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Research Article

Energy Sustainability: A Key to Addressing Environmental, Economic and Societal Challenges

[1]Marc A. Rosen and [2]Yousef Nazzal
[1]Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, 2000 Simcoe Street North, Oshawa, Ontario, L1H 7K4, Canada
[2]Department of Geology and Geophysics, King Saud University, P.O. Box 2455, Riyadh 11451, Saudi Arabia

Abstract: Sustainability is a critically important goal for human activity and development, particularly in the area of energy. Energy resources are critical for economic development and living standards, but their use causes significant environmental impacts. Given the pervasiveness of energy use, energy sustainability is a key to addressing environmental, economic and societal challenges. To achieve energy sustainability, many factors that need to be including harnessing sustainable energy sources, utilizing sustainable energy carriers, increasing efficiency, reducing environmental impact and improving socioeconomic acceptability (e.g., community involvement, affordability, equity and land use). To demonstrate the factors and their importance to energy sustainability, the Red-Mediterranean-Dead Seas Canal Project is considered as a case study. Conclusions are provided related both to steps for energy sustainability.

Keywords: Economics, efficiency, energy sustainability, environment, exergy, life cycle analysis, red-Mediterranean-dead seas canal, sustainability

INTRODUCTION

The globalization of the world's economy and the increasing use energy resources, combined with the environmental impacts of energy processes at local through global levels, are making energy sustainability a global necessity. Properly considered, energy sustainability is much broader in scope than sustainable energy sources, extending to sustainable energy systems. Various definitions of energy sustainability have been proposed (Haberl, 2006; Rosen, 2002; Goldemberg *et al.*, 1988; Niele, 2005; Wall and Gong, 2001; Zvolinschi *et al.*, 2007; Hennicke and Fischedick, 2006; Dunn, 2002; Lior, 2008), but all appear to embody the use sustainable energy resources and the conversion, storage, transport and utilization of them sustainably.

This study extends research previously reported on formulating a pragmatic approach to energy sustainability (Rosen, 2009a) by examining significant factors in achieving energy sustainability globally and how it is a key to addressing environmental, economic and societal challenges. This study also extends the previous report Rosen (2009a) by illustrating the concepts for a case study based on the Red-Mediterranean-Dead Seas Canal Project, which constitute a large-scale example of sustainable energy option. A technical focus is taken, reflecting the importance of technical factors in energy sustainability. Thus, this study focuses on fundamental issues relating to energy sustainability and less on the economics and politics of energy, which vary temporally and spatially and have geopolitical ramifications and energy prices, which can be greatly affected by taxes. The roles of economics, politics and other non-technical factors are nonetheless considered, but the approach likely differs from that of economists, business leaders, politicians and sociologists and is not necessarily comprehensive.

SUSTAINABILITY

More broadly, energy sustainability is being increasingly recognized as a critical component of sustainable development, which was defined by the 1987 Brundtland Report of the World Commission on Environment and Development (Anon, 1987) as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Although the concept of sustainability often lacks in rigour (Lior, 2008), some have tried to apply it. For instance, the Ontario Power

Corresponding Author: Marc A. Rosen, Faculty of Engineering and Applied Science, University of Ontario Institute of Technology 2000 Simcoe Street North, Oshawa, Ontario, L1H 7K4, Canada

Authority in Canada included sustainability as a key factor in its plan for the energy future of Ontario, Canada (OPA, 2006).

Although energy sustainability can be viewed as the application of the general definitions of sustainability to energy, energy sustainability is more complex. Energy sustainability involves the provision of energy services in a sustainable manner, which requires that energy services be provided for all people, now and in the future, in ways that are sufficient to provide basic necessities, affordable, not detrimental to the environment and acceptable to people and the communities in which they live and work.

ENERGY SUSTAINABILITY

The author has previously identified several distinct components to the manner in which energy resources can be used sustainably in society, each of which is a requirement for energy sustainability (Rosen, 2009a):

- **Harness sustainable energy sources:** Sustainable energy sources need to be utilized to satisfy the requirements for energy services sustainably. This is particularly important given increasing populations and living standards, especially as developing countries. Renewable energy includes solar radiation, as well as energy from such other natural forces as gravitation and the rotation of the earth. Several renewable energy types are derived from solar radiation, e.g., wind, hydraulic, tidal, ocean thermal, geothermal (both due to the internal heat of earth and ambient ground temperatures), biomass (provided the rate at which it is used does not exceed the rate at which it is replenished) and, arguably, wastes (material and heat). Non-renewable energy sources include energy resources which are available in limited quantities, e.g., fossil fuels and uranium. Lifetimes for non-renewable resources are often the subject of debate, especially for nuclear fuel, whose lifetime depends on the development of advanced breeder reactors (Cleveland, 2008; Toth, 2008; Rogner *et al*., 2008a, 2008b).
- **Utilize sustainable energy carriers:** Energy carriers include material energy carriers like secondary chemical fuels (e.g., hydrogen, methanol, ammonia) and non-material carriers like electricity, work and thermal energy (hot or cold). Utilizing sustainable energy carriers usually implies the conversion of sustainable energy sources into appropriate energy carriers, which generally are an important consideration in energy sustainability. Conventional and non-fossil fuel energy options are not sufficient for avoiding environmental issues.

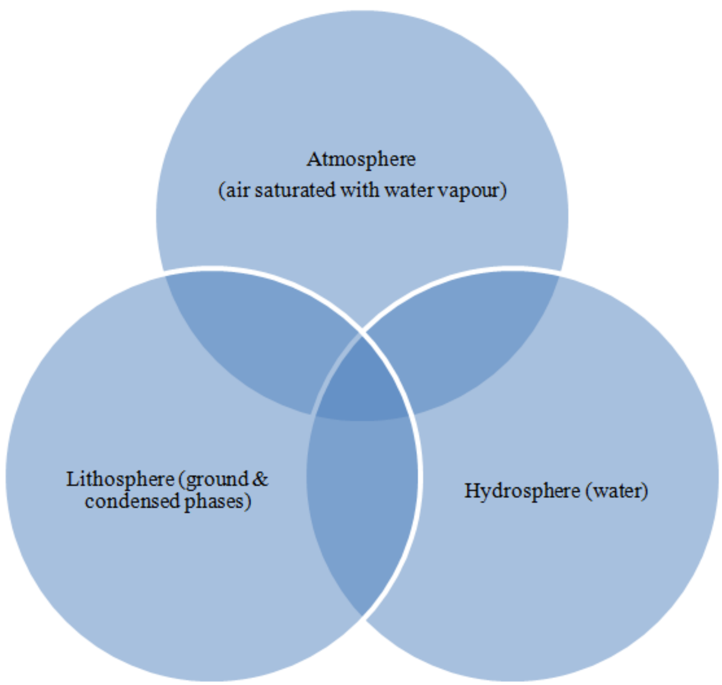

Fig. 1: Illustrative representation of a reference-environment model based on the natural environment (centre), showing the three main environment constituents

such as climate change, in that they are not necessarily readily utilizable in their natural forms. Conversion systems are often needed to render non-fossil energy more conveniently utilizable. Hydrogen energy systems are considered particularly important as they facilitate the use of non-fossil fuels by allowing them to be converted to two main energy carriers: hydrogen and electricity (Scott, 2007; Hennicke and Fischedick, 2006; Marban and Valdes-Solís, 2007; Penner, 2006; Dunn, 2002; Dalcor Consultants Ltd. and Intuit Strategy Inc., 2004; Lattin and Utgikar, 2007; Arnason and Sigfusson, 2000). Hydrogen can be produced from including fossil fuels as well as renewable energy forms via such processes as water electrolysis and thermochemical water decomposition (Penner, 2006; Yildiz and Kazimi, 2006; Sigfusson, 2007; Marchetti, 2006; Soutworth *et al*., 2007).

- **Increase efficiency:** Efficiency improvements include energy conservation, fuel substitution and improved energy management, better matching of energy carriers and demands and more efficient utilization of energy quality. Greater efficiency allows the most benefits to be attained from energy options and reduces environmental impact, supporting sustainability efforts. Many efficiency improvements are best considered with exergy, a measure of the usefulness or quality of an energy form or a substance, which is particularly useful for attaining more efficient energy-resource thereby facilitating sustainability efforts (Dincer and Rosen, 2007; Szargut, 2005; Rosen *et al*., 2008; Rosen and Dincer, 2003; Rosen *et al*., 2005; Barclay, 2006; Rosen, 2009b; Abanades *et al*., 2006; Orhan *et al*., 2010). Exergy is evaluated with respect to a reference environment, such as that in Fig. 1. Exergy analysis identifies meaningful efficiencies and thermodynamic losses and is consequently beneficial in analysis and design and in revealing margins for improvement. Exergy can also be used in conjunction with economics (Rosen and Dincer, 2003; Sciubba, 2004; Zvolinschi *et al*., 2007) and environment and ecology (Dincer and Rosen, 2007; Wall and Gong, 2001; Jorgensen and Svirezhev, 2004).
- **Reduce environmental impact:** Many environmental impacts associated with energy

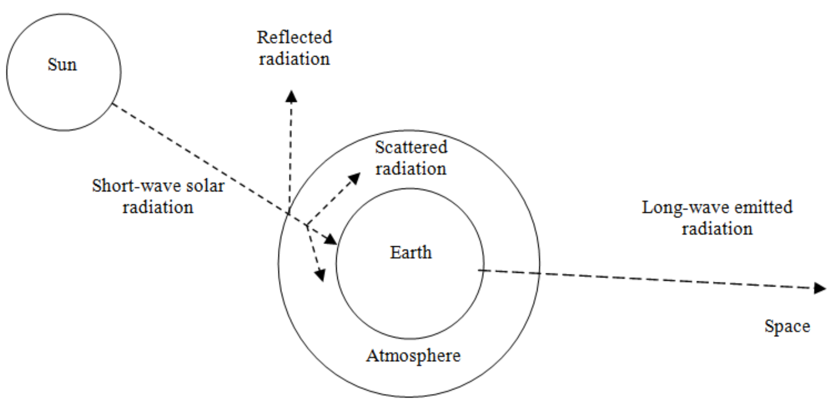

Fig. 2: Earth-sun-space energy balance, showing the input to the earth and its atmosphere of solar radiation and the emission of thermal radiation to space

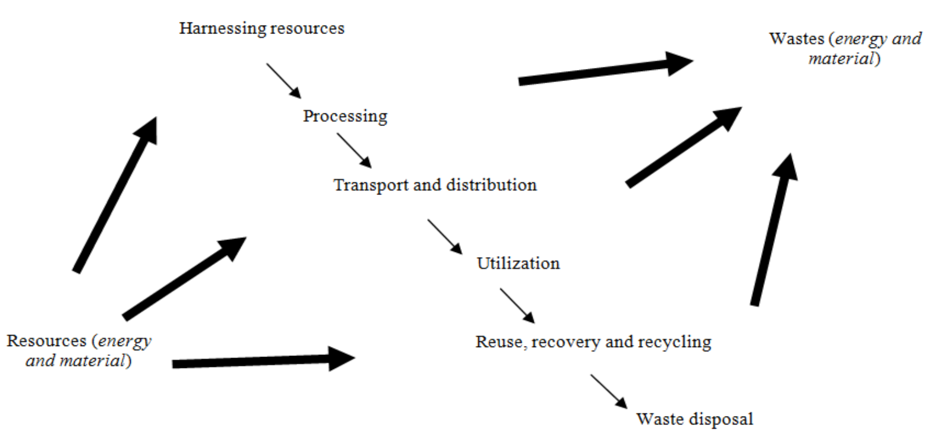

Fig. 3: Scope of life cycle assessment of a product or process, with the input of resources and emission of wastes highlighted

processes need to be addressed to attain energy sustainability, including global warming, the impact on the lithosphere, the hydrosphere and the atmosphere of acidic emissions, the destruction of the atmospheric ozone layer, abiotic resource depletion, radiological effects and ecotoxicity. Mitigating climate change is generally agreed to be an urgent requirement and to demand the use of non-fossil fuels since the main greenhouse gas is carbon dioxide, an emission of fossil fuel combustion (Rosen *et al*., 2008). Most of the energy entering the earth's atmosphere eventually returns to space via an earth-sun-space energy balance (Fig. 2). The mean temperature of the earth is relatively constant when there is no energy accumulation, i.e., global warming is not present and the planet's energy output and input are equal. This earth-sun energy balance is disrupted by global warming since increased atmospheric greenhouse-gas concentrations cause the energy output from the earth and its atmosphere to decrease while energy input remains constant. The life cycle of a product or process must be considered to comprehensively address energy-related environmental impacts (Fig. 3), i.e., Life Cycle Assessment (LCA) must be used (Graedel and Allenby, 2010). LCA allows environmental issues to be quantified and related to the part of the life cycle responsible for them (e.g., acquisition of energy and material resources, utilization, ultimate etc.) and has been applied to natural gas, nuclear power, hydrogen and solar and wind energy processes (Granovskii *et al*., 2007; Utgikar and Thiesen, 2006; Solli *et al*., 2006).

- **Improve socioeconomic acceptability:** Many socioeconomic sustainability factors must be considered for energy sustainability given their relations to energy. Some energy-related socioeconomic sustainability factors follow:
    - Community involvement and social acceptability, since people must be involved in energy-related decisions if energy sustainability is to be attained and a culture of sustainability can evolve when a consultative and collaborative approach is consistently followed
    - Economic affordability and equity, since energy services required to provide basic needs must be affordable to all and societies need to be able to access energy resources, regardless of geographic location, now and in the future
    - Lifestyle, which can be modified to contribute to energy sustainability
    - Land use and aesthetics, which necessitate those energy-related activities, be balanced with such other needs as agriculture and recreation. These factors often are linked to the previously described sustainability approaches, e.g., harnessing sustainable energy sources must account for economics, global stability and geographic and intergenerational equity to maintain a sustainability focus

Taken together, these distinct components of energy sustainability demonstrate that it is a key to addressing environmental, economic and societal challenges. This point is illustrated in the case study, which follows.

CASE STUDY: THE RED-MEDITERRANEAN-DEAD SEAS CANAL PROJECT

To demonstrate the concepts and approaches to energy sustainability presented in this study, a case study is considered, which provides an example of a practical large-scale sustainable energy option. This case study goes beyond the historical tendency of humanity to respond to an increased demand for resources by trying to increase supply. As supplies dwindle sustainable practices are encouraged through demand management for all goods and services, by promoting reduced consumption, using renewable resources where possible and encouraging practices that minimize resource intensity while maximizing resource productivity. Careful resource management can be applied at many scales, from economic sectors like agriculture, manufacturing and industry, to work organizations, the consumption patterns of households and individuals and to the resource demands of individual goods and services.

The present case study is a large-scale option for meeting demands for resources by increasing the Dead Sea resources supply. The Dead Sea and its unique environment are changing. The Dead Sea is a severely disturbed ecosystem, greatly damaged by anthropogenic intervention in its water balance. During the 20^{th} century, the Dead Sea level dropped by more than 25 m and, as of 2006, was at about 420 m below mean sea level. Over the last decade the average rate of water level decline is ~1 m/year, while salt accumulates at the bottom of the lake at a rate of ~0.1 m/year and the volume decreases by some 700 million m^3 annually. Due to the high density of the Dead Sea brine, this volume translates to an annual freshwater deficit of about 850 million m^3. The negative water balance is mainly due to the diversion of water from its catchments area by Israel, Jordan, Syria and Lebanon, as well as the result of the industrial activity in the southern basin of the Dead Sea, which at its current level would otherwise be dry. In 2002 Israel and Jordan jointly announced their interest in stopping the water level decline and the deterioration of the surrounding infrastructure by constructing a Red Sea-Dead Sea Conduit (RSDSC) that will pipe water from the Red Sea to the Dead Sea (Fig. 4). The proposed project

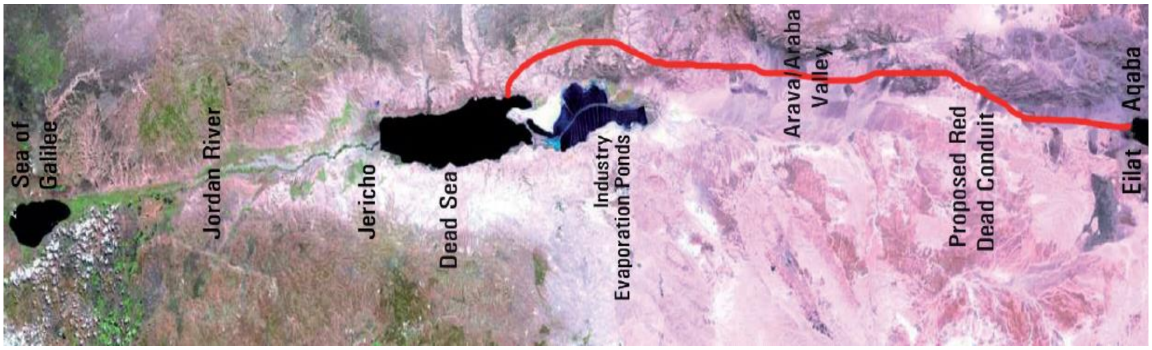

Fig. 4: Proposed Red Sea to Dead Sea conduit route

includes a hydroelectric plant that will utilize the 400 meter elevation difference between the Seas, as well as a desalination (reverse osmosis) plant to provide fresh water. In 2005 Israel, Jordan and the Palestinian Authority submitted to the World Bank terms of reference for "Feasibility Study-Environmental, Technical and Economic and Environmental and Social Assessment." On 10 January 2006 the World Bank announced that steps towards the realization of the feasibility study would take place in 2007 (Geological Survey of Israel, 2005).

Basic features of the Red Sea-Dead Sea Conduit (RSDSC) project: The concept of bringing water via a pipeline or a canal between the Red Sea and Dead Sea has been studied in many forms since the 1800s and more seriously since the mid twentieth century. The Red Sea-Dead Sea water conveyance project represents a significant sustainable option for saving the Dead Sea as well as to desalinate sea water and to generate electricity for Jordan, Palestine and Israel.

The project is anticipated to include an intake canal at the northern tip of the Gulf of Aqaba. The water would then be pumped through either an open canal or a pipeline (about 200 km long) passing through Wadi Araba, Dana Natural Reserve, Ghor Al Safi and Ghor Fifa and ending at the southern part of the Dead Sea. A desalination plant would be built near the shores of the Dead Sea and have an annual capacity of 850 million m^3 of fresh water; the reject brine will be conveyed to the Dead Sea at a rate of 2.6 million m^3/day. A hydropower generating plant would exploit the natural elevation difference (about 400 m) between Red Sea and the Dead Sea to provide energy for hydrostatic desalination of the Red Sea water (Royal Scientific Society of Jordan, 2007).

The cost of this project is expected to be high, about \$0.8 billion for the conduit connecting the Red Sea with the Dead Sea and \$3.0 billion for the desalination project and conveyance system to demand centers. Three alignments have been considered (Beyth, 2007): the RSDSC, the Qatif-Zikim (Qatif) and the Northern alignments.

Socio-economic aspects: The Dead Sea's unique water composition attracts medicinal tourism and the areas around the Dead Sea are of historical and environmental importance. The Dead Sea and it surroundings are facing a great challenge as the sea level has been dropping by nearly 1 m/year due to water diversions upstream and to mineral extraction industries.

The project area includes large and important industries for Palestine, Israel and Jordan, hotels, protected areas, archaeological sites, residential areas and agricultural lands. Palestinian proposals have existed since the Oslo period to establish Palestinian hotels on the northwestern shores of the Dead Sea, to create a Palestinian mineral extraction industry and to develop the many archaeological sites such as Qumrun on the West Bank areas of the Dead Sea. Jericho is the largest city in the Dead Sea area, located near the northwest tip of the Dead Sea. Jericho has a large agriculture and tourism economic base and prior to Israeli military closures was the gateway for tourism to the northwest shores of the Dead Sea. Ein Gedi and Ein Boqeq are the main tourism sites on the Israeli shores of the Dead Sea, with small mostly agricultural communities scattered along the length of the Arava Valley, with the Israeli port city of Eilat at the head of the Gulf of Aqaba.

Socio-economic impact studies were carried out in the project area for different sectors (local residential, industry, tourism and hotel). These studies determined that the majority of the surveyed sectors support the RSDSC project idea, including the majority of the Israeli, Palestinian and Jordanian populations surveyed. The surveys also identified several issues to be addressed before the establishment of the project and during the design phase. These issues include assessments of the need for acquisition of private land, the change of the Dead Sea water characteristics and its effect on tourism, the medical value of the project and the negative impacts of project on the impacts on the marine environment in Eilat and on protected areas and archeological sites along the proposed RSDSC route. The majority of Israelis, Palestinians and Jordanians surveyed were interested in all options beyond the RSDSC, reflecting public interest in having all relevant information available prior to making decisions.

Environmental factors: The RSDSC project has significant environmental benefits as well as challenges. One of the major motivations for the canal project is to compensate the negative water balance. The targeted Dead Sea level recommended in the mid 1980s for the Qatif-Zikim alignment was 390 m below mean sea level (Mediterranean-Dead Sea Co., 1984) and 12 years later for the RSDSC project was 400 m below mean sea level (The Harza JRV Group, 1996). Restoring the Dead Sea level is becoming increasingly important because of four hazardous phenomena resulting from its "rapid" level decline: the formation of more than a thousand sinkholes along the shore of the Dead Sea at the rate of 300/year (Abelson *et al*., 2006); the destruction of infrastructure like roads and bridges by flood erosion; severe ecological damage to the flora and fauna around the Dead Sea; and loss of fresh groundwater due to the change of the groundwater gradient (The Harza JRV Group, 1996). Additionally, the Dead Sea level decline causes direct planning problems.

Two primary options exist to overcome this drop and to create a positive water balance. One is to decrease the use of water and the loss by evaporation in chemical and other industries. The second is to import seawater through the RSDSC. Each option has benefits as well as challenges. The RSDSC option has some environmental challenges: the inflow of seawater or concentrated rejects can lead to an upper, light, stratified water body that may create a lower hypolimnion with a reduced environment (Gavrieli *et al.*, 2005), intensive precipitation of gypsum and a change of the biological environment of the upper epylimnion water mass. This option also has geotechnical challenges (Shirav-Schwartz *et al*., 2006), such building a plant in a seismological active zone, the potential of water leakage and possible contamination of the local aquifer. The Northern alignment has two advantages: diverting 200 million m^3 annually of desalinated water to the Sea of Galilee will make the operation of the Lake of Galilee (a major fresh water reservoir) diversion possible without affecting its water quality. There is a relatively small amount of rejected concentrates in this alignment.

DISCUSSION

The Red Sea-Dead Sea conduit project represents a sustainable energy option which also can avoid the disappearance of the Dead Sea and supply fresh water via desalination to help overcome regional deficiencies. The key project benefits include:

- Providing electricity and fresh water and preserving the Dead Sea, a historical and valuable site
- Improving the quality of life in the project area by creating new jobs for local people and enhancing regional business prosperity
- Enhancing agriculture and tourism by preventing problems like sinkhole formation

Although concerns exist with the RSDSC project, they can be addressed if caution is exercised in the project. For instance, the conduit path and structure should be designed to avoid disturbing protected areas; the ratio of Red Sea water that should be mixed with Dead Sea water to prevent chemical changes in the Dead Sea should be carefully determined utilizing appropriate tools and models; the design should incorporate appropriate measures to protect the conduit during its design and construction in fault areas; and lands should be returned to their original nature before excavation, especially in agricultural and residential areas.

Potential contributions to energy sustainability of the case study: The case study considered in the prior section illustrates many of the energy-sustainability concepts in this study (harnessing sustainable energy sources, utilizing sustainable energy carriers, increasing efficiency, reducing environmental impact and improving socioeconomic acceptability). The contributions of the case study to energy sustainability, in terms of these concepts, are discussed here:

- **Sustainable energy sources:** The case study helps improve the utilization of sustainable energy sources by generating electricity hydroelectrically, while resolving other problems. This project utilizes renewable energy, by exploiting potential energy differences which are created ultimately by solar energy.
- **Sustainable energy carriers:** The energy carrier generated, electricity, is sustainable and beneficial. Using such an energy carrier for the corresponding energy demand helps enhance energy sustainability.
- **Efficiency:** The case study involves technologies that greatly improve the efficiency with which energy resources are used and other services are provided, as hydroelectric power generation is highly efficient. This high efficiency enhances the sustainability of society's energy systems.
- **Environmental impact:** The case study leads to enhance environmental performance in various ways. It generates electricity in a sustainable manner and also addresses environmental threats to the existence of the Dead Sea. These benefits address several key aspects of reducing

environmental impact related to energy: (appropriate resources and carriers and efficiency) and thereby enhance energy sustainability.

- **Socioeconomic acceptability:** Many socioeconomic benefits arise through the case study. For instance, RSDSC project is expected to be economically advantageous, improving some major regional industries like tourism. The project should also enhance fresh water supplies and create job opportunities. Overall, the project may contribute to more affordable energy and other services and enhanced equity. Thus the project has many socioeconomic benefits as required for energy sustainability.

CONCLUSION

It is demonstrated in this study that several crucial factors (harnessing sustainable energy sources, utilizing sustainable energy carriers, increasing efficiency, reducing environmental impact and improving socioeconomic acceptability) need to be addressed appropriately to achieve energy sustainability, which itself is a key to addressing environmental, economic and societal challenges. Advanced tools like exergy analysis for efficiency improvement and life cycle analysis for environmental enhancement can greatly facilitate efforts to achieve energy sustainability. The case study considered illustrates the concepts presented in the study for a major electrical generation project. The results suggest that the energy-sustainability factors considered here can help in identifying and implementing appropriate measures, the results are widely applicable since energy use greatly affects economic development and living standards and impacts the environment. Energy sustainability is a key step to sustainable development.

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