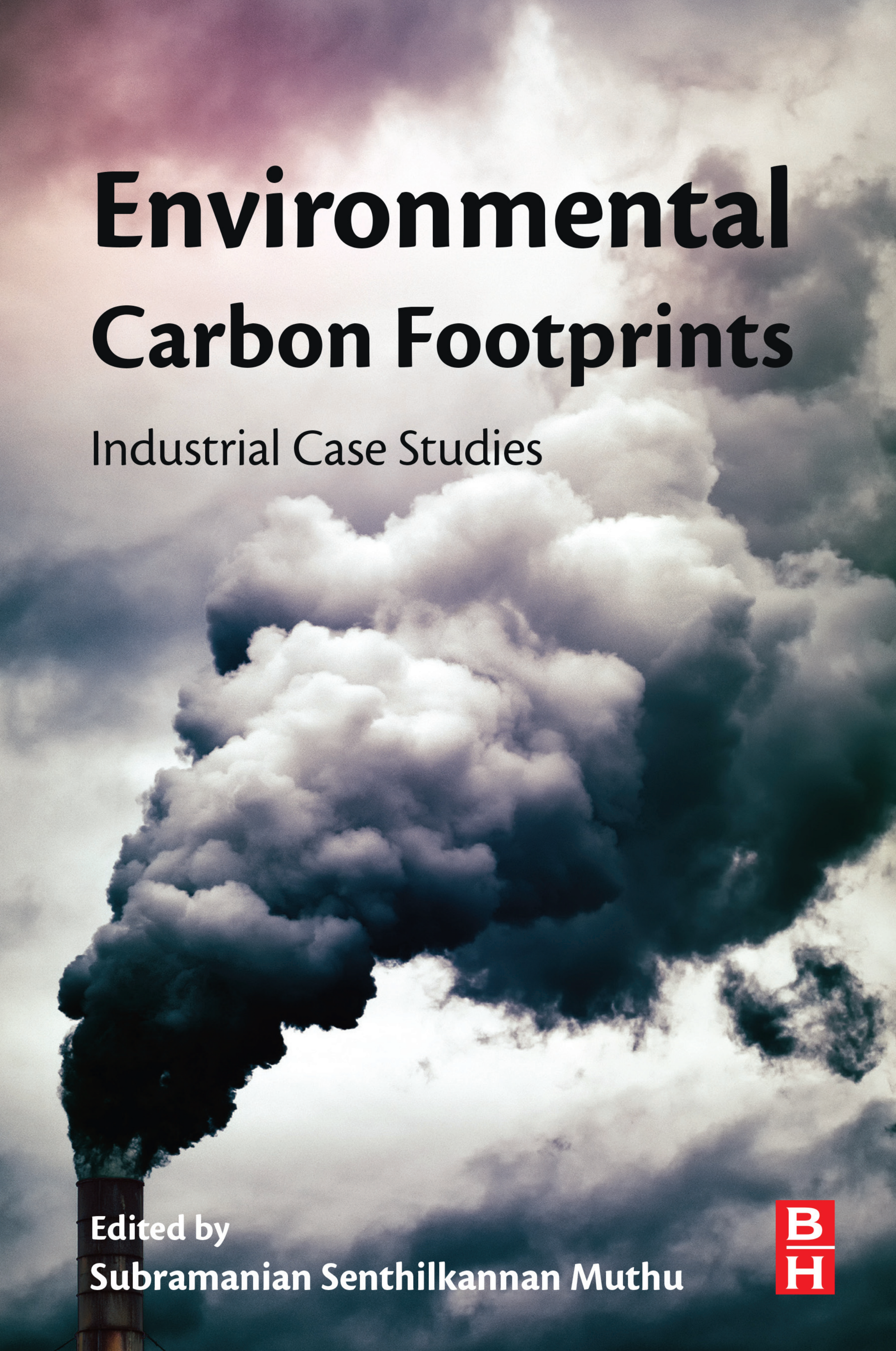
Environmental Carbon Footprints

Industrial Case Studies



Edited by
Subramanian Senthilkannan Muthu

ENVIRONMENTAL CARBON FOOTPRINTS

This page intentionally left blank

ENVIRONMENTAL CARBON FOOTPRINTS

Industrial Case Studies

Edited by

SUBRAMANIAN SENTHILKANNAN MUTHU

ELSEVIER

Butterworth-Heinemann
An imprint of Elsevier

Butterworth-Heinemann is an imprint of Elsevier
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, United Kingdom
50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

ISBN: 978-0-12-812849-7

For information on all Butterworth-Heinemann publications visit our website at https://www.elsevier.com/books-and-journals

Publisher: Matthew Deans
Acquisition Editor: Ken McCombs
Editorial Project Manager: Ashlie M. Jackman
Production Project Manager: Mohanapriyan Rajendran
Designer: Victoria Pearson Esser

Typeset by TNQ Books and Journals

CONTENTS

This page intentionally left blank

CONTRIBUTORS

Madhoolika Agrawal
Department of Botany, Institute of Science, Banaras Hindu University, Varanasi, India

Tolulope J. Akin-Adeniyi
Department of Electrical Electronic Engineering, University of Lagos, Akoka, Nigeria

Tolulope O. Akinbulire
Department of Electrical Electronic Engineering, University of Lagos, Akoka, Nigeria

Olubayo M. Babatunde
Department of Electrical Electronic Engineering, University of Lagos, Akoka, Nigeria

Emanuele Bonamente
University of Perugia, Perugia, Italy

Debrupa Chakraborty
Netaji Nagar College, Kolkata, India

Henry I. Denwigwe
Department of Electrical Electronic Engineering, University of Lagos, Akoka, Nigeria

Sara Feijoo
University of Santiago de Compostela, Santiago de Compostela, Spain

Gumersindo Feijoo
University of Santiago de Compostela, Santiago de Compostela, Spain

Luíza S. Franca
Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

Meenu Gautam
Department of Botany, Institute of Science, Banaras Hindu University, Varanasi, India

Varun Goel
NIT Hamirpur, Hamirpur, India

Sara González-García
University of Santiago de Compostela, Santiago de Compostela, Spain

Sourabh Khurana
OM Institute of Technology and Management, Hisar, India

Luis A. López
University of Castilla-La Mancha, Albacete, Spain

Madelyn Marrero
University of Seville, Seville, Spain

Alejandro Martínez-Rocamora
University of Bío-Bío, Concepción, Chile

Charles Mbohwa
University of Johannesburg, Johannesburg, South Africa

Yolanda Moldes-Diz
University of Santiago de Compostela, Santiago de Compostela, Spain

María T. Moreira
University of Santiago de Compostela, Santiago de Compostela, Spain

Himanshu Nautiyal
THDC Institute of Hydropower Engineering and Technology, Tehri, India

Oludolapo Akanni Olanrewaju
University of Johannesburg, Johannesburg, South Africa

Peter O. Oluseyi
Department of Electrical Electronic Engineering, University of Lagos, Akoka, Nigeria

Bhanu Pandey
Department of Botany, Institute of Science, Banaras Hindu University, Varanasi, India

Glaydston M. Ribeiro
Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

Sara Rinaldi
University of Perugia, Perugia, Italy

Marina S.R. Rocha
Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

Flavio Scrucca
University of Perugia, Perugia, Italy

Subramanian Senthilkannan Muthu
Bestseller, Kowloon, Hong Kong SAR

Venu Shree
NIT Hamirpur, Hamirpur, India

Paramvir Singh
NIT Hamirpur, Hamirpur, India

Jaime Solís-Guzmán
University of Seville, Seville, Spain

Karpagam Subramanian
The Hong Kong Polytechnic University, Kowloon, Hong Kong SAR

Carlos Vázquez-Vázquez
University of Santiago de Compostela, Santiago de Compostela, Spain

Winco K.C. Yung
The Hong Kong Polytechnic University, Kowloon, Hong Kong SAR

Jorge E. Zafrilla
University of Castilla-La Mancha, Albacete, Spain

This page intentionally left blank

BIOGRAPHY

Dr. Subramanian Senthilkannan Muthu is currently working for Lidl Hong Kong as a Sustainability Manager, based out of Hong Kong. He has gained his PhD from The Hong Kong Polytechnic University. He was an outstanding student throughout his studies and bagged numerous awards and medals including many gold medals in his study period. He is a renowned expert in the areas of Environmental Sustainability in Textiles and Clothing Supply Chain, Product Life-Cycle Assessment (LCA), and Product Carbon Footprint Assessment (PCF) in various industrial sectors. He has 5 years of industrial experience in textile manufacturing, research and development, and textile testing and around 7 years of experience in LCA, carbon, and ecological footprints assessment of various consumer products. He has completed many LCA, carbon footprint, and environmental assessment projects in Asia and Europe from both cradle-to-gate and cradle-to-grave stages of many products including apparels, plastics, chemicals, and packaging. He has a wide experience in environmental assessment of textiles and clothing supply chain, and he has worked on recycling of plastics and textiles, green claims, and validation of different consumer products. He has delivered extensive trainings on PCF and LCA to many external clients in India, Colombo, Bangladesh, China, and Hong Kong, apart from the delivery of many invited talks. He has delivered many invited key note speeches in various international conferences across the globe.

He has published more than 75 research publications, written numerous book chapters, and authored/edited multiple books in the areas of carbon footprint, recycling, environmental assessment, environmental sustainability, etc. (over 40 books to his credit). Famous titles of his books list include Assessment of Environmental Impacts of Textiles and Clothing Supply Chain, Assessment of Carbon Footprint in Different Industrial Sectors (two volumes), Roadmap to Sustainable Textiles and Clothing (three volumes), Handbook of Carbon Footprint, Handbook of Life Cycle Assessment (LCA) in Textiles and Clothing, Handbook of Sustainable Apparel Production, and Textiles and Clothing Sustainability (six volumes).

He is acting as an editor, editorial board member, and reviewer for many international peer-reviewed journals of textiles and environmental science disciplines. He is also the series editor of two books series of Springer namely Textile Science and Clothing Technology and Environmental Footprints and Eco-design. He is one of the directors of Textile and Bioengineering Informatics Society, which is a charitable organization created to foster, develop, and promote all aspects of science and technology in bioengineering of materials, fibers, and textiles.

CHAPTER 12

The Role of Demand-Side Management in Carbon Footprint Reduction in Modern Energy Services for Rural Health Clinics

Olubayo M. Babatunde, Peter O. Oluseyi, Tolulope O. Akinbulire, Henry I. Denwigwe, Tolulope J. Akin-Adeniyi
Department of Electrical Electronic Engineering, University of Lagos, Akoka, Nigeria

12.1 DEMAND-SIDE MANAGEMENT

12.1.1 Introduction

Because of globalization, industrialization, and development due to technology, the demand for electrical energy is on the increase. There is therefore a need for efficient energy measures to ensure conservation, thereby saving costs. Demand-side management (DSM) deals with conversion of energy demand of consumers into activities/programs/tactics (e.g., financial incentives and public awareness/education), which brings about less use of energy by the consumers.

Gellings and Parmenter gave a history of DSM in the United States and its influence on energy resources. They also explained the role of DSM in integrated resource planning, the main elements of DSM programs and summarized the key best practices for program design and delivery.

Palensky and Dietrich (2011) described DSM as using measures such as sophisticated real-time control of distributed energy resources, better materials, smart energy tariffs with incentives for certain consumption patterns to improve energy efficiency. Various types of DSM were analyzed, and an overview of modern DSM projects was given.

Haney et al. (2010) highlighted how integrated government DSM policies, targeting residential demand for electricity and heat are more likely

Environmental Carbon Footprints
ISBN 978-0-12-812849-7
http://dx.doi.org/10.1016/B978-0-12-812849-7.00012-X

to be successful than single policies. DSM was also used to show how large untapped potentials could be uncovered through barriers to energy demand reduction.

A study on sustainable energy regulation and policymaking for Africa (Demand-side management sustainable energy regulation and policymaking for africa) examined some of the challenges facing the implementation of DSM programs and also gave a detailed review of DSM measures (this includes review of housekeeping and preventive maintenance, which are the simplest and most effective ways of reducing demand, and marketing of DSM programs) managing and controlling loads from the utility side, converting unsustainable energy practices into more efficient and sustainable energy use, thereby reducing energy demand for the end user. Worldwide, the consumption of energy is massively on the rise, and as a result, the carbon footprint is also increasing in an exponential manner. The rise in energy consumption and carbon footprint are the significant components responsible for "Global Warming." Currently, climate change a consequence of global warming is a global challenge with severe penalties for our socioeconomic infrastructure as well as the natural environment, and future generation. Long-terms planning will be required to slow down the grave effect of climate change. One of the ways of reducing the energy consumption is the adoption of sustainable DSM programs. Sustainability is also imperative in DSM programs. Sustainability means "meeting the needs of the present without compromising the ability of future generations to meet their own needs."

The rest of this chapter gives an in-depth background into the importance of DSM, DSM program types, and the various benefits of its adoption. It further presents the opportunities of adopting DSM in rural healthcare centres (RHC). Finally, a case study validating the effect of adopting DSM in sizing of hybrid renewable energy systems for RHC is analyzed.

12.1.2 Importance of Demand-Side Management

The importance of DSM can be summarized into the following (Demand-side management sustainable energy regulation and policymaking for Africa):

- Reduction in cost of producing energy by generating companies and purchasing energy by consumers.
- Provision for modern technologies and innovation, which create job and bring about economic development.
- Air pollution is reduced, therefore having a positive impact on the environment and social life.

12.1.3 Motivation Behind Demand-Side Management

According to S. Saini, the major motives behind DSM are the need for cost to be reduced and continued sustenance of the environment, also the need for reliability in energy efficiency through the network infrastructure is a motive that encourages DSM.

As a result of the rising costs of power generations and environmental hazard potentials available in power-generating stations because of generation of electricity, DSM therefore not only provides integrated resource planning for reducing costs of generation but also meeting the demands for generation (Course Module). This can be achieved by setting up energy commissions or agencies, which set targets and goals toward energy conservation, load management, and environmental protection. These agencies are to work with public energy utility companies that oversee generation, distribution, and transmission of electricity to ensure the success of these programs. It is very important that, good policies are put in place to sustain DSM programs. Some of these policies include a standard program for cost-benefit analysis of DSM activities, a predetermined target for energy savings, which is generally accepted, a system of funding, which promotes the competitive nature of energy companies practicing DSM, and finally regulation of prices of energy sold by the energy companies to customers who are noneligible for DSM financial incentives to increase sales, save incentives for eligible customers and therefore save energy (Course Module). The implementation of DSM programs can be incurred in cost, either by the government through taxes or by the electricity companies through higher tariffs whose burden on the consumers can be eased by the government through subsidies and loans. The energy commissions and agencies are to also ensure that, no planning of theirs affects environmental and infrastructural development, even as they ensure that the natural environment is not polluted, and it is therefore sustained.

Because of increasing demand for electricity and inadequate infrastructure for transmission and distribution networks in developing and developed countries, the need for DSM program is therefore of priority. Planning through DSM can reduce the need and possibly eliminate the cost of constructing transmission and distribution network infrastructure expansion (Course Module).

12.1.4 Types of Demand-Side Management Measures

DSM measures are classified into three (Demand-side management sustainable energy regulation and policymaking for Africa), namely: energy reduction programs, load management programs, and load growth and conservation programs.

12.1.4.1 Energy Reduction Programs

This is also referred to as "energy-saving tips". Some of the programs require capital, whereas others are capital free.

Energy-saving tips for steaming and heating systems include the following:

1. It should be ensured that there are adequate control for adjusting the quantity of combustion air.
2. It should be ensured that, insulation and refractory pipes are in good condition, their thicknesses should also be appropriate for good modern practice.
3. Combustion conditions should be routinely monitored, and the efficiency should always be kept as high as possible.
4. It should be ensured that, the water treatment system is always in good working order, and there should be constant and regular monitoring of the boiler feed water quality.
5. It should always be ensured that, there are no areas for steam and water leaks in the equipment.
6. Vessels, return lines, and fittings should always be condensed, and any steam present should be insulated
7. Steam leaks and steam traps should always be maintained and repaired when faulty.
8. Flash steam in the plant should always be considered during use.
9. Automatic temperature controls should be placed correctly in equipment wherever waste of steam that can overheat equipment or processes is minimized.

Energy-saving tips for lighting include the following:

1. Efficient energy fluorescent tubes, CFLs, and other low-energy light sources should be used.
2. Luminaries should be cleaned regularly.
3. Appropriate lighting levels at different periods and different zones should be used.
4. Natural light should always be encouraged in areas where possible, e.g., roof panels and skylights, etc.
5. Walls and ceilings should be painted with white or bright colors to improve reflection of light.

Energy-saving tips for motors include the following:

1. Use of highly efficient motors should be encouraged.
2. Improved bearings should be installed, and there should be regular and constant lubrication.
3. Motors should be properly sized and should be used only when needed.
4. All equipment should be maintained regularly.
5. Controls having electronic variable speed where motor loads vary in normal operation should be used.
6. Power factor should be checked regularly and should also be improved using capacitor banks, preferably closely installed to the running equipment.

Energy-saving tips for compressed air systems include the following:

1. Wrong use of compressed air should be discouraged and eliminated.
2. Leaks should be checked out when workshops are typically quiet and are not supposed to be using air.
3. Important parts of the system should be checked regularly to prevent the effect of early damage.
4. Overall system efficiency should be ensured by checking compressor running times to improve the system.
5. System pressure should always be optimized.
6. Heat recovery systems should be installed.

In households, some energy-saving tips include the following:

1. Air infiltration or hot air escapes, and inadequate or failed insulation should be eliminated in fans and vents, heating, cooling and ventilating ducts, and fireplaces, electric outlets, plumbing penetrations through walls, floors, walls, ceilings, doors, and windows.
2. Insulating blankets, insulating pipes, and thermostat set to 50°C should be encouraged for use in hot water cylinders.
3. Incandescent lightings should be replaced with CFLs and LEDs of appropriate and equivalent illumination.
4. Curtains should be used as insulators at night and as a blind against the sun to cool when hot; the curtain should also be open for sun to enter to heat when cold.
5. Dryers, dishwashers, and washing machine should only run with full load.

Some energy-saving measures that require investments include the following:

1. Replacing appliances that are old and worn-out.
2. Making use of a solar water heater.
3. Making use of double-glazing windows.

The measures discussed above are not generally applicable. Some of the generally applicable measures include the following:

1. *Efficient Lighting*: Efficient lighting measures which require investments, are not so large, and the investments are eased through paybacks and subsidies. Changing light bulbs, fittings, switches, and increased use of natural light are some of the tips involved in efficient lighting. Incandescent bulbs lose energy to heat and are therefore inefficient, compact fluorescent lamps with electronic ballasts are more efficient than incandescent bulbs with conventional ballasts, although they are more expensive, they last longer and consume less energy than the required energy for transmitting the light energy output. Some of the most common opportunities involved in efficient lighting include
   a. Long-term benefits by replacing existing lamps with more efficient light sources. This is known as light retrofitting.
   b. Safety in lighting by removing selected lamps, which do not support safety of the lighting zones from existing light fixtures in a uniform pattern throughout specific zones.
   c. Switching off selected areas of lighting with absence of people, whereas adjacent areas remain switched on to save energy, which can be wasted because of little or nonusage.
2. *Energy-efficient Motors:* Energy-efficient motors are needed to sustain manufacturing and mining industries and the natural environment. Many opportunities exist through energy-efficient motors. Air-conditioning for air circulation and compressor motors is a major source of power usage in industries to remove heat, dust, and gases, which can cause loss in energy. High efficiency motors can reduce electrical loads, thereby saving energy and ensuring the ventilation of mines (Pitis (Femco) and Livingstone (Anglo Gold Mining Motors), 2004). Per feasibility studies carried out in 1999 for establishment of motor repair and sales centers in Ghana based on sustainable energy regulation and policymaking training manual (Demand-side management sustainable energy regulation and policymaking for africa). It was concluded that, repeated motor rewinding and refurbishment lead to significant efficiency in losses. The study also made a recommendation on developing and implementing procedures on motor testing, labels, and standards for minimum efficiency and also setting up a facility in Ghana for the manufacture of small electric fan and pump motors (Ahenkorah).

12.1.4.1.1 Energy Management Practices in Organizations

Energy management practices through DSM are very important in industries/organizations for cost reduction of energy. Energy management in organizations depends on organizational budget, skills of staff available, and the nature of the organization. Energy management programs include: capital investment management (including equipment procurement), energy purchasing, performance measurement, energy policy development, metering and billing, energy surveying and auditing, awareness-raising, and training and education. An energy manager in any organization is usually tasked with the following responsibilities:

- Development and evaluation of projects to save energy.
- Proper and regular identification of energy-saving opportunities.
- Regular collection and analysis of energy-related data.
- Constant supervision of energy purchases and equipment procurement.
- Project implementation and future monitoring of implementation performance.
- Effective communication and public relation skills.

Cost-management activities that aid DSM programs include (Martel, 2000) the following:

- Accounting of energy and base-lining analysis.
- Billing of tenants for multiple occupancy buildings.
- Verification of utility bills and tracking of budget.
- Production of load profiles of individual and multiple facilities to ease energy decisions.
- Reporting of management of facility to the senior managers.
- Benchmarking of internal and external energy performance.

12.1.4.1.2 Energy Management in Households

Some good housekeeping tips for energy savings in households include:

- Switching off loads that are not in use: e.g., lightings, computers, monitors, sockets, etc.
- Removing lighting fixtures and pipings that are redundant and contribute to unnecessary heat losses.
- Faulty electricity lines should be replaced to prevent losses and distribution systems should be improved regularly for efficient output.
- Steam leaks and faulty equipment should be replaced or prevented to prevent losses.

12.1.4.1.3 Precautions to Prevent Energy Losses in Building

Some preventive measures for ensuring that energy losses do not occur in industries include the following:

- Filter cleaning on air compressors, pumps, upstream of steam traps in ventilation ducts, and others should be undertaken regularly.

- Hot spots on boilers and furnaces should be monitored regularly and checked for refractory failure.
- Transformer temperatures should be monitored regularly to prevent abnormalities.
- Noise and vibration of bearings should be monitored regularly to prevent failure of bearings.
- Having a routine schedule for lubrication of parts and equipment.
- Regular replacement of worn-out equipment.

Building regulations and standards are also important practices of DSM. Building regulations has an impact on energy efficiency of buildings. Some of these regulations include the following:

- Passive lighting should be encouraged.
- Use of quality building construction materials to reduce heat losses.
- Roof spaces should be insulated.

It is also important as part of customer awareness that, equipment and buildings indicate their expected energy consumption. Customer education and labeling of appliance help customers make good judgment when buying appliances and equipment, thereby reducing energy consumption.

12.1.4.1.4 Energy Auditing

Energy auditing deals with analyzing and surveying the flow of energy to conserve energy in a building/plant. This can be done by using energy record keeping and measuring equipment like energy meters. Energy auditing is an essential component of energy management program, whereby a complete review of energy consumption activities, such as energy consumed in manufacturing and energy consumed in heating or cooling. Energy audits then collate all relevant data to carry out a detailed analysis of the performance of the building or system and to identify deficiencies and make recommendations for improvement.

Kumar et al. (Sameeullah et al., 2014) identified energy-saving methods experienced during an energy audit of a building in India and also gave a detailed explanation on how these methods could be implemented. This was done with the aim of showing the importance of energy audit in energy conservation.

Lamba and Sanghi (2015) gave a complete emphasis and explanation as to how energy audit is a continuous process toward achieving energy efficiency. They gave a detailed analysis on how to conserve and efficiently utilize scarce resources and how to identify and implement energy saving potentials through energy auditing. Opportunities using renewable energy technologies were also discussed.

The following steps explain how energy audit can be carried out in a building:

- Information on the processes employed, machinery characteristics, plant equipment and physical facilities, design data, and production capacities are obtained and collated.
- Historical records, the emissions, energy consumptions, and production levels for machines and energy consuming equipment (over a period of say 2—3 years) are determined.
- The actual operating parameters and performance of equipment and processes should be determined.
- The data obtained and the observations made should be properly established in efficiency of energy utilization by key equipment.
- Constraints to improving performance, including organizational, technical, and financial constraints should be identified and characterized.
- Potential measures for improvement should be identified and financial evaluation, where investment is needed should be carried out.
- A comprehensive action plan, which is very logical to address the constraints, should be developed, including specific recommendations and priorities for the different measures.

Audits can be divided into preliminary audit and detailed audit, which are both discussed, respectively.

1. Preliminary audit: This is an exercise in form of a fieldwork to gather initial data at the primary stages of the auditing program. It is also known as walk-through or short audit. In this type of survey, there is no need for the use of equipment because data from the building are sufficient. Data is collected via a "walk-through" of the building during which the general condition of equipment, the standard of maintenance, the level of operations control exercised by management, and the reporting procedures in effect are observed.

Dongellini et al. (2014) gave a good explanation on how "walk-through" audit is important in reducing energy consumptions for sustainable and energy-efficient manufacturing, continuous energy audit, and process tracking of industrial machines. This was carried out on eight large industrial buildings of a famous car manufacturing holding in Italy. Preliminary audit is very easy and less stressful as few measurement and easy calculations are used. It is therefore quick and can be completed within a short period. The information obtained from a preliminary audit is used for a thorough analysis of the energy performance of a building/plant.

2. Detailed Audit: This is a more comprehensive form of energy auditing. It deals with a survey on home energy by obtaining more detailed information on the home's energy usage, as well as a more proper financial analysis of its energy costs. Portable instruments are commonly used for accessing parameters on equipment and processes, the auditors must be well experienced with a good sense of judgment when collecting and interpreting data. Half of the effort put into a detailed audit should be spent on collecting data on-site, whereas the other half on proper analysis of the data and preparing the report. Detailed energy audit takes a longer time to complete, and it is used for a longer-term performance monitoring.

Singh et al. (2012) defined detailed audit as one, which provides a dynamic model of energy use characteristics of both existing facilities and all energy conservation measures identified, and therefore calibrates the building model against actual utility data to provide a realistic baseline and to compute operating savings for the proposed measures. They also presented a detailed energy audit, for design and implementation of a physically based model for industrial load management, thereby improving the plant efficiency and reducing the energy wastages.

Srinath and Uday Kumar (2014) explained detailed audit in the industrial sector as one requiring a comprehensive recording and analysis of energy consumption data, which is split into various sectors (steam/hot water production, compressed air, electricity, and heating, ventilation, and air conditioning). This is done to present and analyze different parameters that determine each type of energy use (e.g., production capacity, climate conditions, raw materials, and others). A list of potential energy—saving measures, which requires investment capital are presented together with a cost-benefit analysis for each proposed measure.

12.1.4.2 Load Management Program

Load management programs include: load leveling, load control, tariff incentives, and penalties.

12.1.4.2.1 Load Leveling

Load leveling optimizes the generating base load, operating at the present time without the need for reserve capacity to meet the periods of high demand. It therefore reduces fluctuations in customer demand. Classic forms of load leveling include the following:

- Peak clipping: Here the peaks of demand are clipped to reduce the load at peak times and intervals. The diagram of peak clipping is represented in the first diagram of Fig. 12.1.
- Valley filling: Here the low-demand periods are "filled" by building up off-peak capacities achieved by using thermal energy storage to displace fossil fuel loads. The diagram of valley filling is represented in the second diagram of Fig. 12.1.

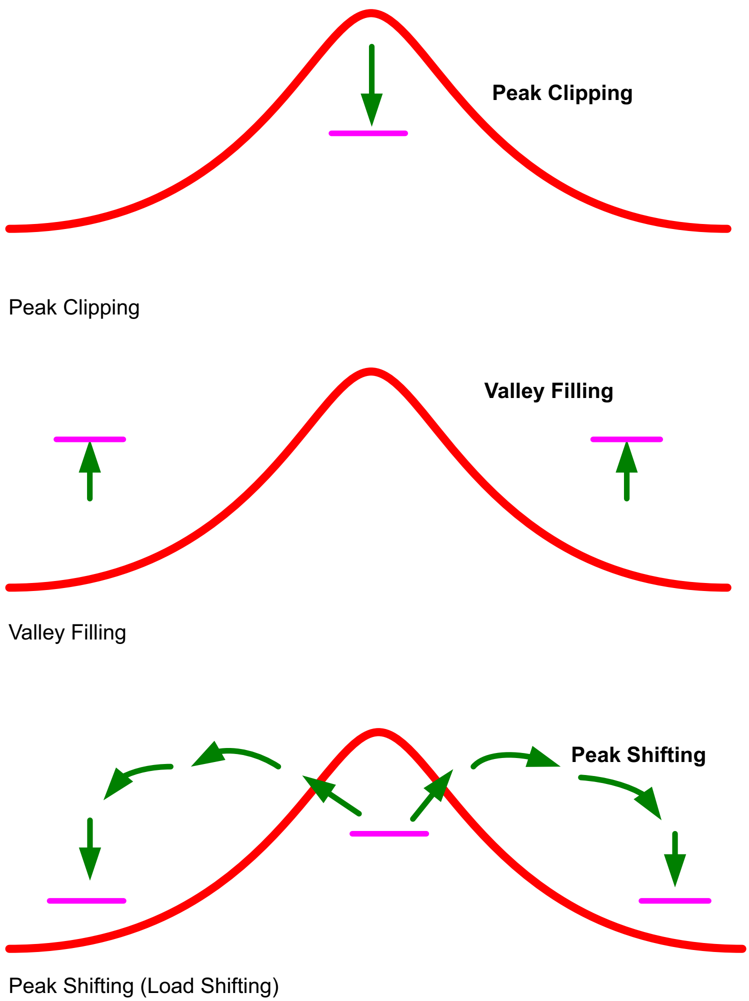


Figure 12.1 Classic forms of load leveling. *(From https://image.slidesharecdn.com/presentazionecordoba-160319093812/95/residential-demand-response-operation-in-a-microgrid-8—638.jpg?cb=1458380410.)*

- Load shifting: Here loads are "shifted" from high demand to low demand to achieve clipping and filling. Some applications of load shifting include: storage space heating, storage water heating, customer load shifting, and coolness storage. The diagram of load shifting is represented in the third diagram of Fig. 12.1.

12.1.4.2.2 Load Control

This is the automatic regulation of load because of heating, cooling, ventilation, and lighting by the utility or electricity company. Here, agreements are made between the customers and utility company to meet peak demand on the grid. This is done by customers using energy storage equipment and generators for backup. Electricity companies can organize a publicized schedule for a systematic switching off supply to different areas within a particular region at different intervals, whereby different areas take turns in losing supply. This is done to enable businesses and homes to plan their use of energy for that period.

12.1.4.2.3 Tariff Incentives and Penalties

Whenever customers use energy at some certain periods of time to ensure a better-priced rate for their energy use, the electricity companies encourages tariff incentives as a reward for these customers. These include the following:

- Providing different charges for power use at different periods, whereby high peak time charges encourage users to carry out their activities requiring high load in an off-peak period when the rates are lower. This is known as time-of-use rates.
- Penalizing users for going below a fixed power factor threshold, usually between 0.90 and 0.95. This is also known as power factor charges.
- Ensuring that, energy rates vary based on the energy provided by the electricity company. This is known as real-time pricing.

12.1.4.3 Load Growth and Conservation Programs

These programs are carried out with the aim of ensuring productivity and environmental compliance on the part of customers while making sure that, electricity companies increase their sale of energy. These programs can eliminate energy practices, which are unsustainable and bringing about more efficient practices such as: reducing the use of fossil fuels and also raw materials. Some of these programs include the following:

- *Strategic load growth:* This is the change of shape in load supplied to the customers by the electricity company which means that, there is a general increase in sales of electricity. This is represented in Fig. 12.2.

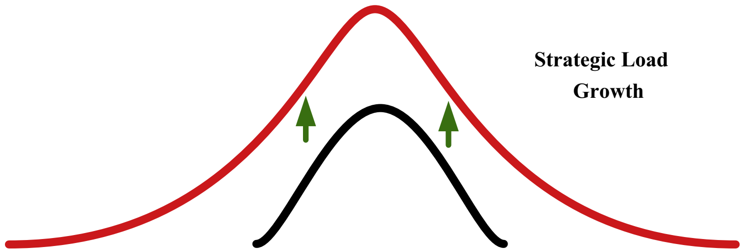


Figure 12.2 Diagram representing strategic load growth. *(From https://image.slidesharecdn.com/presentazionecordoba-160319093812/95/residential-demand-response-operation-in-a-microgrid-8—638.jpg?cb=1458380410.)*

Increase in market share of loads that are or can be served by competing fuels, as well as new areas development encourages load growth. Electrification involving electric technologies, industrial process, heating, and automation are modern day techniques for encouraging load growth.

- *Strategic load conservation:* These are programs targeted at the end use customers, whereby reducing sales as well as a change in the pattern of use is highly encouraged. Some of these programs include: insulation, sealing, and double-glazed windows (also known as weatherization). This is done for improvement in efficiency, in homes, and appliance. Strategic conservation is the change of shape in load supplied to the customers by the electricity company, which is directed at the end use consumption. This is represented in Fig. 12.3.

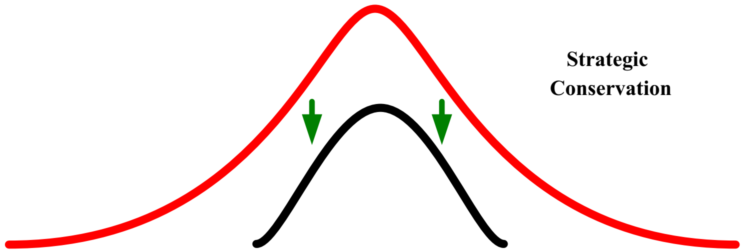


Figure 12.3 Diagram representing strategic load conservation. *(From https://image.slidesharecdn.com/presentazionecordoba-160319093812/95/residential-demand-response-operation-in-a-microgrid-8—638.jpg?cb=1458380410.)*

12.1.5 Information Dissemination on Demand-Side Management

This involves a collective effort from different stakeholders in developing, and implementing energy efficiency policies that are necessary for uninterrupted energy efficiency improvement. Information can be disseminated by awareness through campaigns promoting energy efficiency options and specific DSM techniques. This can be done through visual media (e.g., leaflets, brochures, fliers, posters, and video clips). Advertising and conducting energy audits are modern day forms of information dissemination.

12.1.6 Challenges of Implementing Demand-Side Management Programs

Challenges, ranging from insufficient provision, low awareness of energy, and efficiency/DSM programs to inability of industrial and commercial companies to carry out energy audits to obtain important information on their current operations are current trends affecting developing nations today. This can be as a result of failure by the company's management to explore the potential benefits of energy efficiency and also lack of skilled personnel for performing audits. Some measures that organizations can use in overcoming these challenges include the following:

- Ensuring that, competence and comprehensiveness of the assessment of DSM programs and audits are accomplished.
- Ensuring that, DSM systems and opportunities are well known and understood.
- Ensuring that, accuracy of assumptions is always considered.
- Ensuring that, there is proper awareness on production and safety constraints of involved plants/companies.

Factors that load management programs need to consider increasing energy efficiency include the following:

- Varying prices of electricity and other fuels.
- Cost burden on the customer.
- The value of losses prevented by ensuring an improved and reliable electricity system.
- Losses that can occur in production when implementing DSM programs.

Thorough financial analysis of the benefits of energy efficiency improvement needs to be undertaken when planning to set up DSM activities. Every DSM investments need to be properly accounted for to ensure easy assessment of funds for DSM projects because, if a project is not properly evaluated, approval of funds would be difficult, and this is the most vital challenge of implementing DSM projects.

12.1.7 Case Study—Energy Efficiency Opportunities for Rural Health-Care Facilities

Energy efficiency and conservation are a well-established practice in developed country hospitals and few developing countries. Energy efficiency measures have the tendency to reduce energy consumption as well as health facility's energy bill (Oluseyi et al., 2016). Apart from these, it can reduce emissions from conventional captive diesel/gasoline generators used in powering the facility and also allow backup systems to work more effectively during power outages or failure. Energy-efficient equipment is important for any facility, which is intended to operate off grid or on intermittent power sources or which must rely on battery storage.

Like in other power-consuming sectors, energy efficiency measures should be an essential factor in all existing and new health-care facilities in developing countries. Hence, the use of energy-efficient modern and functional medical equipment should be encouraged. This at times is usually a complex issue as agreement needs to be reached between medical personnel, design engineers, and other stakeholders. For example, in most developing countries with hot climate, there is usually the need for air-conditioning, which usually consumes significant amount of energy. Also, air-conditioning units are particularly sensitive to power fluctuations and, as such, are difficult to keep operational in developing countries. On the other hand, air-conditioned rooms are essential for sensitive laboratory equipment as well as sanitary purposes. In addition to sizing and designing, the operation of the health clinic can also affect its energy efficiency and power demand. The type of equipment purchased is important in reducing power consumption at health facilities. Energy star—rated equipment perform better in energy consumption when compared with conventional and obsolete equipment. All equipment and lighting connected to the storage device (backup) should be energy star—rated. If air-conditioning must be used, units with a high ratio of British thermal unit to watts should be procured. Training of both medical and maintenance staff on the importance of utilizing and ensuring efficient, low-energy operation of a health facility should also be ensured.

Typically, energy-efficient equipment and appliances are more expensive than standard-efficiency models. Conversely, this high cost may be

Table 12.1 Energy efficiency opportunities in health-care centers

Appliance	Energy efficiency/conservation measures
Lights	Lighting retrofits with energy-efficient light bulbs such as CFL or LED lamps. Switch off redundant lamps.
Vaccine refrigerator and ice pack freezer	Energy-efficient refrigerators should be encouraged because these refrigerators use 20% less energy.
Centrifuge	Turn off redundant centrifuge. Select centrifuge models that have relatively low rotor friction, which generates less heat, specifying smaller energy.
Autoclave	The equipment is fitted with a timer to cycle off when not in use. This will save maintenance by replacing the element as well as save energy.
Air-conditioner	Air-conditioner energy efficiency is measured by the energy-efficient ratio (EER) of the equipment. When buying new systems, buy the model with the highest EER rating. For operation, ensure coils are kept clean and that the thermostat is set at a comfortable, but not overly cool, temperature.
Computer	Energy star computers with flat screens and enabled with power management software can consume 40% less electricity than the conventional counterparts.
Printer	60% energy can be saved if printers that enable power management and duplexing features are used.

From http://www.poweringhealth.org/index.php/topics/technology/energyefficiency.

recovered through reduced operational costs of a smaller electricity generation system. Table 12.1 shows energy efficiency opportunities for some appliances/devices used in health clinics.

12.1.7.1 Need for Reliable Electricity in Rural Healthcare Centres

The need for a constant and efficient electrical power supply in our rural and local health-care centers all over the world is now a major concern. This is because of the adverse effect; the lack of a reliable electrical power system exposes the operators of these rural health-care systems and their patients, thereby posing a risk when saving human lives (Jimenez and Olson, 1999). Today, the distribution of vaccines and other temperature sensitive drugs and substances such as: antiretroviral drugs in our health-care centers globally. This has placed its own demand for electricity in health centers where there are limited or even no access to reliable power supply (Olatomiwa et al., 2016). The emergence of highly communicable diseases in modern time such as: the HIV/AIDS and Ebola virus, which were predominant in western Africa, and the Zika virus, which was and is still intense in South American countries, has necessitated the need for an efficient and reliable electricity power supply to fight these diseases to a standstill. For instance, unreliable power supply can hinder the treatment process of these diseases, if there are no refrigerators to store most of the vaccines, which are temperature sensitive, needed to fight these diseases. Also, a health personnel, attending to a patient or trying to take samples for medical tests in an enclosure or room without proper illumination stands the risk of being infected with these diseases easily as a result of poor illumination to comply with the laid down ethics and procedures for fighting the disease. The chances of carrying out the required medical tests could be impeded even during the day because electricity is required to power most medical equipment required to carry out these tests. Furthermore, a patient that arrives a health center that lacks electric power at night for medical attention will have to wait till the next day before proper examination can be carried out, which could be fatal.

Nigeria as a country has persistently been facing the challenge of lack of access to constant modern energy services over the years with the high dependence of its citizens on petroleum fuel for its individual electricity production. This challenge has its tremendous effect in other facets of the economy. In a country where about 40% of its citizens have access to electricity and 80% of this percentage lives in the urban areas (Nwulu and Agboola, 2011), this means that, most rural areas in Nigeria are not connected to national grid and therefore do not have access to electricity. These rural areas depend mostly on their traditionally domestic sources of energy for their livelihood. In a country with an electricity installed capacity of ~6538.3 MW, not more than 4500 MW is ever produced (Nwulu and Agboola, 2011), and with the ever growing demand for electricity all over the country in both urban cities and rural areas, especially in sectors that need critical attention such as: the health sector, there is the need to provide electricity that is reliable, efficient, and constant. As at present, Nigeria has not utilized or tapped fully the renewable energy technology to solve its electricity problems even though it is highly endowed with renewable energy. This form of energy will provide an affordable, reliable, efficient as well as constant source of electrical power, especially to critical sectors of the economy such as: health and in the rural areas that face utmost lack of these basic social amenities for the provision of good, reliable, and stable healthcare system.

Only a few know that, Nigeria is endowed with abundant renewable energy resources such as: solar energy, hydroelectric power resources, wind, biomass with potentials for hydrogen utilization and development of geothermal, and ocean energy (Ohumakin, 2010). As a result of the different resources of renewable energy, various approaches have been applied to determine and meet the optimal size of the system and components (Zhou et al., 2010; Bajpai and Dash, 2012). Renewable energy have been proved to provide quality and reliable electricity for different applications in rural areas (Dihrab and Sopian, 2010; Hiendro et al., 2013).

12.1.8 Methodology

12.1.8.1 Sizing Hybrid Renewable Energy Systems

12.1.8.1.1 Hybrid Optimization Model for Electric Renewables

A typical hybrid system will comprise a photovoltaic (PV) array, wind turbines, possibly a diesel generator, inverters, and battery bank with associated control devices (Lal and Raturi, 2012). Software tools such as Hybrid Optimization Model for Electric Renewables (HOMER) can be used to carry out simulation and optimization of hybrid systems. There are three main tasks that can be carried out by HOMER, which are simulation, optimization, and sensitivity analysis (HOMER Energy LLC: Hybrid optimization model for electric renewable, 2009). The HOMER is designed to perform simulation on long-term operation of a combination of micropower system configurations, with the inclusion of components like PV, wind, small hydro, diesel generators, and storage devices that can be battery banks. The HOMER can also be used for the modeling of grid-connected systems. After the simulation of quite a number of combinations, HOMER will make suggestions based on the net present cost (NPC) optimal configuration of the system. The sensitivity analysis can be performed using the sensitivity variables, i.e., wind, speed, and diesel price, which will enable the designer to determine the best combination of system components under different conditions.

12.1.8.1.2 Researches for Renewable Energy Access for Rural Healthcare Centres

Several researches have been carried out to study the hybrid systems in many locations around the world (Bekele and Palm, 2010; Akinbulire et al., 2014;

Hassan et al., 2011; Nandi and Ghosh, 2010; Rahman and Al-Hadhrami, 2010), Bekele and Palm researched on the feasibility study for a stand-alone solar wind based on hybrid energy system for application in Ethiopia and determined the optimal system for supplying electricity to a neighborhood of 200 families in Ethiopia and discovered that the price for diesel in 2009 was the most cost effective for the diesel generator/battery/converter set up (Bekele and Palm, 2010). The study of the optimization and life cycle cost of a hybrid system for a rural area health clinic in southern Iraq using HOMER software was carried out by Al-Karaghouli and Kazmerski. It was discovered that, the system when consisting the PV/battery inverter, was the most economic system (Al-Karaghouli and Kazmerski, 2010). The study of the technoeconomic evaluation of PV/diesel/battery systems for rural electrification in Saudi Arabia was carried out by Akinbulire et al. (2014). They researched on the effect of the increase in PV/battery on the cost of energy, operational hours of diesel generators, and the reduction in greenhouse gas (GHG) emissions. The study of the renewable energy technologies in the Maldives was performed by Van Alphen et al. (2007), and it was discovered that, 10% of the total electricity needed by Maldives can be supplied using renewable energy resources. Benghamem performed a study of the optimization of tilt angle for solar panel to increase the energy production, using Madinah, Saudi Arabia as case study (Benghanem, 2011) and revealed a gain of 8% at a tilt of solar collector in a particular angle on monthly basis when compared with tilting it annually. Besarati et al. (2013) studied the potential of harnessing solar radiation in different parts of Iran was analyzed and the results revealed that, there is greater potential for renewable energy application in the central and southern part of Iran.

12.1.8.2 Site Description

The sites used for the research were six towns selected across the six geopolitical zone/regions of Nigeria. The towns were selected across the six geopolitical zones to enable the study covers all the characteristics of the weather and climatic conditions of all the zones in Nigeria. Also, the towns selected are not the popular urban cities well known in Nigeria but are towns that are rural in nature and close to rural areas. The towns include: Okrika (south south zone), Ihiala (south east zone), Igbeti (south west zone), Kabo (north east zone), Abadan (North West zone), and Gboko (north central zone). Analysis was performed on these selected sites on the prospects of PV to power RHC.

12.1.8.3 Solar Resource

The NASA website provided the metrological data used in the analysis of this research work. The agency provided the average solar radiation for a stipulated range of time used for the analysis for the sake of the study.

12.1.8.4 Proposed Hybrid System

Based on the amount of solar resources present at these selected sites, the proposed hybrid system will be a combination of PV modules, diesel generators, power converters, and storage batteries. HOMER is the software to be used for this study. It is a general purpose system design tool for electric power systems. The software has several inputs, as well as component's technical and economic details (Olatomiwa et al., 2016). To arrive at an optimal value for system components, HOMER accepts more than one value to be entered to a tune of multiple values. Reliability and efficiency can be strengthened when the right merging of different sources of energy is done. The energy storage requirements are also reduced when compared with systems that have only one renewable energy source (Zhou et al., 2010; Olatomiwa et al., 2014). When solar energy resources and diesel generators are combined, a hybrid solar/diesel generator configuration is formed with an energy storage system to make the system a more reliable source of electrical power. The diesel generator in the hybrid system acts as a backup energy source, when there is redundancy or insufficient renewable energy resources.

The hybrid system design is better because there is more than one source of energy for alternation, and compliments the efforts of one another to achieve a reliable and efficient system in producing the much-needed electrical power for rural health centers, unlike the one source of renewable system that does not have these benefits. Also, in the hybrid system, different components need to be sized so as to achieve the required load demand, while in a single source of renewable system, the system to accommodate the load demand, the becomes oversized.

12.1.8.5 Data Requirements

To achieve the aim of this study, the data required for this analysis are categorized into three, namely: (1) metrological (solar irradiance), (2) estimated load, and (3) the component data. These are discussed in the next section.

12.1.8.6 Metrological Data

For the purpose of this study, a town each falling within a geopolitical zone in Nigeria is picked as a pilot study for the entire geopolitical zone.

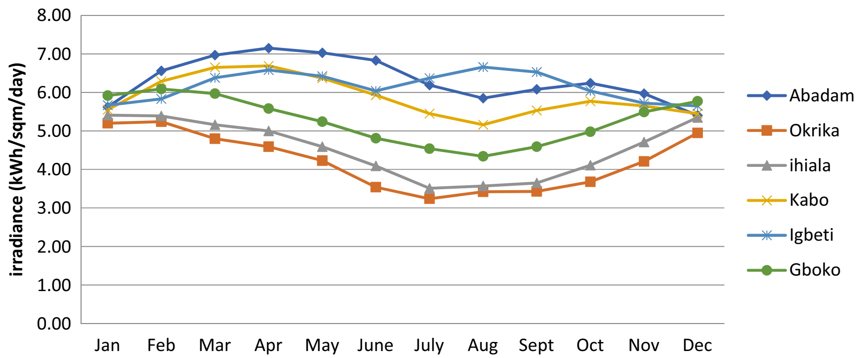


Figure 12.4 The solar irradiance for the chosen cities.

Fig. 12.4 shows the solar irradiance for the chosen cities as obtained from NASA's global satellite database. This serves as input into HOMER to ascertain if the load demand of the clinic can be met.

12.1.8.6.1 Load Data

12.1.8.6.1.1 Categorization of Health Clinics To adequately capture the energy demand of a health facility, it is essential to categorize health facilities based on size and energy consumption. This section describes classes of health facilities and their corresponding energy demand. The energy demands of a health facility will be a critical component in the selection of the most appropriate electrification technology. The descriptions provided are according to United States Agency for International Development documents available in open literature (http://www.poweringhealth.org/index.php/topics/technology/energyefficiency).

12.1.8.6.1.2 Health Post Health post is the smallest, most basic health facility in terms of size and services provided. These facilities usually do not have a permanent doctor or nurse. Most times, the health post may have a full- or part-time primary health-care provider and trained health officers. Services provided by health post facilities include: the treatment of minor illnesses, the nursing of minor injuries and, and the provision of basic immunization services. Because of the limited medical services provided, the medical equipments are few, and as a consequence, the overall energy consumption is moderately low. The energy demands of a health post will be satisfied through category of health clinic electrification options, while taking into account the reduced daily demand for energy.

12.1.8.6.1.3 Health Clinics Health clinics are generally larger than health posts and engage one or more full-time nurses. Clinics may also employ part-time medical doctors, depending on the services provided, size and location. Health clinics offer comprehensive category of services when compared with health post. Therefore, it is expected that it acquires more medical equipment so as to enable more sophisticated and advanced diagnoses. They can be subdivided into the three categories (Categories I, II, and III). Rural health clinics generally fall into one of the three categories, based on the type and number of medical devices used in the facility and the frequency with which they are used on a daily basis (http://www.poweringhealth.org/index.php/topics/technology/energyefficiency).

Category I Health Clinic (low-energy requirements, 5–10 kWh/day)

1. Typically located in a remote setting with limited services and a small staff.
2. Approximately 0–60 beds.
3. Electric power is required for:
   - lighting the facility during evening hours and to support limited surgical procedures (e.g., suturing)
   - maintaining the cold chain for vaccines, blood, and other medical supplies—one or two refrigerators may be used
   - utilizing basic lab equipment—a centrifuge, hematology mixer, microscope, incubator, and hand-powered aspirator.

Category II Health Clinic (moderate energy requirements, 10–20 kWh/day)

1. Approximately 60–120 beds.
2. Medical equipment similar to Category I Health Clinic; frequency of use and number of devices are key factors of differentiation between Category I and II health clinics.
3. Separate refrigerators may be used for food storage and cold chain.
4. Communication device, such as a radio, may be utilized.
5. May accommodate more sophisticated diagnostic medical equipment and perform more complex surgical procedures.

Category III Health Clinic (high energy requirements, 20–30 kWh/day)

1. Approximately 120 beds or more.
2. May serve as a regional referral center and coordinate communication between several smaller facilities and hospitals in large cities.
3. May need to communicate with remote health centers and hospitals by way of telephone, fax, computer, and Internet.

4. May contain sophisticated diagnostic devices (X-ray machine, CD4 counters, blood typing equipment, others) requiring additional power.

12.1.8.6.1.4 Energy Assessment of a Rural Health Center Because health-care facilities offer a comprehensive variety of health services, it is essential to specify energy needs based on equipment required for such services. In literature and practice, this has enjoyed limited attention (http://www.who.int/hia/green_economy/modern-energy-services/en/). Therefore, this area needs more attention by health and energy professional at the international, regional and national level, and grassroots. Nevertheless, infrastructural studies such as Service Availability and Readiness Assessment (SARA) itemized a detailed list of medical equipment accessible in health facilities, and the outcome of these reviews can be adopted as a basis for evaluating prevailing energy needs. In the survey, SARA classified health services, essential electric equipment and its indicative power requirements as: (1) infrastructure (lighting, communication, water supply, and waste management); (2) medical devices; and (3) support appliances for specific health services, which include vaccination, infectious and non-communicable disease treatment, emergency care such as blood transfusions and surgical services. An extract of this is presented in Table 12.2.

12.1.8.6.1.5 Criteria for Selection of the Appropriate Energy System for the Load For the selection of appropriate hybrid power system for health-care facilities, a list of factors needs to be considered. These include the following:

- *Peak power capacity*: This is defined as the maximum capacity the system can supply.
  Different appliances consume different amount of electricity, which ranges from a few watts to several kilowatts. Similarly, the various power-generating systems generate different quantities of electricity. The generated electricity should adequately meet the expected electrical load demand. Hence, the use of energy-efficient equipment is of great emphasis, so as to reduce the available peak power needs of the health-care facilities.
- *Daily energy capacity*: Generally, energy use by various appliances in health-care facility could be classified as continuous (e.g., refrigerators and space heating) and intermittent such as in laboratory equipment. The intermittent loads are load that are operated periodically, either in the evening or early morning (radio, laptop, and others) or some

Table 12.2 Health equipment by power load level

Health services	Electrical devices	Indicative power rating (W)	AC power supply	DC power supply
Infrastructure				
Basic amenities	Lightings:			
	Incandescent bulb	10.8 W/m^2	110/220 V	—
	Halogen bulb	1.8 W/m^2	110/220 V	12 V
	CFL bulb	2.16 W/m^2	110/220 V	—
	LED bulb	1.8—2.14 W/m^2	110/220 V	10—30 V
	Security lighting/outdoors CFL/LED	40—160 W	110/220 V	10—30 V
	Laptop desktop incandescent	200—600 W	110/220 V	10—30 V
		20—60 W	110/220 V	12—20 V
	Mobile phone battery (charging)	5—20 W	110/220 V	5—16.5 V
	Desktop computer	15—200 W	110/220 V	8—20 V
	Printer (ink jet)	65—100 W	110/220 V	12—20 V
	VHF radio receiver: standby	2 W	110/220 V	12 V
	transmitting	30 W	110/220 V	12 V
	Ceiling fan	50—100 W	110/220 V	—
	Refrigerator (for food and water)	150—200 W	110/220 V	—
	Portable air-conditioner (AC)	1000—1500 W	110/220 V	48 V

Specific services				
General outpatient services	Nebulizer	80–90 W	110/220 V	–
	Oxygen concentrator	270–310 W	110/220 V	–
	Pulse oximeter	50 W	110/220 V	–
Antenatal child and adolescent health	Vaccine refrigerator	60–115 W	110/220 V	N/A
Obstetric and new born	LED lighting (phototherapy)	440 W	110/220 V	–
	Suction apparatus	90–200 W	110/220 V	–
	Vacuum aspirator	36–96 W	110/220 V	3–6 V
	Neonatal incubator	800–1035 W	110/220 V	–
	Ultrasound	800–1000 W	110/220 V	–
General diagnostics, blood analysis, and laboratory equipment	Laboratory refrigerator	60–160 W	110/220 V	–
	Centrifuge	250–400 W	110/220 V	–
	Hematology analyzer	230–400 W	110/220 V	–
	Blood chemistry analyzer	45–88 W	110/220 V	–
	CD4 counter	200 W	110/220 V	12 V
	Microscope (with LED light)	20–30 W	110/220 V	3–6 V
	X-ray machine (portable)	3–4 kW	110/220 V	–
	Laboratory incubator	200 W	110/220 V	12 V
Basic surgical services	Suction apparatus	90–200 W	110/220 V	–
	Anesthesia machine	1440 W	110/220 V	

From http://www.who.int/hia/green_economy/modern-energy-services/en/.

medical equipment operated once or twice a day (e.g., autoclaves for instrument sterilization). The breakdown for expected daily energy capacity needed for the health-care facilities considered for this chapter is presented in Table 12.3. This is an extract from the SARA requirement (Table 12.2). The proposed energy system must be capable of supplying the daily energy requirements of a typical rural health clinic.

- *Evening peak hours' supply*: In a typical RHC, some patients, including pregnant women may show up for treatment in the evening time. To avoid or minimize wasting time during their daytime jobs. In case of first aid emergencies, the availability of power supply in health-care facility in the evening and during the night hours is considered imperative for quality health-care delivery, especially when there are no referral clinics nearby. In RHC that have enough personnel to do night duties, electric power supply in the evening is vital to enable them feel secured and improve their productivity during night shifts. Therefore, the power supply is designed to suit the expected nighttime load demand.
- *Duration of supply*: The duration of power supply to health-care facility is dependent on size as well as types of health-care services rendered. It is expected that, electricity supply be available to power all equipment required to enhance quality medical services delivery at all times RHCs, with maternal health care and childbirth services or other emergency services are expected to have power supply for basic applications. Some equipment, such as laboratory equipment, for testing of samples collected during the day and analyzed in a batch is used intermittently. However, other appliances such as of refrigerators are run as base load and may require continuous electricity supply.
- *Reliability:* Reliability in this context deals with the probability of power failure because of unmet load. Unmet load is electrical load that the power system is unable to serve. It occurs when the electrical demand exceeds the supply. Because of the sensitive nature of services rendered by RHCs during power disruptions, health facility is expected to be provided with backup power generators. This will improve the reliability of the system and as such, reduce the loss of load. Backup generators may not provide sufficient electricity for all the equipment; nevertheless, it should serve as support to priority applications such as: lighting, refrigerators, and other critical equipments. Consequently, reliability of the power supply is given significant attention, while sizing and designing the power system.

Table 12.3 Clinic appliances and their power ratings

S/ no	Power consumption	Qty	Power (CME) watts	Power (EEME) watts	Total (watts)	Total (watts)	Daytime hours 7 a.m.–6 p.m.	Evening hours (6–10p.m.)	Night hours (10p.m.–7a.m.)	Total hours/day	Total energy (CME) (kWh/day)	Total energy (EEME) (kWh/day)
1	Refrigerator-vaccine (RV)	1	60	40	60	40	5	3	2	10	0.6	0.4
2	Refrigerator-nonmedical (RNM)	1	300	125	300	125	2	2	1	5	1.5	0.625
3	Centrifuge	2	242	242	484	484	4			4	1.936	1.936
4	Microscope	2	20	20	40	40	6			6	0.24	0.24
5	Blood chemical analyzer (BCA)	1	88	45	88	45	4			4	0.352	0.18
6	Hematology analyzer (HA)	1	230	230	230	230	4			4	0.92	0.92
7	CD4 Machine	1	200	200	200	200	4			4	0.8	0.8
8	Radio	1	30	15	30	15	10			10	0.3	0.15
9	Tube fluorescent lights (TFL)	4	40	18	160	72	8			8	1.28	0.576
10	Wall fan	5	65	65	325	325	8			8	2.6	2.6
11	Halogen lamp (security)	1	100	50	100	50	0	3	8	11	1.1	0.55
12	Desktop computer	1	230	65	230	65	4			4	0.92	0.26
	Total energy (kWh/day)										12.548	9.237
	% Energy reduction										26%	
	Oil equivalent of energy saved										0.0003	tonnes
	CO_2 emission reduction										4.3043	kg/day

CME, Conventional medical equipment; *EEME*, energy efficient medical equipment.

- *Environmental health and sustainability*: It is expected that, energy supply to any health-care facility should not lead to environmental hazards. Environmental impart such as air pollution, water pollution, and noise pollution in any quantities that could further deteriorate the health of patients, affect the medical staff or people living at the health-facility premises, should be avoided. This can be achieved by making sure high penetration of renewable energy sources. This will ensure high value of renewable energy fraction. Consequently, reduction of GHG emission per kWh of power generated will lead to environmental sustainability. To this aim more priority should be given renewable energy sources than captive gasoline or diesel generator source in providing power supply to the rural health-care facilities.

A 24-h energy demand is required, so as to determine the sizes of the components. Because of the nonavailability of a typical load demand for RHC in Nigeria, load profile based on SARA as indicated by UNICEF for a standard rural health center is developed for the purpose of this study. This was centered on the estimates of the medical equipment, power ratings at different times of the day and night. It is assumed that, the power will vary across the hour of the day, and that the clinic is only operational between 8a.m. and 5p.m. daily. Essential appliances such as refrigerator, operated intermittently during the night. Two kinds of medical devices and appliances are modeled for the load-conventional (inefficient) and energy-efficient equipment. The existing devices in most RHC visited are conventional and obsolete technologies. The various appliances used in this study and the presumed distribution of the daily energy consumption by appliance are shown in Table 12.3 and Fig. 12.5A and B, respectively. The fan and the centrifuge consume bulk of the power during the daytime.

As shown in Fig. 12.6, the peak load of 1.557 kW/day and 1.411 kW/day occur for both types on load between 12p.m. and 2p.m. To model the change in pattern of electricity usage during the year, a day-to-day variability of 10% and hour-to-hour random variability of 15% was specified in HOMER. The clinic utilizing conventional equipment will require 12.55 kWh/day to run its services, whereas the clinic deploying energy-efficient appliance and equipment will require 9.24 kW/day-26% less than the former. The oil equivalent of energy saved and the CO_2 avoided with use of energy efficient medical equipment (EEME) as against conventional medical equipment (CME) is 0.0003 tonnes/day and 4.3043 kg/day. The hourly load distribution analysis for pre-and post-DSM is given in Tables 12.4 and 12.5.

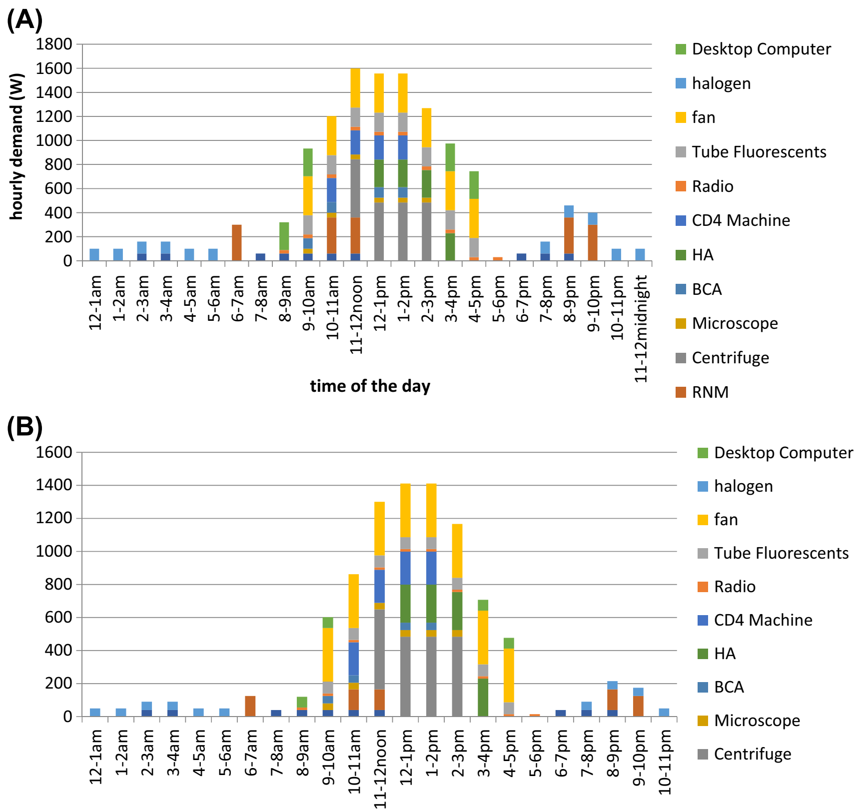


Figure 12.5 (A) Daily energy demand contributions of conventional appliances. (B) Daily energy demand contributions of energy-efficient appliances. *BCA*, blood chemical analyzer; *HA*, Hematology analyzer; *RNM*, Refrigerator-nonmedical.

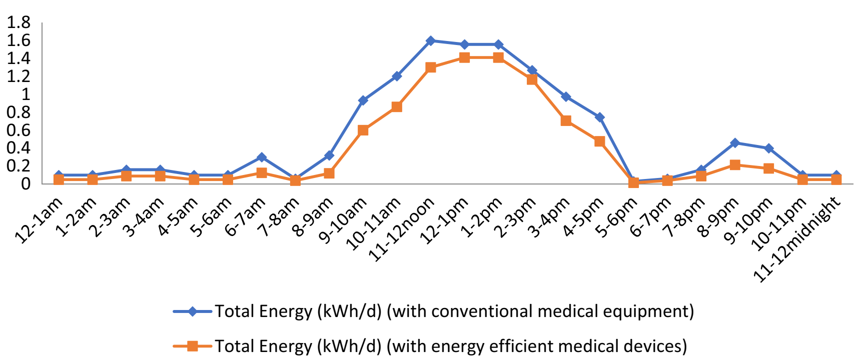


Figure 12.6 Electric load profile for both scenarios (conventional and energy-efficient devices).

Table 12.4 Hourly distribution of load demands without demand-side management

Time of the day	RV	RNM	Centrifuge	Microscope	BCA	HA	CD4 machine	Radio	Tube fluorescent	Fan	Halogen	Desktop computer	Total energy (Wh/d)
12−1a.m.											100		100
1−2a.m.											100		100
2−3a.m.	60										100		160
3−4a.m.	60										100		160
4−5a.m.											100		100
5−6a.m.											100		100
6−7a.m.		300											300
7−8a.m.	60												60
8−9a.m.	60							30				230	320
9−10a.m.	60			40	88			30	160	325		230	933
10-11a.m.	60	300		40	88		200	30	160	325			1203
11−12noon	60	300	484	40			200	30	160	325			1599
12−1p.m.			484	40	88	230	200	30	160	325			1557
1−2p.m.			484	40	88	230	200	30	160	325			1557
2−3p.m.			484	40		230		30	160	325			1269
3−4p.m.						230		30	160	325		230	975
4−5p.m.								30	160	325		230	745
5−6p.m.								30					30
6−7p.m.	60												60
7−8p.m.	60										100		160
8−9p.m.	60	300									100		460
9−10p.m.		300									100		400
10−11p.m.											100		100
11−12midnight											100		100
Total	600	1500	1936	240	352	920	800	300	1280	2600	1100	920	12548

BCA, blood chemical analyzer; *HA*, Hematology analyzer; *RNM*, Refrigerator-nonmedical; *RV*, refrigerator-vaccine.

Table 12.5 Hourly distribution of load demands with demand-side management

Time of the day	RV	RNM	Centrifuge	Microscope	BCA	HA	CD4 machine	Radio	Tube fluorescent	Fan	Halogen	Desktop computer	Total energy (Wh/d)
12−1a.m.											50		50
1−2a.m.											50		50
2−3a.m.	40										50		90
3−4a.m.	40										50		90
4−5a.m.											50		50
5−6a.m.											50		50
6−7a.m.		125											125
7−8a.m.	40												40
8−9a.m.	40							15				65	120
9−10a.m.	40			40	45			15	72	325		65	602
10−11a.m.	40	125		40	45		200	15	72	325			862
11−12noon	40	125	484	40			200	15	72	325			1301
12−1p.m.			484	40	45	230	200	15	72	325			1411
1−2p.m.			484	40	45	230	200	15	72	325			1411
2−3p.m.			484	40		230		15	72	325			1166
3−4p.m.						230		15	72	325		65	707
4−5p.m.								15	72	325		65	477
5−6p.m.								15					15
6−7p.m.	40												40
7−8p.m.	40										50		90
8−9p.m.	40	125									50		215
9−10p.m.		125									50		175
10−11p.m.											50		50
11−12midnight											50		50
Total	400	625	1936	240	180	920	800	150	576	2600	550	260	9237

BCA, blood chemical analyzer; *HA*, Hematology analyzer; *RNM*, Refrigerator-nonmedical; *RV*, refrigerator-vaccine.

Table 12.6 Assumption regarding component sizing and cost

Component parameter	Value	Component parameter	Value
PV		**Converter**	
Rated capacity	1 kW	Rated power	1 kW
Derating factor	80%	Efficiency	90%
Capital cost	$4250	Capital cost	$621.80
replacement cost	$4200	Replacement cost	$569
Operational life	20 years	O & M cost	$3/year
Ground reflectance	20%	Operational life	15 years
Battery		**Diesel**	
Rating	4 V, 1900 Ah	Rated power	1 kW
Round-trip efficiency	85%	Capital cost	$280
Min. state of charge	40%	Replacement cost	$280
Capital cost	$269	O & M cost	0.5$/h
Replacement cost	$260	Operational life	15000 h
O & M cost	$5/year	Minimum load ratio	30%
Operational life	4 years		

O & M cost, operation and maintenance cost; *PV*, photovoltaic.

12.1.8.6.1.6 Component Data The initial selections of components are based on the load profile in Fig. 12.6. The details of components and other assumption regarding them are specified in Table 12.6. Prices are specified in US dollar. HOMER models two types of dispatch strategies—"load following," where the generator supplies exactly enough power to serve the load in the event of insufficient renewable energy and the "cycle charging," where the generators run at full load and excess electricity charges the batteries. In this study, both dispatch strategies were specified.

12.1.8.7 Emission Factors

An emission factor is a characteristic value that relates to the quantity of a pollutant released into the atmosphere with an activity associated with the release of that pollutant. These factors are usually calculated by dividing the weight of a pollutant by a unit weight, volume, distance, or interval of the activity emitting the pollutant. These factors are used to calculate emissions from different sources of air pollution.

These factors are averages of all reliable available data and are assumed to be typical for long-term means of the source category. The emission factor is used to compute the total emission from a source. Table 12.7 shows the state-by-state average emission factors for all the pollutants that HOMER

Table 12.7 Average emissions factors for the year 2000 for each us state

Serial number	State	Average grid emissions factors			SN	State	Average grid emissions factors			SN	State	Average grid emissions factors		
		CO_2 g/kWh	SO_2 g/kWh	NO_x g/kWh			CO_2 g/kWh	SO_2 g/kWh	NO_x g/kWh			CO_2 g/kWh	SO_2 g/kWh	NO_x g/kWh
1	Alabama	656	3.76	1.38	18	Kentucky	1011	5.7	2.41	35	North Dakota	1086	4.41	2.27
2	Alaska	586	0.61	2.21	19	Louisiana	629	1.6	1.15	36	Ohio	836	7.5	2.33
3	Arizona	533	0.74	1.06	20	Maine	297	0.96	0.65	37	Oklahoma	833	1.57	1.66
4	Arkansas	659	1.57	1.1	21	Maryland	623	4.58	1.58	38	Oregon	149	0.26	0.25
5	California	287	0.08	0.26	22	Massachusetts	587	2.53	0.91	39	Pennsylvania	560	4.32	1.23
6	Colorado	913	1.85	1.59	23	Michigan	710	3.2	1.52	40	Rhode Island	454	0.09	0.24
7	Connecticut	335	1.02	0.62	24	Minnesota	744	2.26	1.78	41	South Carolina	405	2	0.89
8	Delaware	894	5.93	1.59	25	Mississippi	597	3.2	1.55	42	South Dakota	378	1.25	1.61
9	District of Columbia	1205	6.18	2.36	26	Missouri	898	2.79	1.96	43	Tennessee	621	3.96	1.51
10	Florida	644	2.74	1.53	27	Montana	662	0.79	1.29	44	Texas	666	1.38	1.05
11	Georgia	641	3.87	1.43	28	Nebraska	702	1.95	1.42	45	Utah	950	0.71	2.01
12	Hawaii	779	2.08	2.38	29	Nevada	704	1.35	1.34	46	Vermont	26	0.02	0.14
13	Idaho	42	0.04	0.07	30	New Hampshire	321	3.12	0.64	47	Virginia	559	2.64	1.17
14	Illinois	503	2.24	1.23	31	New Jersey	332	0.96	0.62	48	Washington	130	0.72	0.25
15	Indiana	977	6.01	2.37	32	New Mexico	969	1.83	2.32	49	West Virginia	920	5.84	2.62
16	Iowa	894	3.13	1.84	33	New York	444	1.88	0.66	50	Wisconsin	799	3.01	1.7
17	Kansas	848	2.36	1.93	34	North Carolina	586	3.45	1.33	51	Wyoming	1044	1.69	1.84

From https://www.epa.gov/energy.

models. Prior to simulating the energy system, HOMER defines the emission factors (kg of pollutant emitted divided by the unit of fuel consumed) for each pollutant. Subsequently, it computes the annual emission of that pollutant by multiplying the emission factors by the total annual fuel consumption. Emissions factors for four of the six pollutants: carbon monoxide, unburned hydrocarbons, particulate matter, and nitrogen oxides are directly specified. Using these values and the carbon and sulfur content of the fuel, HOMER estimates the emissions factors for the two-remaining pollutants: carbon dioxide and sulfur dioxide. To achieve these, HOMER uses three primary assumptions following:

- Any carbon in the fuel that does not get emitted as carbon monoxide or unburned hydrocarbons get emitted as carbon dioxide.
- The carbon fraction of the unburned hydrocarbon emission is the same as that of the fuel.
- Any sulfur in the burned fuel that does not get emitted as particulate matter gets emitted as sulfur dioxide.

Eq. (12.1) is generally used in the estimation of the emission.

$$E = A_r \times E_f \times \left(1 - \frac{EF_\eta}{100}\right) \tag{12.1}$$

where E = emissions; A_r = activity rate; E_f = emission factor; and EF_η = overall emission reduction efficiency (%).

12.1.8.8 Results and Discussion

Systems constraints along with input parameters described in Table 12.3 were used in the simulations of the PV battery system to obtain the optimal configuration. Optimal system configuration is obtained by choosing suitable system components, depending on parameters such as: solar irradiance, diesel price, and maximum capacity shortage. The most viable system depends on the total net present cost (TNPC), as well as the hourly performance. This section presents the result obtained from the simulations, both in graphical and tabular forms.

12.1.9 System Configuration

Displayed in Table 12.8 is the optimal system architecture for the selected geopolitical zones, with both CME and EEME. It is worth noting that, during component sizing and optimization, HOMER priorities continuous satisfaction of load. It also makes sure, there is minimum diesel consumption, and the PV array is not oversized. In Table 12.8, for both case of

Table 12.8 System configuration for the six geopolitical zones

City	Gboko		Igbeti		Kabo	
Load type	**EEME**	**CME**	**EEME**	**CME**	**EEME**	**CME**
PV array (kW)	3	3	3	3	3	3
Generator (kW)	2	2	1	2	2	2
Number of batteries	2	3	2	3	2	3
Converter (kW)	2	2	2	2	2	2
Dispatch strategy	LF	CC	CC	CC	LF	CC
	Ihiala		**Abadam**		**Okrika**	
PV array (kW)	3	3	3	3	3	3
Generator (kW)	2	2	1	2	2	2
Number of batteries	3	3	2	3	3	3
Converter (kW)	2	2	2	2	2	2
Dispatch strategy	LF	LF	CC	CC	LF	LF

CC, Cycle charging; *CME*, conventional medical equipment; *EEME*, energy efficient medical equipment; *LF*, load following; *PV*, photovoltaic.

CME and EEME, the PV array size across the sampled locations is the same (3 kW). Except for Gboko and Abadam with a smaller size of diesel generator of 1 kW for EEME loads, all other locations require a 2 kW generator for both EEME and CME loads. For all locations, the number of batteries required with the use of CME is three each, whereas with the use of CME; all locations returned two batteries each except for Ihiala and Okrika with three batteries each. The latter is because of the fact that, Ihiala and Okrika, receives the lowest average solar irradiance. The size of the converter for both categories of medical equipment for all locations is 2 kW.

12.1.10 Economic Analysis

Table 12.9 shows the economic analysis of the optimal configuration of the system in the six geopolitical zones. It gives the breakdown of the initial capital cost (ICC), operating cost, TNPC, and the levelized cost of energy (LCOE). The percentage reduction that accrues with the use of EEME instead of CME is also shown in Table 12.9. With 17% reduction, Igbeti and Abadam had the highest percentage reduction in TNPC and operating cost. Gboko recorded the least percentage difference of 15%. If installed, clinics in Igbeti will have the highest TNPC of $17,611 and $20,948 for EEME and CME, respectively. The initial cost of system installation using CME is the same across all locations that were considered ($15,252),

Table 12.9 Economic analysis of optimal system architecture

City	Gboko			Igbeti			Kabo		
Load type	**EEME**	**CME**	**% Reduction**	**EEME**	**CME**	**% Reduction**	**EEME**	**CME**	**% Reduction**
Initial capital cost	14,983	15,252	2%	14,757	15,252	3%	14,983	15,252	2%
Operating cost	262	628	58%	198	584	66%	213	599	64%
Total net present cost	16,937	19,940	15%	16,238	19,611	17%	16,573	19,724	16%
Levelized cost of energy	0.672	0.585	−15%	0.645	0.575	−12%	0.658	0.579	−14%
	Ihiala			**Abadam**			**Okrika**		
Initial capital cost	15,252	15,252	0%	14,757	15,252	3%	15,252	15,252	0%
Operating cost	290	728	60%	200	585	66%	316	763	59%
Total net present cost	17,414	20,690	16%	16,249	19,621	17%	17,611	20,948	16%
Levelized cost of energy	0.691	0.607	−14%	0.645	0.576	−12%	0.699	0.615	−14%

CME, Conventional medical equipment; *EEME*, energy efficient medical equipment.

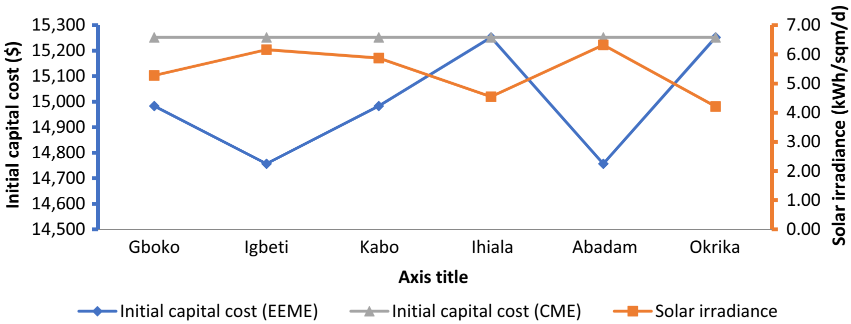
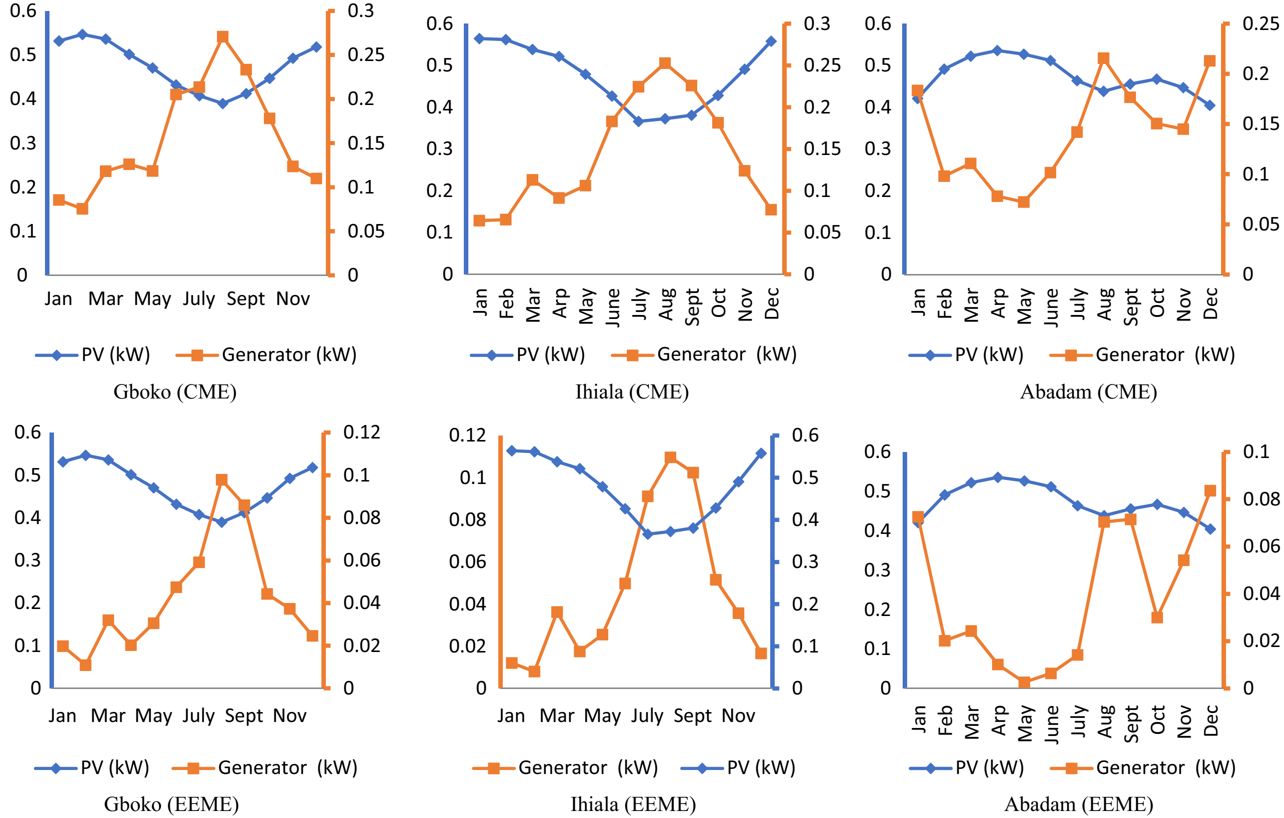


Figure 12.7 Relationship between initial capital cost for both energy efficient medical equipment (EEME) and conventional medical equipment (CME) and solar irradiance.

whereas that of the EEME varies directly. In the solar irradiance as could be seen in Fig. 12.7. At higher solar irradiance, the ICC is lower and high at lower, solar irradiance. The LCOE was higher for PV—DG battery system with EEME loads and lower for CME. In all scenarios, all capital cost for EEME and CME are close with just a maximum of 3% difference.

Fig. 12.8 shows the monthly contributions of the PV and diesel generator for the six locations across the six geopolitical zones. The contribution pattern of the PV array follows the same pattern for both types of loads across all sites except Igbeti. Generally, PV contribution falls to its lowest in the month of August, except in Igbeti, which experiences its lowest in the months of April and August. It can also be observed that, the diesel generator contribution peaks when the PV contribution is at its lowest across all locations.

Table 12.10 shows the breakdown of annual electricity production across all sites. Okrika recorded the highest annual electricity production of 4611 kWh/years and 5468 kWh/years, for EEME and CME, respectively. With the use of EEME, Okrika has the highest electricity production of 680 kWh/years, whereas Gboko produce the highest excess electricity of 1360 kWh/years with the use of CME. Unmet load and shortage capacity is mostly low and negligible as compared to the load served. The highest renewable energy fraction of 91.8% and 73.2% can be observed in Kabo. This is expected because it receives the highest solar irradiance out of all the locations considered. Okrika has the lowest renewable faction of 86.3% and 71% for EEME and CME, respectively. This location receives the lowest average solar irradiance. Across all locations, the value of the renewable fraction for EEME is higher that, CME with the highest increment of 28% in Kabo and least in Ihiala (21%).


PV (kW)
Generator (kW)
Gboko (CME)
Ihiala (CME)
Abadam (CME)
Gboko (EEME)
Ihiala (EEME)
Abadam (EEME)
Jan Feb Mar Arp May June July Aug Sept Oct Nov Dec

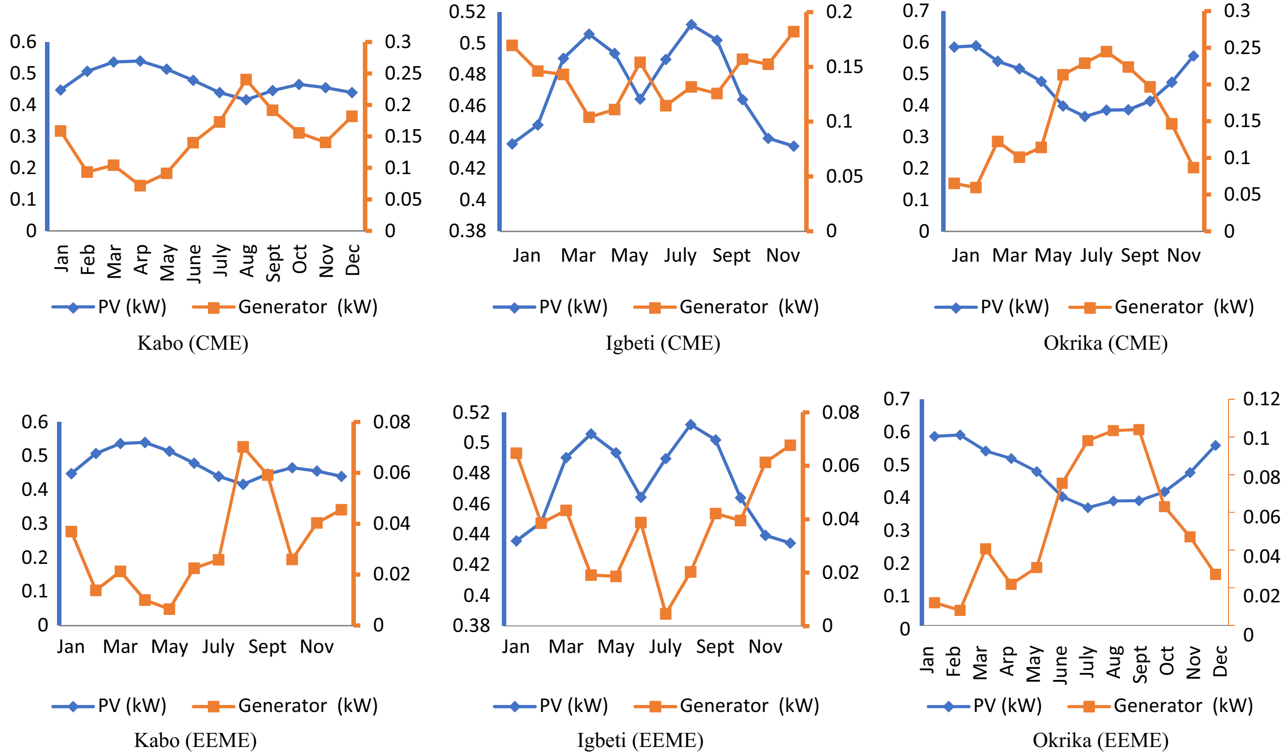


Figure 12.8 Monthly average electricity production. *CME*, Conventional medical equipment; *EEME*, energy efficient medical equipment; *PV*, photovoltaic.

Table 12.10 Energy production for optimal system

City	Gboko		Igbeti		Kabo	
Load type	**EEME**	**CME**	**EEME**	**CME**	**EEME**	**CME**
Annual electricity Production (kWh/year)	4522	4148	4482	5383	4425	5425
Excess electricity (kWh/year)	613	1360	545	36	518	53.6
Unmet load (kWh/year)	0.00000775	2.2	0.0427	0.000012	0.00000696	0.000011
Shortage capacity (kWh/year)	0.0185	0	1.33	0	0	0
Renewable fraction	0.889	0.702	0.901	0.729	0.918	0.732
	Ihiala		**Abadam**		**Okrika**	
Annual electricity production (kWh/year)	4556	5399	4485	5383	4611	5468
Excess electricity (kWh/year)	626	147	548	34.1	680	218
Unmet load kWh/year	0.00000771	0.49	1.24	0.0000128	0.00000753	0.598
Shortage capacity (kWh/year)	0.108	3.27	2.95	0	0.118	3.97
Renewable fraction	0.879	0.726	0.9	0.729	0.863	0.71

CME, Conventional medical equipment; *EEME*, energy efficient medical equipment.

12.1.11 Emission Results

The environmental benefit analysis of the proposed hybrid photovoltaic system is first considered in terms of the amount of fossil fuel consumed by the generator. This information is then employed to estimate the quantity of emissions produced by the generator. The emissions by the generator are assumed to be the quantity of emissions avoided by the solar PV system. As indicated in (U. S, 1998), various values of CO_2 emission factors are reported in the literature; 3.2, 3.15, and 3.0 kg CO_2/L of diesel, respectively. This work adopted an emission factor of 2.66 kg CO_2/L of diesel to evaluate the quantity of carbon dioxide. All other factors used by homer is given in Appendices A.1. All emissions are estimated by HOMER software and results are given in Table 12.11. Emissions are directly proportional to the quantity of diesel consumed by the generator. The diesel consumption will depend on the annual running hours, total load severed annually, which also depends on whether the solar resource can adequately meet the load or not. Table 12.12 shows the diesel consumption reduction that is achievable with the use of EEME as against CME. Fig. 12.9A and B show the relationship between CO_2 emission and diesel consumption for both CME and EEME. Ihiala consumed the highest liter of fuel and consequently the highest level of emission, whereas as expected, Kabo had the least fuel consumption as well as emission. There was a 72% reduction in Kabo, 74% in Igbeti and Abadam, whereas Okrika recorded the least reduction of 64%. The relationship between the running hours of diesel generator for both load types (EEME and CME) is shown in Fig. 12.10. The RHC located in Okrika has the highest diesel generator running hours for both equipment types, whereas Abadam recorded the least diesel generator running hour.

12.1.12 Conclusion

Various aspects of DSM are very crucial in ensuring that, energy resources available to a country is efficiently used. So many benefits of DSM include: provision of relief to power grids and generation plants, mitigation of emergencies in electrical systems, minimization of blackouts to increase reliability of energy systems, reduction in energy prices, mitigation of emergencies in electrical systems, to reduce or partially eliminate investments in generation of energy, reduction of dependency on expensive imports, transmission and distribution networks, and reduction of environmental emissions.

Table 12.11 Emission for both conventional medical equipment (CME) and energy efficient medical equipment (EEME)

City	**Gboko**			**Igbeti**			**Kabo**		
Load type	**EEME**	**CME**	**% Reduction**	**EEME**	**CME**	**% Reduction**	**EEME**	**CME**	**% Reduction**
Carbon dioxide	488	1391	65%	328	1278	74%	364	1317	72%
Carbon monoxide	1.2	3.43	65%	0.81	3.16	74%	0.899	3.25	72%
Unburned hydrocarbons	0.133	0.38	65%	0.0898	0.35	74%	0.0996	0.36	72%
Particulate matter	0.0908	0.259	65%	0.0611	0.238	74%	0.0678	0.245	72%
Sulfur dioxide	0.98	2.79	65%	0.659	2.57	74%	0.732	2.64	72%
Nitrogen oxides	10.7	30.6	65%	7.23	28.2	74%	8.03	29	72%
	Ihiala			**Abadam**			**Okrika**		
Carbon dioxide	526	1586	67%	332	1281	74%	593	1669	64%
Carbon monoxide	1.3	3.91	67%	0.819	3.16	74%	1.46	4.12	65%
Unburned hydrocarbons	0.144	0.434	67%	0.0908	0.35	74%	0.162	0.456	64%
Particulate matter	0.0979	0.295	67%	0.0618	0.238	74%	0.11	0.311	65%
Sulfur dioxide	1.06	3.19	67%	0.667	2.57	74%	1.19	3.35	64%
Nitrogen oxides	11.6	34.9	67%	7.31	28.2	74%	13.1	36.8	64%

Table 12.12 Diesel fuel consumption analysis

Location	Gboko	Igbeti	Kabo	Ihiala	Abadam	Okrika	Base case
Fuel consumption (EEME)L/yr	185	125	138	200	126	225	20364
Fuel consumption (CME)L/yr	528	485	500	602	486	634	20364
% reduction	65%	74%	72%	67%	74%	65%	0

CME, Conventional medical equipment; *EEME*, energy efficient medical equipment.

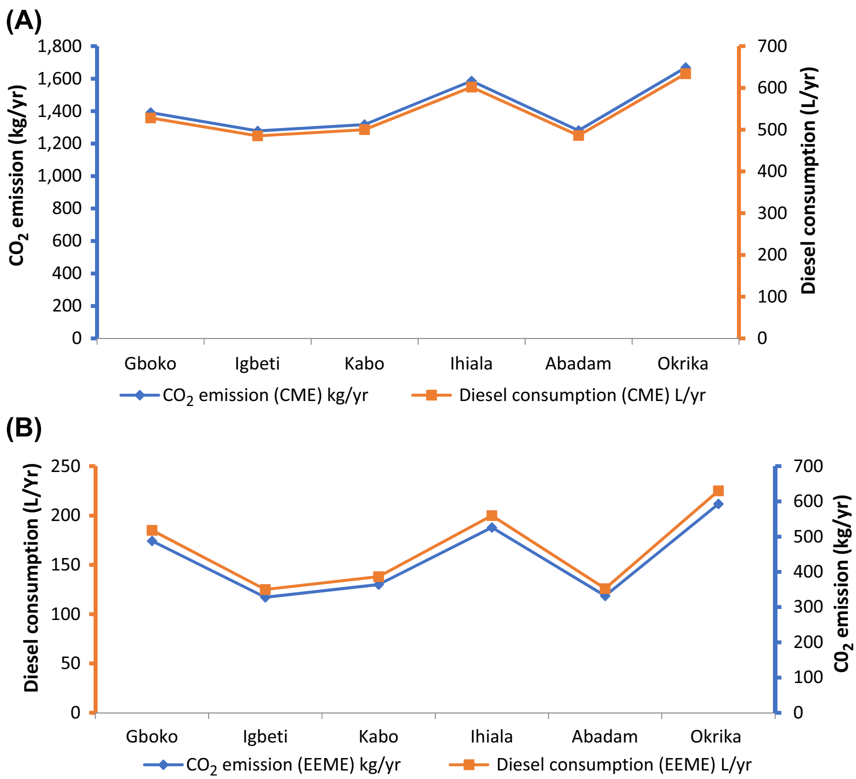


Figure 12.9 (A) The relationship between CO_2 emission and diesel consumption for conventional medical equipment (CME). (B) The relationship between CO_2 emission and diesel consumption for energy efficient medical equipment (EEME).

The technoeconomic and emission comparison of deploying energy efficiency as a DSM tool in sizing alternative energy for a typical health-care center has been presented in this chapter. In conclusion, this study validates the effectiveness of utilizing energy efficient-equipment as compared with

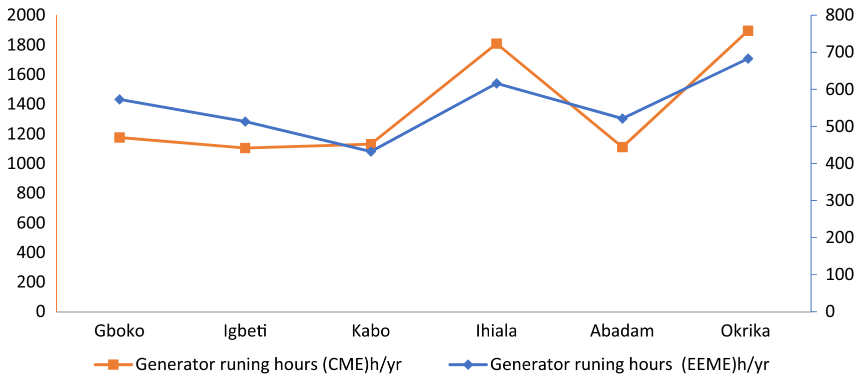


Figure 12.10 Generator running hours. *CME*, conventional medical equipment; *EEME*, energy efficient medical equipment.

conventional ones. It shows that, investments in more energy-efficient medical devices, though at higher costs, has the tendency to reduce the capital investment in hybrid renewable energy system for a rural health clinic, and as such, removes major barrier to the consumption of greener energy systems at lower costs over its life span.

For newly proposed clinics of similar status in rural communities of developing countries like the ones described in this study, a similar load profile is expected as the cautious selection of energy-efficient medical devices and energy conservation practices along with a hybrid PV/generator/battery system architecture would most possibly ensure the lowest NPC without compromising quality and reliability energy services delivery. The application of energy-efficient equipment is seen to increase the renewable energy penetration, across the six geopolitical zones in Nigeria. This in turn reduces the use operational hours of use of captive generators and consequently, the carbon footprint.

In terms of retrofitting, older health centers, the cost of procurement of energy-efficient equipment may initially appear expensive. Conversely, the NPC of the system over its life span makes investments in more energy-efficient devices reduce generator fuel costs considerably over time. Apart from this, cost of offsetting the effect of emission is also an advantage.

It is worth noting that, this model did not fully quantify the initial cost and maintenance costs of procuring newer, and more energy efficient medical equipment but only the approximate estimate. In future study, a search light can be beamed to explore these costs, the effect of inflation, carbon tax, as well as the variation in diesel fuel price, and solar irradiance so as to create a robust cost-benefit and environmental assessment model. Furthermore, health centers with constrained budgets, and facing challenges, choosing between investing in hybrid energy system or efficient medical devices, models that fully consider both supply and demand side, management options can help generate a precise assessment of costs and benefits, based on the options available locally.

APPENDICES

A.1 Emission Factors

Carbon monoxide	6.5	g/L of fuel
Unburned hydrocarbons	0.72	g/L of fuel
Particulate matter	0.49	g/L of fuel
Portion of fuel sulfur converted to particulate matter	2.2	%
Nitrogen oxides	58	g/L of fuel

A.2 Destination of Fuel Carbon

Carbon dioxide	99.5%
Carbon monoxide	0.4
Unburned carbon	0.1
Total	100

A.3 Conversion Factor (Abolarin et al., 2013)

1 kW = 100 W
12,000 kWh = 1 tonne of oil equivalent
1 L = 2.68 × 10−3 tonnes of CO_2
1 kWh = 1.25 × 10−3 tonnes of CO_2

REFERENCES

Abolarin, S.M., Gbadegesin, A.O., Shitta, M.B., Yussuff, A., Eguma, C.A., Ehwerhemuepha, L., Adegbenro, O., 2013. A collective approach to reducing carbon dioxide emission: a case study of four University of Lagos Halls of residence. Energy Build. 61, 318−322.

Ahenkorah, A.K.O., Capacity Building in Energy Efficiency and Renewable Energy Regulation and Policy-Making in Africa, Ghana − Energy Efficiency Country Profile.

Akinbulire, T.O., Oluseyi, P.O., Babatunde, O.M., 2014. Techno-economic and environmental evaluation of demand side management techniques for rural electrification in Ibadan, Nigeria. International Journal of Energy and Environmental Engineering 5 (4), 375−385.

Al-Karaghouli, A., Kazmerski, L., 2010. Optimization and life cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software. Solar Energy 84, 710–714.

Bajpai, P., Dash, V., 2012. Hybrid renewable energy systems for power generation in stand-alone applications a review. Renewable & Sustainable Energy Reviews 16 (1), 2926–2939.

Bekele, G., Palm, B., 2010. Feasibility study for a stand-alone-solar wind based hybrid energy system for application in Ethopia. Applied Energy 87, 487–495.

Benghanem, M., 2011. Optimization of tilt angle for solar panel: case study for Madinah, Saudi-Arabia. Applied Energy 88 (4), 1427–1433.

Besarati, S.M., Padilla, R.V., Goswami, D.Y., Stefamakos, E., 2013. The potential of harnessing solar radiation in Iran: generating solar maps and viability study of PV power plants. Renewable Energy 53, 193–199.

Course Module, Energy Efficiency and Demand Side Management. University of Warwick, REEEP.

Demand-Side Management Sustainable Energy Regulation and Policymaking for Africa.

Dihrab, S.S., Sopian, K., 2010. Electricity generation of hybrid PV/wind systems in Iraq. Renewable Energy 35 (6), 1303–1307.

Dongellini, M., Marinosci, C., Morini, G.C., 2014. Energy audit of an industrial site: a case Study. Energy Procedia 45, 424–443.

https://www.epa.gov/energy.

Gellings, C.W., Parmenter, K.E., Energy Efficiency and Renewable Energy Handbook.

Haney, A.B., Tooraj, J., Platchkov, L.M., Pollitt, M.G., 2010. Demand-Side Management Strategies and the Residential Sector: Lessons from International Experience.

Hassan, K., Faitma, K., Mahmood, H.S., 2011. Feasibility of hybrid power generation over wind and solar standalone system. In: 5th Power Engineering and Optimization Conference (PENCO), 7, pp. 6–7.

Hiendro, A., Kumianto, R., Rajagukguk, M., Simarajuntak, Y.M., 2013. Techno-economic analysis of photovoltaic/wind hybrid system for onshore remote area in Indonesia. Energy 59, 652–657.

HOMER Energy LLC: Hybrid Optimization Model for Electric Renewable, 2009. http://www.homerenergy.com/.

https://image.slidesharecdn.com/presentazionecordoba-160319093812/95/residential-demand-response-operation-in-a-microgrid-8–638.jpg?cb=1458380410.

Jimenez, T., Olson, K., 1999. Renewable Energy for Rural Health Clinics.

Lal, S., Raturi, A., 2012. Techno-economic analysis of a hybrid mini-grid system for Fiji Islands. International Journal of Energy and Environmental Engineering 3, 10.

Lamba, M.K., Sanghi, A., 2015. Energy audit on academic building. International Journal of Engineering Research and General Science 3 (4).

Martel, C.M., May 2000. Lessons in MRP Can Help Control Deregulated Energy Costs, 25 (5), p. 14.

Nandi, S.K., Ghosh, H.R., 2010. Prospect of wind-PV battery hybrid power system as an alternative to grid extension in Bangledash. Energy 35, 3040–3047.

Nwulu, N.I., Agboola, O.P., 2011. Utilizing renewable energy resources to solve Nigeria's electricity generation problem. International Journal of Thermal and Environmental Engineering 3 (1), 15–20.

Ohumakin, O.S., 2010. Energy utilization and renewable sources in Nigeria. Journal of Engineering and Applied Sciences 5 (2), 171–177.

Olatomiwa, L., Mekhilef, S., Huda, A., 2014. Optimal sizing of hybrid energy system for a remote telecom tower: a case study in Nigeria. In: IEEE Conference on Energy Conversion (CENCON), pp. 243–247.

Olatomiwa, L., Mekhilef, S., Ohunakin, O.S., 2016. Hybrid renewable power supply for rural health clinics (RHC) in six geo-political zones of Nigeria. Sustainable Energy Technologies and Assessments 13, 1–12.

Oluseyi, P.O., Babatunde, O.M., Babatunde, O.A., 2016. Assessment of energy consumption and carbon footprint from the hotel sector within Lagos, Nigeria. Energy & Buildings 118, 106–113. http://dx.doi.org/10.1016/j.enbuild.2016.02.046.

Palensky, P., Dietrich, D., 2011. Demand side management: demand response, intelligent energy systems, and smart loads. IEEE Transactions on Industrial Informatics 7 (3), 381–388.

Pitis (Femco), C.D., Livingstone (Anglo Gold Mining Motors), A., 2004. Energy efficient fans in underground auxiliary ventilation systems. In: Paper Presented at ICUE Conference (Cape Town, South Africa).

http://www.poweringhealth.org/index.php/topics/technology/energyefficiency.

Rahman, S., Al-Hadhrami, M.L., 2010. Study of a solar PV-diesel battery hybrid power system for a remotely located population near Rafha Saudi-Arabia. Energy 36, 4986–4995.

Saini, S., The Growing Need of Demand-Side Management, Energy Program, Sanc oGlobals

Sameeullah, M., Kumar, J., Lal, K., Chander, J., 2014. Energy audit: a case study of hostel building. International Journal of Research in Management, Science & Technology 2 (2).

Singh, H., Singh, M., Singh, G., 2012. Energy audit: a case study to reduce lighting cost. Asian Journal of Computer Science and Information Technology 2 (5), 119–122.

Srinath, G., Uday Kumar, N., 2014. Energy audit as a tool for improving system efficiency in industrial sector. International Journal of Engineering Research and Applications 4 (6), 6–11. ISSN: 2248-9622.

Van Alphen, K., Wilfred, G.J.H.M., Herkert, M.P., 2007. Renewable energy technologies in the Maldives – determining the potential. Renewable & Sustainable Energy Reviews 11, 1650–1674.

http://www.who.int/hia/green_economy/modern-energy-services/en/.

Zhou, W., Lou, C., Li, Z., Lu, L., Yang, H., 2010. Current status of research on optimum sizing of stand-alone hybrid solar-wind power generation systems. Applied Energy 87, 380–389.

This page intentionally left blank

INDEX

"*Note:* Page numbers followed by "f" indicate figures and "t" indicate tables."

B

C

D

E

I

K

L

R

S

T

U

V

This page intentionally left blank

Environmental Carbon Footprints

Industrial Case Studies

Case studies are the most flexible of all research designs, allowing the researcher to retain the holistic characteristics of real-life events, while investigating empirical events. *Environmental Carbon Footprints: Industrial Case Studies* provides a wide range of industrial case studies beginning with the textiles, energy systems, and conventional and biofuels.

Each footprint case study is associated with the background information, scientific consensus and reason behind its invention, methodological framework, assessment checklist, calculation tool/technique, applications, and challenges and limitations. More importantly, application of each indicator/framework in various industrial sectors and their associated challenges, futuristic views are worthwhile to learn.

Key Features

- Includes case studies from a various industries such as textiles, energy systems, and conventional and biofuels.
- Provides calculation tool/technique, applications, and challenges and limitations for determining carbon footprints on industry by industry bases.
- Each case study provides the background information, scientific consensus, and reason behind its invention.

Dr. Subramanian Senthilkannan Muthu is currently working for Lidl Hong Kong as a Sustainability Manager, based out of Hong Kong. He has gained his PhD from The Hong Kong Polytechnic University. He is a renowned expert in the areas of Environmental Sustainability in Textiles & Clothing Supply Chain, Product Life Cycle Assessment (LCA) and Product Carbon Footprint Assessment (PCF) in various industrial sectors. He has published more than 75 research publications, written numerous book chapters and authored/edited multiple books in the areas of Carbon Footprint, Recycling, Environmental Assessment, Environmental Sustainability, etc. (over 40 books to his credit)

ENGINEERING

ISBN 978-0-12-812849-7

ELSEVIER

Butterworth-Heinemann
An imprint of Elsevier
elsevier.com/books-and-journals