equipment costs (investment costs)	X		
Revenues	X		
Taxes	X		
Discount analysis	X		
Capital costs		X	
Interest rate		X	
Repayment period		X	
Consumables costs		X	
Training costs		X	
Maintenance costs		X	
End of life costs		X	
Number of years between present and future time		X	
Net present value			X
Long term commitments			X
Security of supply			X
Adequately proven technology			X
Risk minimization			X
Strength and diversification of local economy			X
Reliability of energy			X
No blocking of other deliverable developments			X

- Functional Unit. The functional unit was constituted by the operation of the power supply system for a calendar year. The choice of the functional unit was made to avoid overlooking the natural energy implications dictated by normal climatic variations during a calendar year.
- System boundaries. The LCA was developed as *"cradle to grave"* mode. Thus, the boundaries of the system included the collection of raw materials, the preparation of semi-finished products, the production of components (such as the inverter, the electrical system and PV modules), and the use. All the impacts arising from the structures/systems in common to all the three solutions (e.g. shelter, battery, etc.) were not considered. Furthermore, it was not possible to analyze the storage system of metal hydrides, as it is a highly innovative technology and, reliable data are not available.
- Data collection and evaluation methods. The inventory analysis was based on primary data obtained from the existing literature and from the secondary data preloaded on SimaPrò Software ©. Environmental impacts of secondary data were defined according to Ecoinvent database and related to:
  - Generation of electricity from a photovoltaic system consisting of modules in mono-crystalline silicon;
  - Generation of electrical energy from an internal combustion engine fueled with diesel;
  - Generation of electricity from a fuel cell PEM.
- Results. The Eco-indicator 99 method was used to crry out the analysis of impacts. The Eco-Indicator assessment method (EI 99) was developed by PRe' consultants in 1999 and offers a broad perspective on the environmental impact of a good or service [33]. The method uses the damage-oriented approach. In Eco-Indicator 99 three types of environmental damages are considered:

- *Human Health*, consists of the idea that all human beings, in present and future, should be free from environmentally transmitted illnesses, disabilities or premature deaths.
- *Ecosystem Quality*, consists of the idea that non-human species should not suffer from the disruptive changes of their populations and geographical distribution.

Table 3
Social indicators.

Social Indicators	Literature sources													
	UNEP [53]	GRI [20]	Da Silva et al. [9]	Jørgensen et al. [55]	Barthel et al. [3]	Dreyer et al. [13]	Flysjö [17]	Gauthier [18]	Hunkeler [28]	Grießhammer [21]	Méthot [35]	Nazarkina and Le Bocq [38]	Schmidt et al. [49]	Spillemaeckers [51]
Total number of employees, for type of contract, measured of diversity and type of work		X		X	X	X	X	X	X	X	X		X	X
Average salary of workers			X	X	X	X	X	X	X	X	X	X	X	X
Valorization of the diversity	X	X		X	X	X	X	X	X	X	X	X	X	X
Health and safety of working conditions	X	X		X	X	X	X	X	X	X	X	X	X	X
Professional development and employability	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Company commitment for improving environmental quality					X	X	X	X	X	X	X	X	X	X
Child labour	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Forced and compulsory work	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Marketing policy	X	X		X	X	X	X	X	X	X	X	X	X	X
Knowledge and management of potential damage of products and services	X	X		X	X	X	X	X	X	X	X	X	X	X
Practice against corruption and illegal price fixing	X	X		X	X	X	X	X	X	X	X	X	X	X
Freedom of association and collective bargaining				X	X	X	X	X	X	X	X	X	X	X

Table 4
Selected indicators.

Categories	Indicators	Definition
Environmental indicators	Human health	Public health problems caused by environmental contamination.
	Ecosystem quality	Knowledge of the interaction of the physical, chemical and biotic environment is essential to guide management and policies for the decision makers.
	Resources	Environmental resources management aims to ensure that ecosystem services are protected and maintained for future human generations, and also maintain ecosystem integrity through considering ethical, economic, and scientific (ecological) variables.
	Noise Impact	Excessive noise seriously harms human health and interferes with people's daily activities.
Economic indicators	Installation Plant	Costs incurred on the installation, construction, and equipment used.
	Maintenance	Costs associated with keeping equipment/machine in good condition by regularly checking it and repairing it when necessary.
	Operating cost	Costs associated with the expenses which are related to the operation of device, component, piece of equipment or facility. They are the cost of resources used by an organization just to maintain its existence.
	Disposal	Costs associated with the disposal of the devices/equipment at the end of life.
Social indicators	Health and Safety	Health and safety policies that relate to measures taken by employers regarding working conditions that are aimed creating a healthy and safe environment for employees.
	People development	Particularly today, it is imperative to develop existing talent with a focus on business objectives and growth opportunities.
	Green product and renewable resources	The opportunities to reduce the environmental and health impacts span from big decisions. The products we use must be a part of the greening process. Reducing our environmental impacts requires thinking and learning about not just how we use products, but where they came from and where they're going.
	Economic development	Economic development is the sustained, concerted actions of policy makers and communities that promote the standard of living and economic health of a specific area. Economic development can also be referred to as the quantitative and qualitative changes in the economy. Such actions can involve multiple areas including development of human capital, critical infrastructure, regional competitiveness, social inclusion, health, safety, literacy, and other initiatives.

Table 5
Solution A

Component	Required size	Selected size	Selected Model (brand)	Note	η
Reciprocating diesel engine	5.6 [kW]	8.6 [kW]	Lombardini LWD502	Aspirated diesel 4T	0.27
AC electric generator	5.6 [kW]	8.6 [kW]	Parker MB205	Servomotor AC Brushless 3F	0.967
Fuel tank	11000 [l]	11000 [l]	Emiliana serbatoi GE TANK	Tank dispenser horizontal axis	
Rectifier AC/DC	8A, 600V	30A, 800V	Semikron SKB30/08A1	Three-phase rectifier	0.996
Charge controller DC/DC		48V, 50A 2.4 kW	SMA Sunny charger 50	Charge controller with MPP Tracking	0.98
Buffer battery	4 kWh	48V, 36A, fino a 2 kWh	STORELIO ES200500IT	Lithium Iron Phosphate	0.95
Inverter DC/AC	5.6 kW	6	SMA Sunny Island 6.0H	System with battery management and multicluster	0.93

Table 6
Solution B.

Component	Required size	Selected size	Selected Model (brand)	Note	η
Reciprocating diesel engine	5.6 [kW]	8.6 [kW]	Lombardini LWD502	Aspirated diesel 4T	0.27
AC electric generator	5.6 [kW]	8.6 [kW]	Parker MB205	Servomotor AC Brushless 3F	0.967
Fuel tank	7010 [l]	8000 [l]	Emiliana serbatoi GE TANK	Tank dispenser horizontal axis	
Rectifier AC/DC	8A, 600V	30A, 800V	Semikron SKB30/08A1	Three-phase rectifier	0.996
Charge controller DC/DC		48V, 50A 2.4 kW	SMA Sunny charger 50	Charge controller with MPP Tracking	0.98
Buffer battery	4 kWh	48V, 36A, fino a 2 kWh	STORELIO ES200500IT	Lithium Iron Phosphate	0.95
Inverter DC/AC	5.6 kW	6	SMA Sunny Island 6.0H	System with battery management and multicluster	0.93
Photovoltaic modules	5 kWp	5	ERA SOLAR ESPMC 150/24	Panels monocrystalline silicon	
Water tank [l]	73	150	ROTOTEC V150	Outdoor cistern	
Electrolyzer	3	5.5 [kW, 1Nm3/h]	VOLTIANA Pressurised Water Electrolyzer	Electrolyzer 20 bar and 1Nm3	0.6
Metal hydrides tank	1.7 m3	3000 l equivalenti	ENESSERE Hydra Cartridges-3000	Cartridge metal hydrides	
Oxygen tank	0.1 m3	50 l (a 25 bar)	BLUGAS bombola 50 l	Steel cylinder at high pressure	
Fuel Cell	4.6 [kW]	5	Ballard ElectraGen H2	PEM	0.45
Pumps	included in the electrolyzer				

Table 7
Solution C.

Component	Required size	Selected size	Selected Model (brand)	Note	η
Reciprocating diesel engine	5.6 [kW]	8.6 [kW]	Lombardini LWD502	Aspirated diesel 4T	0.27
AC electric generator	5.6 [kW]	8.6 [kW]	Parker MB205	Servomotor AC Brushless 3F	0.967
Fuel tank	7010 [l]	8000 [l]	Emiliana serbatoi GE TANK	Tank dispenser horizontal axis	
Rectifier AC/DC	8A, 600V	30A, 800V	Semikron SKB30/08A1	Three-phase rectifier	0.996
Charge controller DC/DC		48V, 50A 2.4 kW	SMA Sunny charger 50	Charge controller with MPP Tracking	0.98
Buffer battery	4 kWh	48V, 36A, fino a 2 kWh	STORELIO ES200500IT	Lithium Iron Phosphate	0.95
Inverter DC/AC	5.6 kW	6	SMA Sunny Island 6.0H	System with battery management and multicluster	0.93
Photovoltaic modules	5 kWp	5	ERA SOLAR ESPMC 150/24	Panels monocrystalline silicon	

- *Resources*, consists of the idea that the nature's supply of non-living goods, which are essential to the human society, should be available also for future generations.

A series of complex damage models had to be developed in order to be able to use the weights for the three damage categories. Characterization was based on the following consideration.

- *Emissions:* The characterization factors were calculated at the endpoint level (damage). The damage model for emissions includes fate analysis, exposure, effects analysis and damage analysis. This model was applied to the following impact categories: Carcinogens, Respiratory organics, Respiratory inorganic, Climate change, Radiation, Ozone layer, Ecotoxicity. The DALY (Disability Adjusted Life Years) scale, developed by Ref. [37] was used. The original purpose of the DALY concept was to have a tool to analyze the rationale of national health budgets.
- *Acidification/Eutrophication:* Damage to ecosystem quality was assessed as a result of emission of acidifying substances to air. Damage was expressed in Potentially Disappeared Fraction (PDF)*m2*year/kg emission [56].
- *Land use:* Land use (in man-made systems) has an impact on species diversity. Based on field observations, a scale is developed expressing species diversity per type of land use. Species diversity depends on the type of land use and the size of the area. Both regional effects and local effects were taken into account in the impact category: Land use. Damage was assessed as a result of either conversion or occupation of land and expressed in Potentially Disappeared Fraction (PDF)*m2*year/m2 or m2a.
- *Resource depletion:* Mankind will always extract the best resources first, leaving the lower quality resources for future extraction. The damage of resources will be experienced by future generations, as they will have to use more effort to extract remaining resources. This extra effort was expressed as "surplus energy" [8].

The following tables show the main components of the three systems.

Each table analyzes: Component for specific solution (A, B and C); Required Size for each component; Selected Size; Selected Model (brand) and efficiency (η). The following analysis is fundamental for environmental characterization of each solution (Tables 5–7).

The following Fig. 8 shows the analysis performed according to the method Eco-Indicator 99 (egalitarian Version) for solution A.

Results for the Damage Assessment (solution A) showed that:

- For Human Health the damage was 0.00833 Disability-adjusted life year (DALY). The impact category that produced the maximum damage was Respiratory inorganic (0.00557 DALY) followed by Climate Change (0.0252 DALY).
- For Ecosystem Quality the damage was 605 PDFm2yr. The impact category that produced the maximum damage was Land use (325 PDFm2yr) followed by Acidification/Eutrophication (181 PDFm2yr) and then Ecotoxicity (99 PDFm2yr).
- For Resources the damage was 36.7 MJ Surplus E4. The impact category that produces the damage was almost exclusively the Fossil fuels (36.941 MJ Surplus), being Minerals quantified in only 72 MJ Surplus.

Fig. 9 shows the analysis performed according to the method Eco-Indicator 99 (egalitarian Version) for solution B.

Results for the Damage Assessment (solution B) showed that:

- For Human Health the damage was 0.00695 DALY. The impact category that produced the maximum damage was Respiratory inorganic (0.00463 DALY) followed by Climate Change (0.0196 DALY).
- For Ecosystem Quality the damage was 544 PDFm2yr. The impact category that produced the maximum damage was Land use (241 PDFm2yr), followed by Ecotoxicity (161 PDFm2yr) and Acidification/Eutrphication (142 PDFm2yr).
- For Resources the damage was 2.66 E4 MJ Surplus. The impact category that produced the damage was still almost exclusively the Fossil fuels (2.62 MJ Surplus E4), being Minerals quantified in only 375 MJ Surplus.

Fig. 10 shows the analysis performed according to the method Eco-Indicator 99 (egalitarian Version) for solution C.

Results for the Damage Assessment (solution C) showed that:

- For Human Health the damage was 0.00683 DALY. The impact category that produced the maximum damage was Respiratory inorganic (0.00453 DALY) followed by Climate Change (0.0197 DALY).
- For Ecosystem Quality damage was 511 PDFm2yr. The impact category that produced the maximum damage was Land use (246 PDFm2yr), Acidification/Eutrphication (142 PDFm2yr) and then from Ecotoxicity (123 PDFm2yr).
- For Resources in damage was 2.72 E4 MJ Surplus. The impact category that produced the damage was still almost exclusively the Fossil fuels (2.7 MJ Surplus E4), being Minerals quantified in only 245 MJ Surplus.

Some relevant impact categories used in this research were Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Photochemical Oxiden Creation Potential (POCP), Acidification Potential (AP).

The following figures (Figs. 11–13) show the different comparisons using the methodology Eco-indicator 99 (red solution A, the solution B in green and yellow in the solution C).

Table 8 shows the allocation of scores, for each category of damages, for the three analyzed solutions.

Subsequent to, the Environmental Analysis (LCA), *the Economic Analysis (LCC)* was carried out. The aim of this phase was to quantify the economic impact of the power supply system of a radio station for mobile telecommunications. The main features of Economic Analysis (LCC) are described as follows:

- Functional Unit. The considered functional unit was constituted by the operation of the product for a calendar year, considering a useful life of 20 years.
- System boundaries. The costs of facilities/common systems in all the three solutions (for batteries, etc.) were not considered except for the cost of the shelter, which index significantly affected the cost of the system.
- Data collection and evaluation methods. The inventory analysis was based on primary data obtained from the existing literature (for maintenance costs), market surveys (for the costs of the components) and data on energy consumption. The tables (Tables 9–11) show the cost of the main components of the three selected systems.
- Results. Installation costs, cost of maintenance and spare parts, operating costrs (fuel) and disposal costs were analyzed as outcomes.

The energy analysis showed the following consumptions (Table 12).

Table 13 shows the enhancement of the chosen cost indicators.

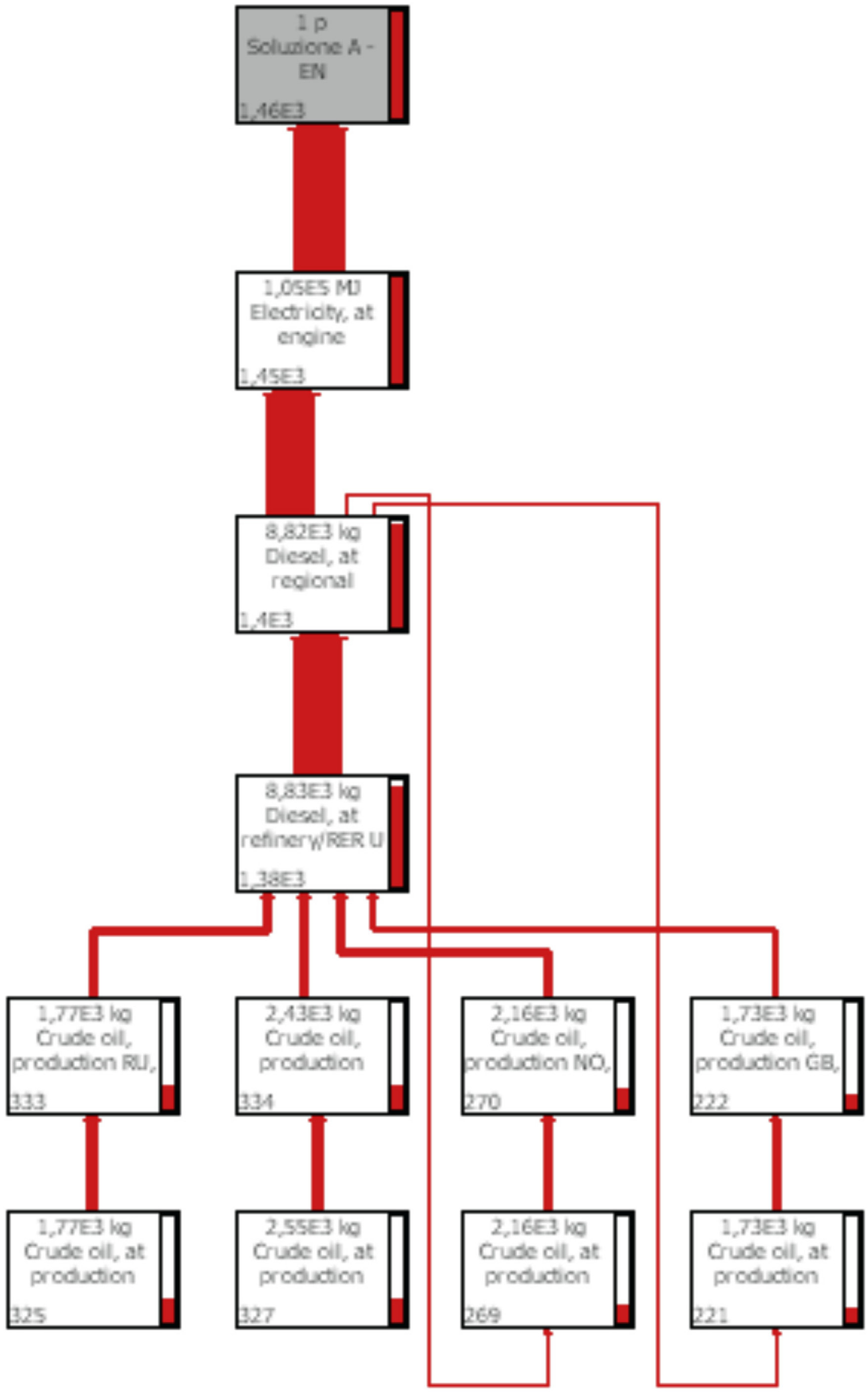

Fig. 8. Network according to Eco-indicator 99 for solution A

4.3. Phase 3: assessment

Phase 3 represents the crucial phase of the methodological approach. The critical issue was the construction of the AHP model according the above considerations and assumptions. The AHP model is shown in Fig. 14.

The goal of the AHP model was to define a ***Relative Sustainability Index*** – ***RSI*** I_S^i, in order to improve and to measure the sustainability performance of our system.

RSI represents a single index that aggregates the weights of each criteria and subcriteria taking into account those criteria and subcriteria that could have different importance depending on the managerial point of view and strategy.

Taking into account the AHP model, there were 3 criteria that represented the three dimensions/pillars of sustainability. For each criteria there were four subcriteria which were selected to perform our analysis.

As explained above, AHP is a multi-criteria decision-making tool enabling the user to establish weights for selected criteria by means of a series of pairwise comparisons, according to the proposed hierarchical structure and the 1–9 point Saaty's scale.

Fig. 15 shows the weights for Environmental criteria.

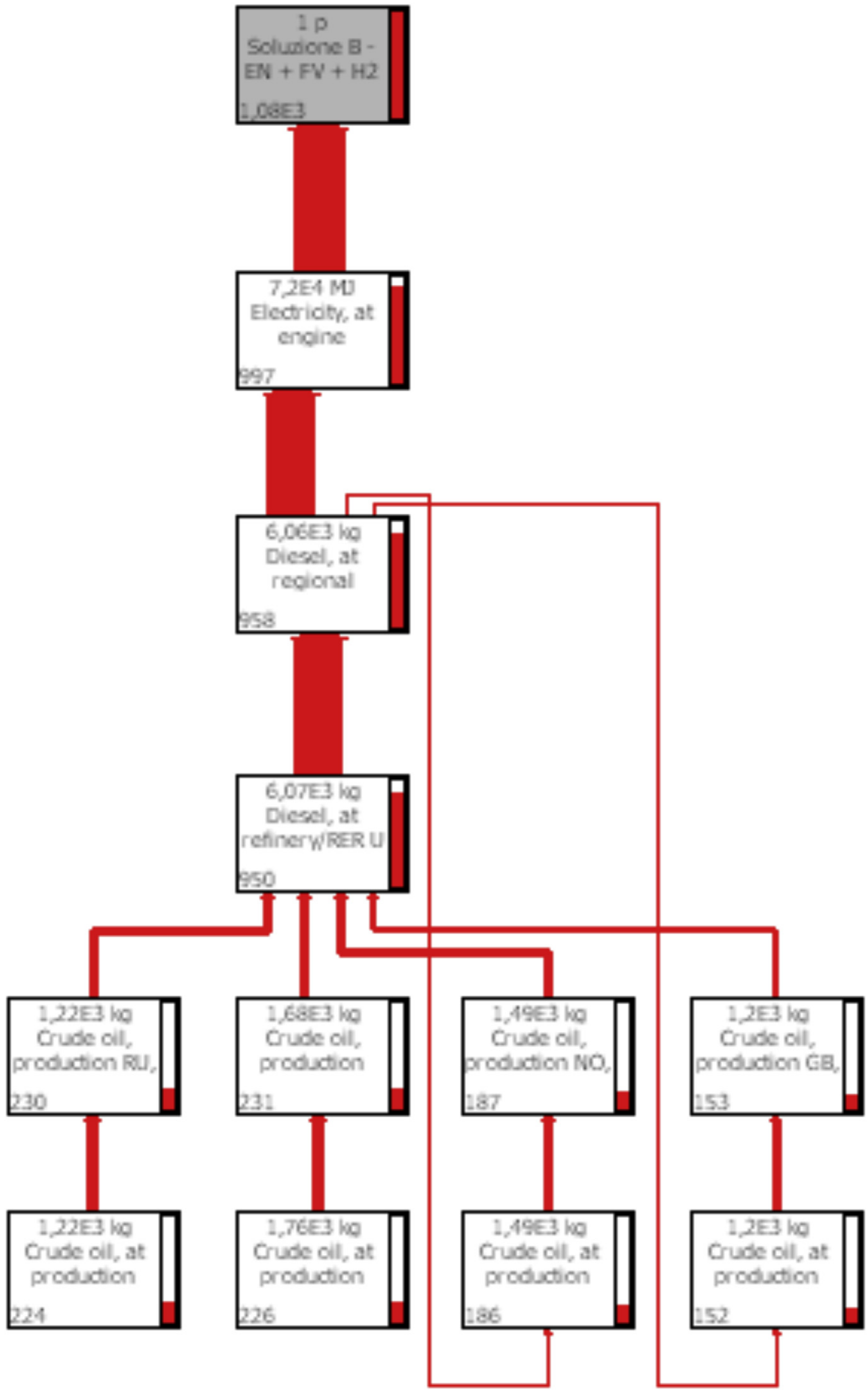

Fig. 9. Network according to Eco-indicator 99 for solution B.

In a similar way the weights for the Economic and Social criteria were obtained, as shown in Figs. 16 and 17.

Once the weights were defined for each subcriterion it was possible to assess the **Relative sustainability index**, according the following assumptions (shown in Table 14).Where:

$$I^A_{LCA} + I^B_{LCA} + I^C_{LCA} = 100$$

$$I^A_{LCC} + I^B_{LCC} + I^C_{LCA} = 100$$

$$I^A_{LCSA} + I^B_{LCSA} + I^C_{LCSA} = 100$$

Relative Sustainability Index on the i-th alternative was given by the following equation

$$I^i_S = \beta_{En} * I^i_{LCA} + \beta_{Ec} * I^i_{LCC} + \beta_{So} * I^i_{LCSA} \quad (1)$$

where:

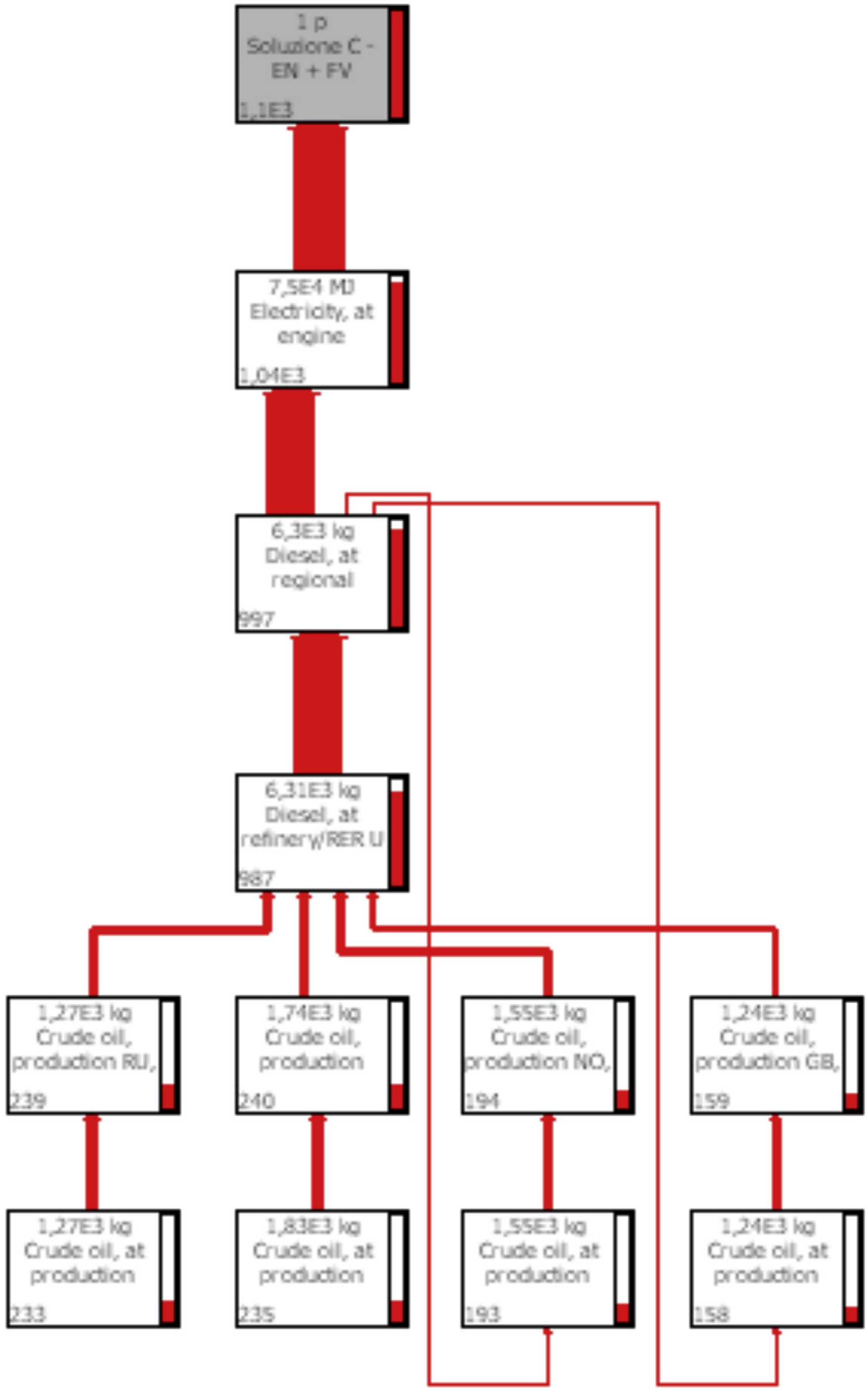

Fig. 10. Network according to Eco-indicator 99 for solution C.

- β_{En} is the variable weight attributed to the environmental component
- β_{Ec} is the variable weight attributed to the economic component
- β_{So} is the variable weight attributed to the social component
- with $\beta_{En} + \beta_{Ec} + \beta_{So} = 100$

This method allowed to make different choices depending on the strategy of the decision maker. To this end, four different perspectives (balanced, economic, social and environmental) were defined as shown in Table 15.

As a result, the method had not a single output value, but different values depending on the chosen perspective.

This represents a value for decision makers because with four different perspectives, it is possible to choose the most appropriate for the specific purpose and then perform a sensitivity analysis.

Table 16 shows a summary on the calculation of the Relative sustainability index.

Moreover, Fig. 18 shows the Relative sustainability index in a graphical way.

The value of the proposed methodological approach was to make possible to choose the most appropriate solution according to the "favorite" perspective and perform a sensitivity analysis, as

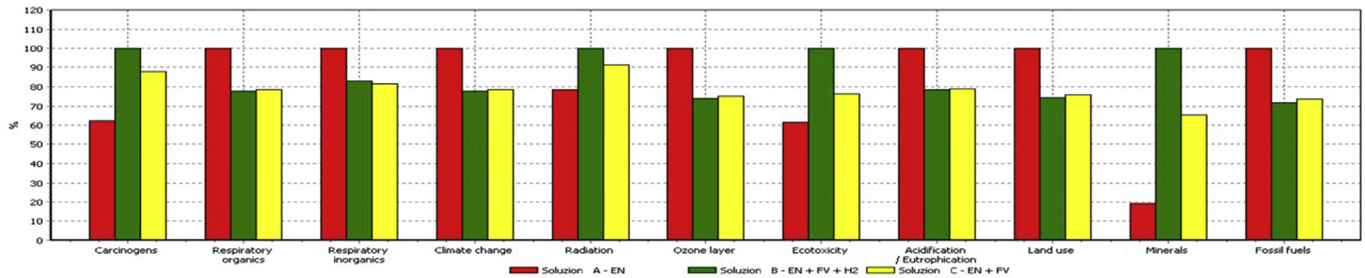

Fig. 11. Comparison of the three solutions - Phase Characterization – Ecoindicator 99.

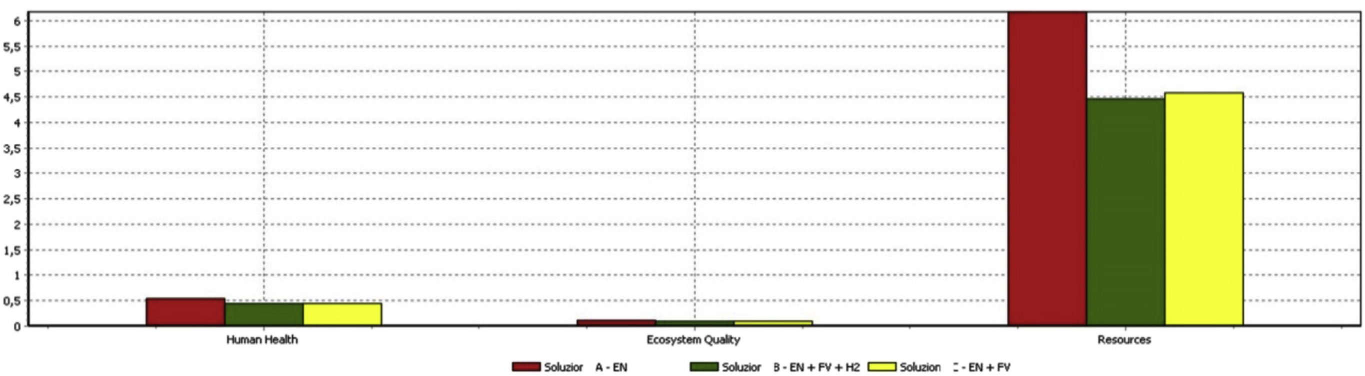

Fig. 12. Comparison of the three solutions - Phase Normalization.

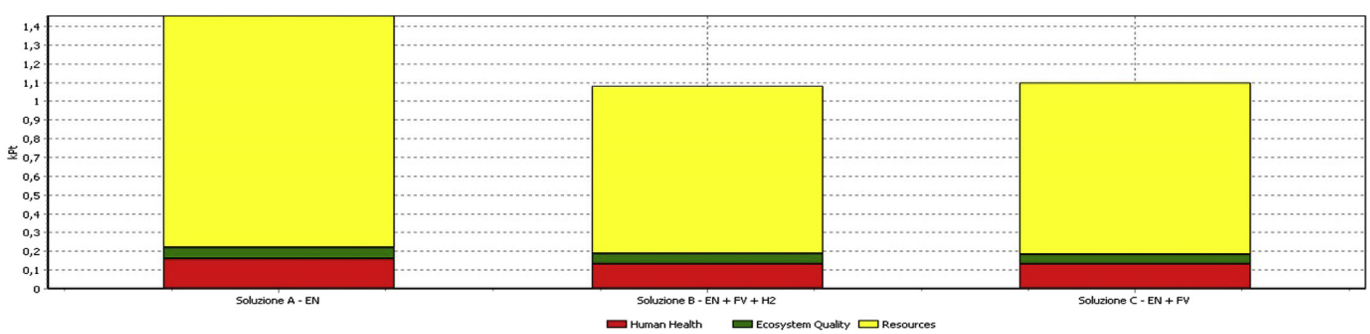

Fig. 13. Comparison of the three solutions: Attribution Score Total.

Table 8
The allocation of scores, for each category of damages, for the three analyzed solutions.

Description	u.m.	Solution A	Solution B	Solution C
Human Health	DALY	162.0	135.0	133.0
Ecosystem Quality	PDFm2yr	59.0	53.1	49.9
Resources	MJ Surplus	1230.0	894.0	915.0

shown in the following equations.

$$I_S^A = \beta_{En}*0.1327 + \beta_{Ec}*0.6345 + \beta_{So}*0.2795$$

$$I_S^B = \beta_{En}*0.4366 + \beta_{Ec}*0.1493 + \beta_{So}*0.4247$$

$$I_S^C = \beta_{En}*0.4307 + \beta_{Ec}*0.2162 + \beta_{So}*0.2959$$

By changing the numerical value of β, the relatively integrated index of each solution was obtained as shown in Fig. 19.

Figs. 20 and 21 show a two-dimensional sensitivity analysis. A comparison between solution A vs solution C is shown in Fig. 20. Moreover, a comparison between solution C vs solution B is shown in Fig. 21.

Because different technologies have different energy conversion efficiencies, the choice of a specific technology impacts on the results of the assessment.

5. Results

This section includes the discussions on the LCA outcomes, and the summary and interpretation of the overall results.

Obviously performing LCA model for an innovative system as the system under study was not easy due to the difficulty of collecting data. The most critical aspect of using LCA methodology is that the results are highly dependent on the availability of data and the study is performed through an iterative process using a series of

Table 9
Cost data solution A.

Component	Q.ty	Total cost [€]	Unit cost [€]	Cost maintenance [% Purchase cost]	Maintenance cost per year	Lfe [years]	N° substitutions in 20 years
Reciprocating diesel engine	1	3000		0.1	450	10	1
AC electric generator	1	1300		0.02	91	10	1
Fuel tank	1	2500		0.1	250	20	0
Rectifier AC/DC	1	750		0.02	52.5	10	1
Charge controller DC/DC	3	1935	645	0.02	135.45	10	1
Buffer battery	3	3750		0.02	825	5	4
Inverter DC/AC	1	2250	375	0.02	157.50	10	1
Shelter	1	25000		0.01	250	20	0
Others (installation, tooling etc.) [% total cost]		8097			0		

Table 10
Cost data solution B.

Component	Q.ty	Total cost [€]	Unit cost [€]	Cost maintenance [% Purchase cost]	Maintenance cost per year	Lfe [years]	N° substitutions in 20 years
Reciprocating diesel engine	1	3000		0.1	450	10	1
AC electric generator	1	1300		0.02	91	10	1
Fuel tank	1	2000		0.1	200	20	0
Rectifier AC/DC	1	750		0.02	52.5	10	1
Charge controller DC/DC	6	3870	645	0.02	270.9	10	1
Buffer battery	3	3750		0.02	825	5	4
Inverter DC/AC	6	13500	375	0.02	945	10	1
Photovoltaic modules	1	4000	800	0.02	80	20	0
Water tank [l]	1	150		0.1	15	20	0
Electrolyzer	1	3900	1300	0.1	390	20	0
Metal hydrides tank	1	1000	1000	0.02	20	20	0
Oxygen tank	2	1200	600	0.01	72	10	1
Fuel Cell	1	8000	1600	0.05	800	10	1
Pumps	included in the electrolyzer						
Shelter	1	25000		0.01	250	20	0
Others (installation, tooling etc.) [% total cost]		14284					

Table 11
Cost data solution C.

Component	Q.ty	Total cost [€]	Unit cost [€]	Cost maintenance [% Purchase cost]	Maintenance cost per year	Lfe [years]	N° substitutions in 20 years
Reciprocating diesel engine	1	3000		0.1	450	10	1
AC electric generator	1	1300		0.02	91	10	1
Fuel tank	1	2000		0.1	200	20	0
Rectifier AC/DC	1	750		0.02	52.5	10	1
Charge controller DC/DC	6	3870	645	0.02	270.9	10	1
Buffer battery	3	3750		0.02	825	5	4
Inverter DC/AC	6	13500	375	0.02	945	10	1
Photovoltaic modules	1	4000	800	0.02	80	20	0
Shelter	1	25000		0.01	250	20	0
Others (installation, tooling etc.) [% total cost]		11434					

Table 12
Comparisons - consumptions.

Description	u.m.	Solution A	Solution B	Solution C
Cost of fuel (diesel) The cost of fuel (diesel) has been hypothesized to 1.1 €/l.	l	10.223	7.014	7.316
Cost replenishing water The cost of water has been hypothesized to 0.1 €/l.	l	0	73	0

approximations and dynamic specifications of data. However, the strength of the LCA methodology is a life long learning process allowing to analyze the environmental impacts. In the present study data were searched in SimaPrò Software © library. On the basis of the results showed in Figs. 11–13 it is evident that the greatest impact was attributable to solution A, due to a higher fuel consumption in categories Respiratory organics/inorganic, Climate Change and Fossil Fuels. Though, the solutions B and C had the most impact in Carcinoges and Ecotoxicity categories for the effect of the materials contained in the storage system. From the conducted analysis it could be useful to note the that product alternatives have excellent performance in one subcriterion, but not so good in other criteria. Moreover, in order to achieve an overall and objective evaluation, the calculation of the single criterion score, was carried

Table 13
Comparison - costs.

Description	u.m.	Solution A	Solution B	Solution C
Installation cost	€	48.582.00	85.704.00	68.604.00
Cost of maintenance and spare parts	€/y	2.211.45	4.461.40	3.164.40
Operating cost	€/y	11.245.30	7.722.70	8.047.60
Disposal cost	€	2.000	2.750.00	2.500.00

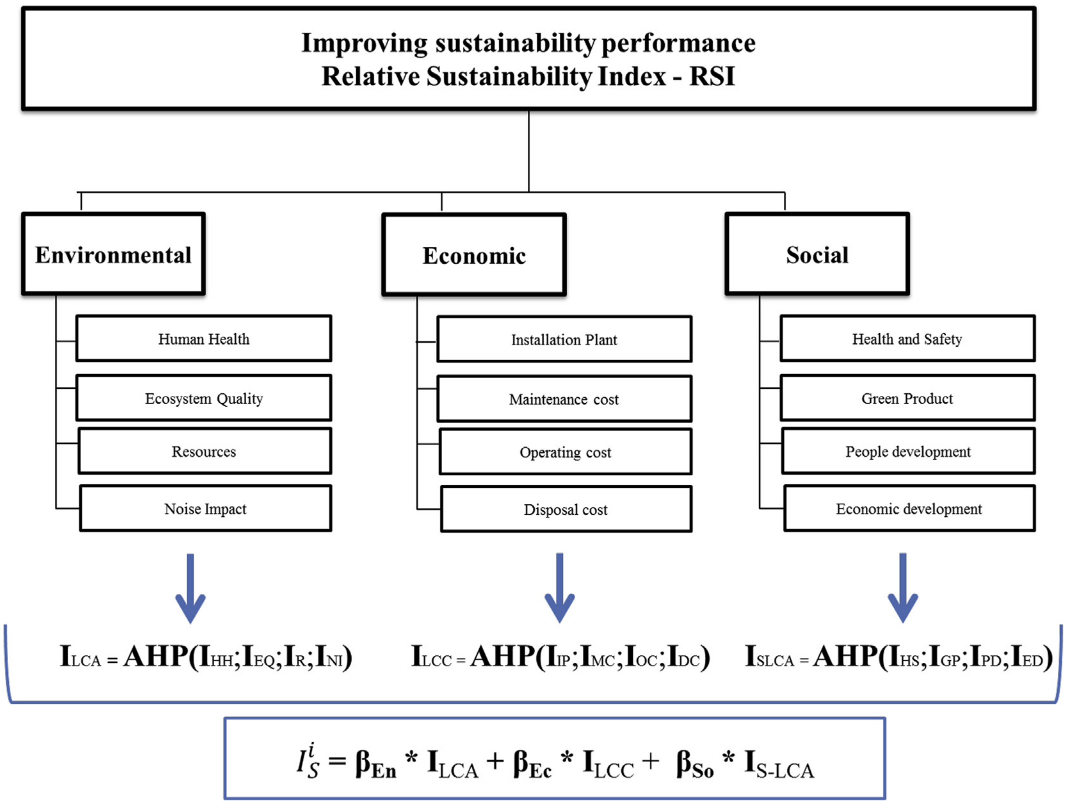

Fig. 14. AHP model.

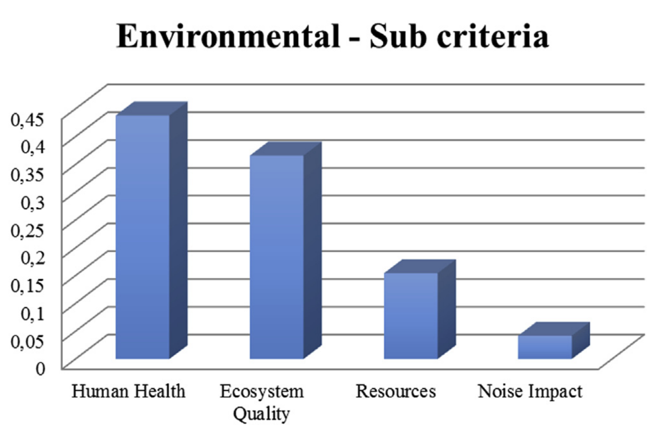

Fig. 15. Weights for the Environmental criteria.

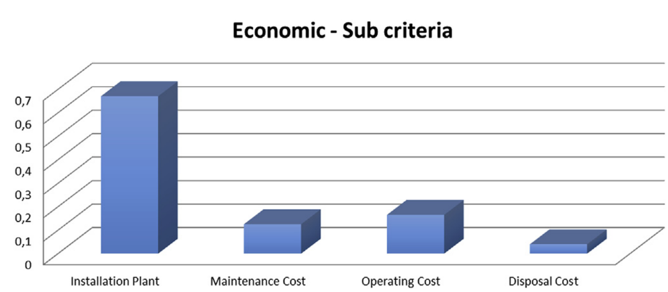

Fig. 16. Weights for the Economic criteria.

out via the AHP analysis. As discussed in section 4.3, the final step of the AHP was to define the weights of the Environmental criteria, Economic criteria and Social Criteria to assess the Relative sustainability index. As shown in Fig. 15, regarding the Environmental criteria, the Human Health and Ecosystem Quality were around 40%, while as shown in Fig. 16 in relation to the Economic criteria, the Installation Plant was around 70%. Finally, as shown in Fig. 17 regarding the Social criteria, Health and Safety was around 60%. Table 16 shows that solution A was preferable to the others in regard to economic criteria due to lower plant costs; solution B was preferable to the others with respect to the environmental and social criteria due to the introduction of innovative green energy technologies, such as the storage systems in fuel cells; solution C was preferable to the others with respect to the environmental criteria due to the introduction of renewable energy.

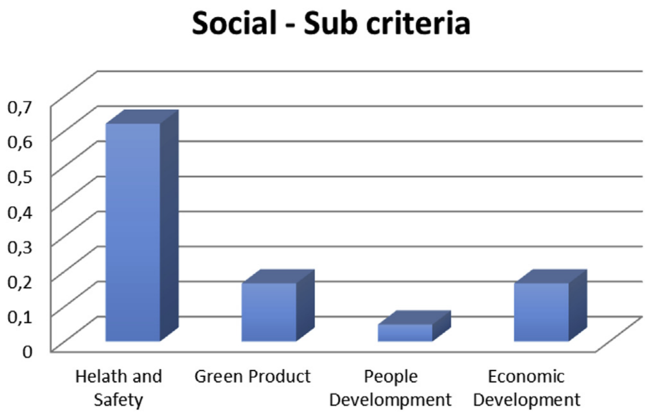

Fig. 17. Weights for the Social criteria.

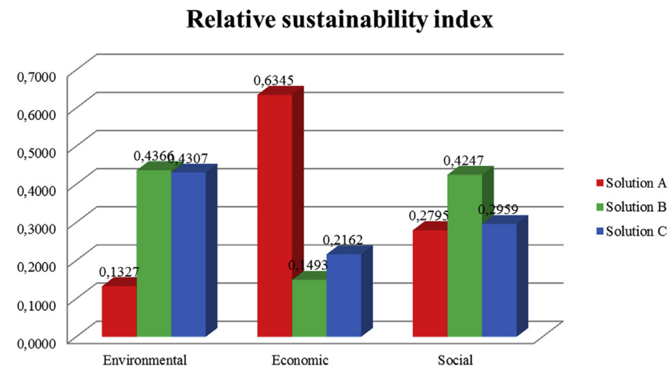

Fig. 18. The Relative sustainability index - graph.

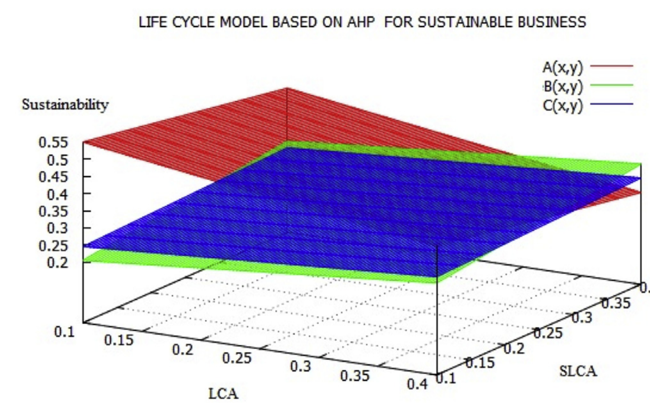

Fig. 19. Comparison of the sustainability indexes of the three solutions – sensitivity analysis.

Table 14
Relationship among solution and pillars.

Solution	Relative sustainability Index – RSI I^i_S		
	Pillar LCA	Pillar LCC	Pillar LCSA
A	I^A_{LCA}	I^A_{LCC}	I^A_{LCSA}
B	I^B_{LCA}	I^B_{LCC}	I^B_{LCSA}
C	I^C_{LCA}	I^C_{LCC}	I^C_{LCSA}
	100%	***100%***	***100%***

Table 15
Variation of β according to different scenario.

Perspective	β_{En}	β_{Ec}	β_{So}
Balanced	33%	34%	33%
Economic	25%	50%	25%
Social	25%	50%	25%
Environmental	50%	25%	25%

Table 16
The Relative sustainability index.

Code	Subcriteria	Subcriteria weights	Perspective	Weights for different solutions			Weights for different solutions/ subcrit.			Relative sustainability index		
				A	B	C	A	B	C	A	B	C
HH	Human Health	0,43811	0.33	0,142857	0,42857	0,42857	0,06259	0,18776	0,187761241	0,1326696	0,4366253	0,4306943
EQ	Ecosystem Quality	0,36582		0,142857	0,42857	0,42857	0,05226	0,15678	0,156779843			
R	Resources	0,15413		0,100498	0,46647	0,43303	0,01549	0,0719	0,066743222			
NI	Noise Impact	0,04193		0,055636	0,48145	0,46291	0,00233	0,02019	0,019409984			
IP	Installation Plant	0,67026	0.34	0,730645	0,08096	0,18839	0,48972	0,05426	0,126272962	0,63452375	0,14930664	0,2161695
MC	Maintenance Cost	0,12512		0,728584	0,10884	0,16258	0,09116	0,01362	0,020341884			
OC	Operating Cost	0,16492		0,149373	0,47423	0,3764	0,02463	0,07821	0,062075393			
DC	Disposal Cost	0,0397		0,730645	0,08096	0,18839	0,02901	0,00321	0,007479242			
HS	Helath and Safety	0,62084	0.33	0,33333	0,33333	0,33333	0,20694	0,20694	0,206944597	0,27945316	0,42468921	0,2958514
GP	Green Product	0,16545		0,209843	0,54995	0,24021	0,03472	0,09099	0,03974291			
PD	People Development	0,04826		0,09739	0,56954	0,33307	0,0047	0,02749	0,01607391			
ED	Economic Development	0,16545		0.2	0.6	0.2	0,03309	0,09927	0,03309			

Fig. 19 shows that only for higher values attributable to social and environmental components, the company may be considered more sustainable and innovative solutions. However, the traditional solution with only the internal combustion engine is preferable for values of equilibrium between the three different pillars of sustainability.

6. Conclusion

To reduce environmental damage, the peculiarities of environmental issues must be understood. Most previous researches performed relevant assessments either qualitatively or quantitatively. The main purpose of this work was to implement simultaneously qualitative and quantitative assessments in considering complex environmental issues. Although quantitative approaches could be presented via numbers, which are often preferred, some considerations that are not easily quantified are apt to be neglected. The

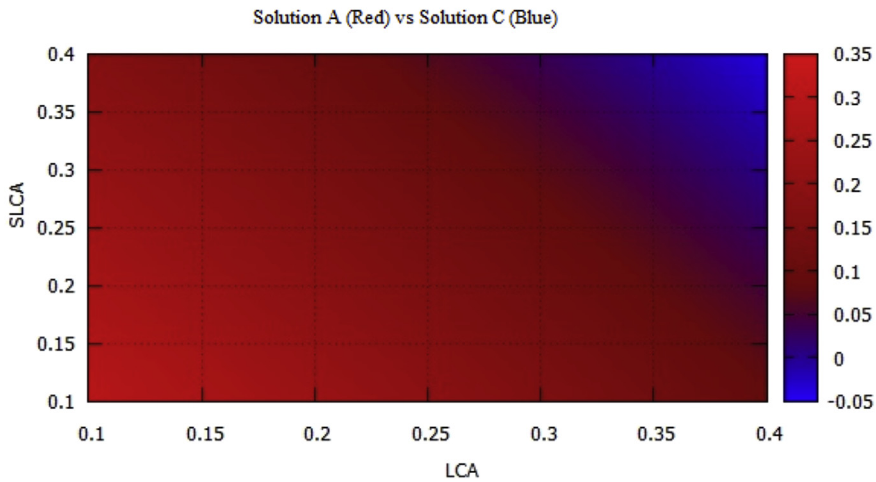

Fig. 20. Comparison between solution A vs solution C – sensitivity analysis.

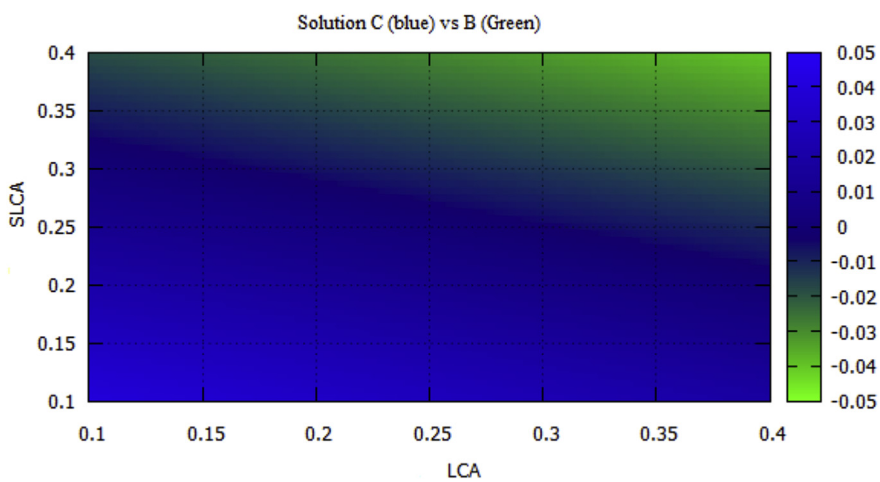

Fig. 21. Comparison between solution C vs solution B – sensitivity analysis.

general aim of this paper was to contribute to the development of a comprehensive, yet practical and reliable tool for sustainability assessment.

Since many tools currently exist, there is more need to highlight complementarities or possibilities for integration rather than generating new tools. In our opinion in a complex scenario, a "practical" tool may be useful to model the alternatives decision to conduct effective decisions in relation to the amount of available data and in relation to context in which the tool is applied. Definitively, a specific methodological framework was proposed. Thus, in the present work an integrated methodological approach for assessment of environmental, social and economic performance was proposed. With the proposed approach, alternatives can be easly compared using the formulated AHP model with a *fluctuant weight analysis*, based on the result of LCA, SLCA and LCC. The obtained results may be used as initial guidelines for judging the feasibility of using a certain product/device. In addition, these alternatives were compared on a common basis (the same set of criteria) with respect to their environmental, social and economic dimensions/pillars. This solves the frequent, but difficult question of how to interpret and compare the results of separate LCA analyses that have been performed on these alternatives. The results was a dynamic analysis and iterative integrated sustainability assessment of corporate performance. The strength of the proposed method is the simplicity and at the same time completeness of the analysis. Furthermore, the flexibility and the adaptability to different scenarios represents a strategic implication of the model, which gives a better insight into the complex world of sustainability assessment. The contribution of this research laid in identifying, characterizing, and discussing key parameters that affect the LCA of a novel compressed air energy storage system proposed as a suitable technology for the energy storage in a small scale stand-alone renewable energy power plant (photovoltaic power plant) that is designed to satisfy the energy demand of a radio base station for mobile telecommunications. The main limitation was due to the data collection because existing data base were not exhaustive. Future works intend to fill up this gap.

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