IntechOpen

Low Carbon Transition

Technical, Economic and Policy Assessment

Edited by Valter Silva,
Matthew Hall and Inês Azevedo

LOW CARBON TRANSITION - TECHNICAL, ECONOMIC AND POLICY ASSESSMENT

Edited by **Valter Silva, Matthew Hall**
and **Inês Azevedo**

Low Carbon Transition - Technical, Economic and Policy Assessment
http://dx.doi.org/10.5772/intechopen.70981
Edited by Valter Silva, Matthew Hall and Inês Azevedo

Contributors

Raúl Andrés Molina Benavides, Hugo Sánchez Guerrero, Daniel Mateus, Esam Elsarrag, Yousef Alhorr, Yemane Weldu, Anbumozhi Venkatachalam, Erdem Cuce, Pinar Mert Cuce, Ahmet Besir, Chukwuemeka Ikedi, Eduardo Mirko Turdera, Marli Garcia, Warangkana Jutidamrongphan, Luke Makarichi, Samnang Tim, Valter Silva, João Cardoso, Daniela Eusébio

© The Editor(s) and the Author(s) 2018
The rights of the editor(s) and the author(s) have been asserted in accordance with the Copyright, Designs and Patents Act 1988. All rights to the book as a whole are reserved by INTECHOPEN LIMITED. The book as a whole (compilation) cannot be reproduced, distributed or used for commercial or non-commercial purposes without INTECHOPEN LIMITED's written permission. Enquiries concerning the use of the book should be directed to INTECHOPEN LIMITED rights and permissions department (permissions@intechopen.com).
Violations are liable to prosecution under the governing Copyright Law.

Individual chapters of this publication are distributed under the terms of the Creative Commons Attribution 3.0 Unported License which permits commercial use, distribution and reproduction of the individual chapters, provided the original author(s) and source publication are appropriately acknowledged. If so indicated, certain images may not be included under the Creative Commons license. In such cases users will need to obtain permission from the license holder to reproduce the material. More details and guidelines concerning content reuse and adaptation can be foundat http://www.intechopen.com/copyright-policy.html.

Notice

Statements and opinions expressed in the chapters are these of the individual contributors and not necessarily those of the editors or publisher. No responsibility is accepted for the accuracy of information contained in the published chapters. The publisher assumes no responsibility for any damage or injury to persons or property arising out of the use of any materials, instructions, methods or ideas contained in the book.

First published in London, United Kingdom, 2018 by IntechOpen
eBook (PDF) Published by IntechOpen, 2019
IntechOpen is the global imprint of INTECHOPEN LIMITED, registered in England and Wales, registration number: 11086078, The Shard, 25th floor, 32 London Bridge Street
London, SE19SG – United Kingdom
Printed in Croatia

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

Additional hard and PDF copies can be obtained from orders@intechopen.com

Low Carbon Transition - Technical, Economic and Policy Assessment
Edited by Valter Silva, Matthew Hall and Inês Azevedo

p. cm.

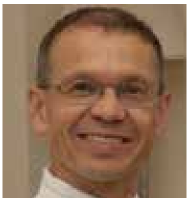
Print ISBN 978-1-78923-969-0

Online ISBN 978-1-78923-970-6

eBook (PDF) ISBN 978-1-83881-506-6

Meet the editors

Valter Silva, BSc, Ph.D., is presently working as a Senior Researcher in the Polytechnic Institute of Portalegre, Portugal. He undertook his Ph.D. in Chemical Engineering from the Porto University in 2009. He obtained a specialist degree in numerical simulation in Engineering by ANSYS and the Polytechnic University of Madrid in 2015. Dr. Silva has published more than 70 works in international peer-review journals (large majority related to low carbon technologies) and conferences. He wrote 9 book chapters and is editing 2 books. His h-index is 17 with over 700 citations. He is leading several international partnerships regarding low carbon technologies. He won several projects and grants in the low carbon field with a total funding of 800 k€. Dr. Silva has been using his expertise in this field to conduct several successful projects with portuguese companies.



Prof. Matthew J. Hall is a faculty member in the Thermal Fluids Systems program in the Department of Mechanical Engineering at the University of Texas at Austin. He holds the Louis T. Yule Fellowship in Engineering. His research focus is engine combustion processes with an emphasis on optical measurement techniques, engine sensor development and waste heat recovery. He has served on the College of Engineering faculty since 1991 and has published more than 100 technical articles. He is a Fellow of the Society of Automotive Engineers, and is an Associate Editor for the Society of Automotive Engineers' International Journal of Engines.

Dr. Hall received B.S. and M.S. degrees in Mechanical Engineering from the University of Wisconsin, and his Ph.D. in Mechanical and Aerospace Engineering from Princeton University. He held post-doctoral positions at Sandia National Laboratories' Combustion Research Facility and the University of California-Berkeley.

Inês M.L. Azevedo is Full Professor in the Department of Engineering and Public Policy at Carnegie Mellon University, and the PI and the co-Director for the Climate and Energy Decision Making Center. Her research focuses on how to transition to a sustainable, low carbon, affordable and equitable energy system. She has participated as an author and committee member in several U.S. National Academies reports. Prof. Azevedo has received the World Economic Forum's "*Young Scientists under 40*" award, the C3E Research Award for Women in Energy, and she was selected by the Federation of American Scientists as one of the key speakers for their 70th anniversary symposium.

Contents

Preface

The policymakers' will and decision to support low carbon technologies still remains the key factor in determining the pace of deployment of this field. Some key issues that will shape the continuous rise of low carbon technologies over the next years are: the degree of international agreement regarding the standardization of practices and guidelines to ensure technology and market conditions; new additional measures to support low carbon technologies beyond the carbon pricing; the role of emerging countries in adopting greener solutions; and the implementation of effective lean procedures to target more ambitious energy saving gains.

Throughout this book, low carbon transition is viewed from several different angles with studies approaching effective technologies to mitigate pollutant emissions and efficient energy strategies but also promoting technical, economic, policy-making and environmental assessment of implementing low carbon solutions. This book presents not only a theoretical overview of the different approaches but also contains material that covers practical analysis applied to several real cases.

This book provides graduate students, teachers, researchers, and other professionals, who are interested in low carbon technologies with a good basis of theoretical knowledge and valuable insights into practical case studies and reports.

The book includes seven chapters from several researchers and institutions around the world. I would like to express my most sincere gratitude to all the contributors for sharing their work and expertise in this book.

I owe a debt of gratitude to Ms. Danijela Sakic for her outstanding support and help in bringing out the book in the present form.

I am also indebted to my research team, Mr. João Cardoso, and Ms. Daniela Eusébio and to my co-editors, Prof. Matthew Hall and Prof. Inês Azevedo for their efforts in all the book stages and valuable suggestions during the review process.

Finally, my special thanks to the Polytechnic Institute of Portalegre (my institution) and IntechOpen Science team for their concern and valuable support to make this book possible.

Dr. Valter Silva
Polytechnic Institute of Portalegre, Portugal

Matthew Hall
University of Texas at Austin, USA

Ines Azevedo
Carnegie Mellon University, Pittsburgh, USA

Section 1

Introduction

Chapter 1

Introductory Chapter: Low Carbon Economy. An Overview

João Cardoso, Valter Bruno Reis e Silva and
Daniela Eusébio

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.80920

1. Introduction

In the broad spectrum of the feasible decarbonization pathways, the challenge for political and economic decision-makers is to weigh uncertain impact from different technologies. This is not an easy task, and most countries are trying to undertake common global policies such as the Paris Agreement in 2015. Beyond global actions, specific local actions adapted to different national scenarios are of utmost importance.

Climate change is one of greatest environmental, social, and economic threats of our time. According to the Intergovernmental Panel on Climate Change (IPCC), greenhouse gas emissions (GGE) have increased since the preindustrial era and are now the highest in history [1]. The concentration of carbon dioxide in the atmosphere is now 1.5 times higher than the preindustrial era. As a result, earth's average surface temperature has increased by around 0.6°C from the beginning of the twentieth century and is expected to reach 1°C by 2035 [2]. Current projections point that if no additional mitigation efforts are implemented, the estimated warming in 2100 will be in the range between 2.5 and 7.8°C (when compared with the preindustrial levels). According to the scientific community, consequences of temperatures at or above 4°C include significant species extinction, extreme weather events, enormous risks to global and regional food security, consequential constraints on common human activities, and increased likelihood of triggering tipping points and limited potential for adaptation in some cases.

2. Leading technologies

Beyond these critical and most likely events, the climate changes pose a set of adverse conditions and risks to businesses coming from supply chain disruptions due to unexpected weather phenomena and because consumers demand a serious commitment from brands in the preservation and sustainability of the environment. Simultaneously, this low carbon transition era could be a silver bullet for companies leading the new trends that will pave the future energy paths and solutions.

A first measure to guide the companies in this transition was to put a price in an externality, such as carbon. This would help to level the costs for new low carbon solutions and favor the capital injection in innovation and scale-up activities. Irrespective to the total success of this measure, the truth is that a price for carbon was and still is an important policy action despite the deregulated field of low carbon technologies. Additional incentive measures should go through a more effective coordination between countries and intra-countries, the agreement of renewable electricity standards, and other financial actions as tax credits and cash grant.

There is a set of relevant low carbon technologies, but it seems the front-runners are the LEDs, solar PV, onshore wind, and hybrid and electric vehicles [3]. Bioenergy seems to be going through a transitional phase with strong oscillations derived from changing political policies [4]. In fact, the pace of these technologies depends on how they shape their performance and cost but also on the regulatory measures from national and international governments and organizations.

While the LED technology seems to target a maturation state with the abrupt fall of the incandescent light bulbs, the solar PV and onshore wind technologies still fight to achieve a total consolidation in the market. An ambiguous behavior is expected regarding these technologies; while the emerging countries looking for deployment in the renewable energy field usually find in the solar PV and onshore wind the most adequate solutions, the major governments start to cut subsidies threatening large advances in the installed capacity. With the recent ripple effect of the VW scandal and consequent stricter rules regarding emissions, the emergence of hybrid and electric vehicles seems to be an undeniable reality. Despite the many hurdles that characterize the success of this kind of vehicles, several policy measures are expected to ease the deployment of this technology with tax exemptions, subsidies, accessible parking, and significant, logistical, and infrastructure improvements. The bioenergy sector seems to lose its strength in the recent times due to changing policies, the absence of a regulated market for biomass pricing, and the lack of standardized pretreatment procedures that are able to provide a consistent product [5]. Furthermore, some of the technologies related to biomass conversion are still characterized by obsolete procedures regarding energy efficiency [6].

3. Policy and conclusions

It is not expected in the next few years that major technological breakthroughs and energy efficiency measures can assume a key role to ensure net economic benefits with improved environmental sustainability procedures and reduced costs for the stakeholders. However, the key players seem a bit wary to accept this challenge mainly because this requires upfront investments that will be only recovered with time and because many of the actions to accomplish significant saves are intimately related with long-term behavioral changes by the consumers. Once again, the adopted policies by the governments will decide the success of implementing effective energy efficiency actions by defining the consumer acceptance and the chances to get successful business models in large scales.

The last years can be seen as the watershed era for the low carbon economy. This implies that the main stakeholders should give some thoughts on the way to pave our future by balancing the economic prosperity without endangering the future generations.

Author details

João Cardoso, Valter Bruno Reis e Silva* and Daniela Eusébio

*Address all correspondence to: valter.silva@ipportalegre.pt

C3i – Interdisciplinary Centre for Research and Innovation, Polytechnic Institute of Portalegre, Portalegre, Portugal

References

[1] IPCC. In: Team CW, Pachauri RK, Meyer LA, editors. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: Intergovernmental Panel on Climate Change; 2014

[2] Joselin Herbert GM, Unni Krishnan A. Quantifying environmental performance of biomass energy. Renewable and Sustainable Energy Reviews. 2016;**59**:292-308

[3] Kooroshy J, Ibbotson A, Lee B, Bingham D, Simons W. The Low Carbon Economy GS SUSTAIN Equity Investor's Guide to a Low Carbon World. New York: Goldman Sachs; 2015-25. 2015

[4] Ramos A, Monteiro E, Silva VB, Rouboa A. Co-gasification and recent developments on waste-to-energy conversion: A review. Renewable and Sustainable Energy Reviews. 2018;**81**:380-398

[5] Couto N, Silva VB, Rouboa A. Assessment on steam gasification of municipal solid waste against biomass substrates. Energy Conversion and Management. 2016;**124**:92-103

[6] Silva V, Couto N, Eusébio D, Rouboa A, Brito P, Cardoso J, et al. Multi-stage optimization in a pilot scale gasification plant. International Journal of Hydrogen Energy. 2017;**42**:23878

Section 2

Green Technology Solutions

QGreen Low-Carbon Technology: Cooling Greenhouses and Barns Using Geothermal Energy and Seawater Bittern Desiccant

Esam Elsarrag and Yousef Alhorr

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.74921

Abstract

In hot-humid climates, cooling greenhouses and barns are needed to protect crops from extremely high temperature and to ensure high-yielding dairy cows. In Qatar, outside air temperature exceeds 46°C during summer, and the wet-bulb temperature can exceed 30°C which makes greenhouses and barns unworkable during this season. This study provides theoretical and experimental data for cooling greenhouses and barns using highly efficient and low-carbon technology (QGreen). QGreen uses groundwater (geothermal) for indirect-direct evaporative cooling coupled with desiccant dehumidification. The desiccant used is seawater bittern which is a by-product of the desalination process. A desiccant indirect-direct evaporative cooling panel system is designed and analyzed. The results show that the use of groundwater will enhance the efficiency and reduce the wet-bulb temperature dramatically. As a result, the efficiency of the overall cooling system is enhanced by more than 50% compared to the direct evaporative cooling efficiency that was recorded.

Keywords: desiccant cooling, greenhouse, barns, seawater, CO_2 emissions, brine

1. Introduction

The Gulf Region can be characterized by an extreme set of climatic conditions which are identified in the literature [1]. Extreme climatic conditions impose a heavy reliance on cooling, mostly electricity-based, and thus a strong and structural dependency of a high-energy resource. In addition to the dry-bulb temperature and solar radiation, the humidity is high in summer which raises the cooling challenges. The average hourly outdoor web-bulb temperature for Doha city is shown in **Figure 1**. Consequently, greenhouses in arid conditions suffer to produce crops during summer months, and dairy cow milk production is also impacted. Maintaining reasonable temperature and humidity levels for both greenhouses and barns became a vital challenge that meets these industries in the region. Plant dehydration and loss occurs during the hot and dry summer months and winter heating months. Serious problems occur when the humidity in the greenhouse and propagation environments is low. Plants will suffer and typically slow or halt the growing process.

Greenhouses and barns are important for food security in the region. However, they require temperature and humidity control to ensure sustainable crop and milk production. Therefore, energy-efficient cooling solutions are more urgent today.

In hot-dry climates, evaporative cooling is one of the least expensive techniques and most effective active cooling technologies available in favor of greenhouses to lower the supply of air temperature and provide desired indoor climate [2]. Also, convective combined with an evaporative cooling system of the barn microenvironment is normally used when cattle suffer from severe heat stress in hot-dry climates, functioning by the simple physics of transferring surrounding air heat to evaporating water [3].

Evaporative cooling pads made of fibrous material woven together with large gaps in the grooves are added to the air inlets of tunnel-ventilated barns. In this way, the incoming air is pulled through a saturated medium where the conversion of water from a liquid to a vapor phase removes heat energy from the incoming air, which lowers its temperature but increases its relative humidity. Cooling efficiency is about 55–75% for most evaporative cooling pads, but these water-based systems are prone to plugging and algae growth [4].

The fan-pad systems, which are direct evaporative coolers, in greenhouses have been available several decades ago [5], and various aspects are available in the literature studies continuously

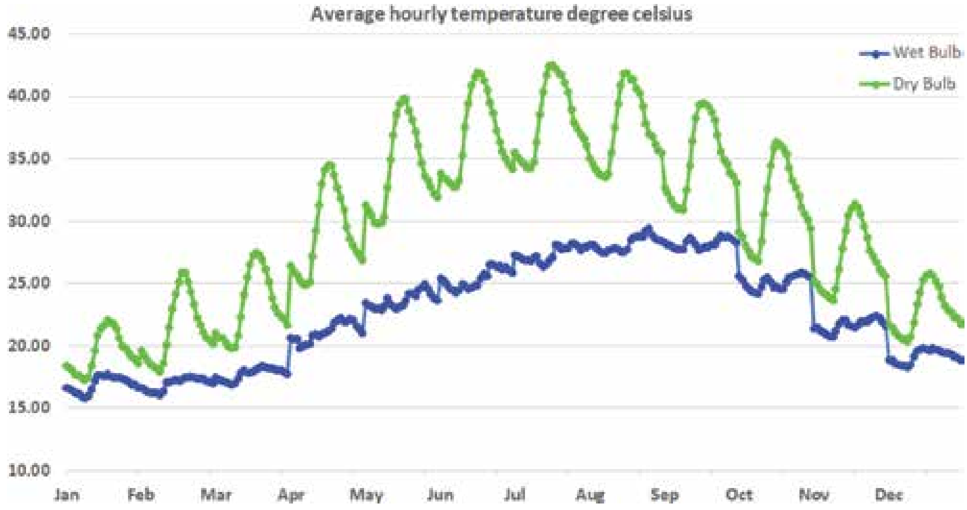


Figure 1. Average hourly temperature (Doha, Qatar).

being conducted to upgrade the performance of these systems. Several adjustments to the fan-pad system were present always to obtain better performance.

Some researchers have changed the traditional fan-pad setup in the greenhouse with mounted evaporative cooling boxes. They compared the performance of the later system with the original one but with four different pad types. They concluded that a better performance for the new system would be obtained in case of non-hermetic greenhouses [6]. Other researchers combined indirect evaporative cooling heat exchanger with cooling pads in one experimental setup while using groundwater as a cooling agent, and the results showed an enhanced cooling efficiency compared with the mere direct evaporative cooling system [7]. For greenhouse applications, an experimental study showed a reasonable performance of evaporative cooling pads operating under humid subtropical climate [8].

An interesting widely used second option of evaporative cooling for greenhouses is the fogging system, which use high-pressure nozzles and water pumps to generate fog droplets. This system has proven to be an effective cooling method for greenhouses in many areas in the world [9]. It provides a spatial distribution of the temperature which creates a high range of desired temperature and humidity in the greenhouse during most months of the year [10].

However, a portion of water does not evaporate or simply fall on the floor making a determination of evaporated fraction essential for evaluating the system performance and cooling efficiency. Investigators have extended the research perimeter of fogging system effectiveness by studying its effect on eggplant crop. They found that its stomatal conductance increased by about 73%, 31% decrease in crop transpiration, did not affect the fruit quality, and enhanced the mean fruit weight and marketable fruits and total fruit number per plant reduced though [11].

Foggers use atomizing nozzles to evaporate water. High-pressure (>200 psi) fogging systems integrating a ring of fogging nozzles to circulation fans disperse very fine droplets of water into the surrounding air. As fog droplets are emitted, they are immediately spread into the fan's air stream where they soon evaporate. Cattle are immediately cooled down as cooled air is blown over their bodies, and they inspire it [4].

A comparison study between fan sprinkler and fogging cooling systems was conducted on ten Holstein cows in Brazil. It was found that there was almost no difference in response of cows to the two systems [12]. An experimental study compared two commercially available systems (Korral Kool and FlipFan) used to cool Holstein dairy cows located in the Kingdom of Saudi Arabia. Both cooling systems were found effective in mitigating the heat, with a preference for the FlipFan system as it consumed less water and electricity and did not require the use of curtains on the shade structure [13].

The common research trend of nurturing the literature with better and more precise results always continues when investigators correlate the ambient temperature with the physiological variables of Holstein cows (with and without cooling) monitored during morning and afternoon milking under five different weather patterns throughout the year by the convective evaporative cooling system. The outcomes showed the usual positive relationship between the variables and the temperature, and the cooled cows exhibited higher milk production [14]. Different heat-load management strategies were compared to obtain the best configuration with the highest milk yield in the subtropical environment [15]. The treatment of open-sided iron-roofed day pen adjacent to dairy plus sprinklers gave the highest milk yield (23.9 L per cow per day).

Misting systems generate larger droplets (15 and 50 μm in diameter) than fogging systems but cool the air by the same principle. A study was designed to investigate the effects of wallowing and misting against no cooling in physiological responses of lactating Murrah buffalo during summer months in Mathura, India. The authors concluded that misting and wallowing were equally effective in a hot and dry period of summer, whereas wallowing was more effective during the hot and humid period of summer. As expected, the results showed higher milk yield in cooled buffaloes compared to the uncooled group during the experimental period [16].

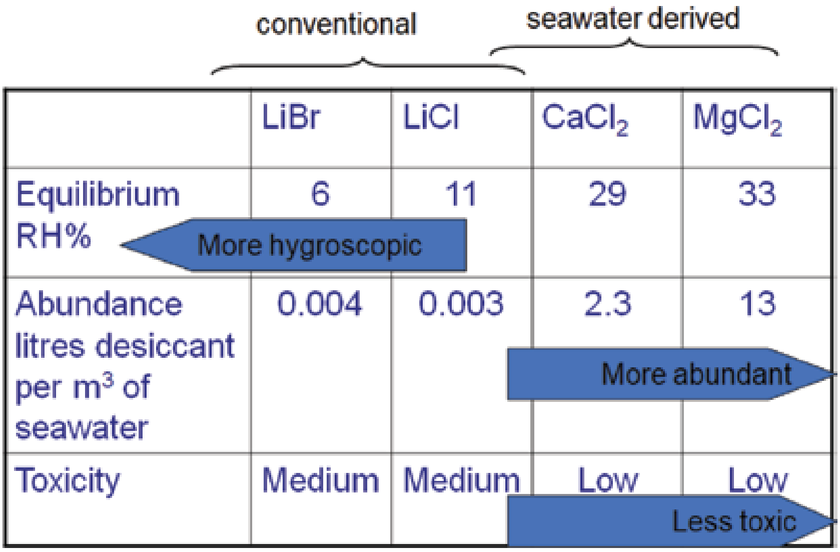
Tunnel ventilation system has air inlets at one end of the barn and exhaust fans at the other. This technology works to enhance convective heat loss by removing excess heat and humidity from the immediate surroundings of animals.

It has been found that using sprinkling in combination with supplemental airflow results in a rapid change in cow body temperature and respiration rate and is superior to either a fan or sprinkling alone [17]. The simplest implementation of this cooling practice, which has been used, is wetting the cattle with manual sprinklers while increasing air velocity with fans directed towards the cows to increase the rate of water evaporation from the skin, and that leads to cooling effect [18].

Low-profile, cross ventilated barns were developed to move air parallel to the body of the cows when they are lying in stalls, while traditional tunnel ventilation moves air parallel to the ridge of the building. A ceiling could be used to limit the size of the cross-sectional area. However, most often, vertical baffles are used to accelerate the air at the cow body level to the desired velocity. Researchers experimentally investigated the effectiveness of tunnel ventilation cooling. They reported a dramatic reduction in heat stress and comfort of lactating dairy cows when compared with traditional cooling technologies under the climatic conditions present in the Southeastern United States [19].

In hot-humid climate, humidity control is essential to achieve sufficient cooling levels for dairy and crop production. Desiccant evaporative cooling systems can provide such needs. There are two types of desiccant systems: liquid and dry. Liquid desiccant systems commonly use two chambers with air/liquid contact surfaces. In the conditioning chamber, the process air is dehumidified as the concentrated desiccant absorbs moisture from the air. In the regeneration chamber, the air is humidified as moisture is transferred from the dilute desiccant to the scavenging air. The desiccant or exhaust air is usually heated to promote desiccant regeneration. A desiccant pump, level controls and heat exchanger are typically included in the system. The heat required for regenerating the desiccant can be supplied by fossil fuel, waste heat and solar energy.

Several liquid desiccants, including aqueous solutions of the organic compounds (e.g. triethylene glycol) and aqueous solutions of inorganic salts (e.g. lithium chloride), have been employed to remove water vapor from the air. The process equipment utilized for liquid–gas contacting is falling film, spray or packed towers.



	conventional		seawater derived	
	LiBr	LiCl	$CaCl_2$	$MgCl_2$
Equilibrium RH%	6	11	29	33
Abundance litres desiccant per m^3 of seawater	0.004	0.003	2.3	13
Toxicity	Medium	Medium	Low	Low

Figure 2. Comparison between conventional salts and seawater bittern.

Several researchers addressed the possibility of using desiccant dehumidification and solar energy [20–24] in conjunction with evaporative cooling systems to be more adaptive with the humid. Their target is to lower the average daily maximum greenhouse temperatures by about 4–6°C compared with the normal evaporative system.

This chapter discusses and analyzes an efficient system to cool greenhouses and barns. The system utilizes desalinated groundwater and seawater bittern to cool and dehumidify the air in a compact panel. The concept applied is the so-called green panel due to its low impact on the environment regarding recycling the desalination brine and also using waste heat or renewables to provide sufficient environmental and control for both plants and cattle.

Figure 2 summarizes the difference between the magnesium-based desiccant and conventional desiccants regarding toxicity, availability, cost and equilibrium humidity.

2. Desiccant dehumidification and regeneration effectiveness

Although today's computers are much faster than a few years ago, some researchers and designers have found the time-consuming finite difference model when predicting the performance of complicated systems over a long period. However, for desiccant cooling, the finite difference model requires the heat and mass transfer coefficients to be experimentally determined. The quick alternative method that can be used to predict the outlet conditions from the dehumidifier and regenerator is the effectiveness method. But this requires effectiveness correlations to be developed [25, 26].

2.1. The dehumidifier effectiveness

The dehumidifier undergoes simultaneous heat and mass transfer. The mass transfer effectiveness can be defined as the ratio of actual change in air humidity ratio across the absorber divided by the maximum possible change [23]:

$$\varepsilon_m = \frac{\omega_{a,i} - \omega_{a,o}}{\omega_{a,i} - \omega_e} \tag{1}$$

The maximum outlet achievable difference in the air is obtained when the air is in equilibrium with the inlet desiccant solution (Pv,o = Ps,i).

In such a case, the air leaves the absorber with the equilibrium humidity ratio ^{e} that would be obtained when the partial pressure of water in the air is equal to the vapor pressure of the inlet desiccant solution, that is, when the driving force is zero [23].

The heat transfer effectiveness can be defined as the ratio the total heat transfer between the air and the solution to the maximum possible heat:

$$\varepsilon_h = \frac{h_{a,i} - h_{a,o}}{h_{a,i} - h_e} \tag{2}$$

where:

$$h_a = C_{P,a}(T_a - T_0) + \omega[C_{P,v}(T_a - T_0) + \lambda] \tag{3}$$

$$h_e = C_{P,a}(T_{s,i} - T_0) + \omega_e[C_{P,v}(T_{s,i} - T_0) + \lambda] \tag{4}$$

The outlet conditions from the dehumidifier can be predicted if both the heat and mass transfer effectiveness are known. It can be done easily by rearranging Eq. (1) and Eq. (2) to calculate $\omega_{a,o}$ and $h_{a,o}$.

$$\omega_{a,o} = \omega_{a,i} - \varepsilon_m(\omega_{a,i} - \omega_e) \tag{5}$$

$$h_{a,o} = h_{a,i} - \varepsilon_h(h_{a,i} - h_e) \tag{6}$$

The two values can be represented in the psychrometric chart to obtain the dehumidified air conditions. But this requires effectiveness correlations for simultaneous heat and mass transfer. A simplified empirical effectiveness correlation can be used. The correlation assumes that the moisture effectiveness changes greatly with air and desiccant flow rates and negligible impact of other inlet parameters [27]:

$$\varepsilon_d = 0.67 \times (m_L)^{0.403} \times (m_a)^{-0.352} \tag{7}$$

However, the enthalpy effectiveness is influenced by both the air and desiccant inlet parameters. The following correlation for enthalpy effectiveness can be used for predictions [27]:

$$\varepsilon_h = 0.015 \times (\Delta h_{ai})^{0.831} \times (m_L)^{0.712} \times (\Delta\omega_{ai})^{-0.537} \times (m_{ai})^{-0.352} \tag{8}$$

2.2. The regenerator effectiveness

The effectiveness of the regenerator is defined as the actual change in the solution vapor pressure across the packed regenerator divided by the maximum possible change [Elsarrag 2008]. The maximum outlet achievable difference is obtained when the outlet desiccant solution is in equilibrium with the inlet air (Pso = Pai). The following definition is used to evaluate the effectiveness of packed bed regenerators [26]:

$$\varepsilon = \frac{P_{si} - P_{so}}{P_{si} - P_{ai}} \tag{9}$$

where

$$P_{si} = f(X_i, T_{si});$$

$$P_{so} = f(X_o, T_{so});$$

$$P_{ai} = f(\omega_{ai}) = f(T_{dbi}, T_{wbi})$$

Accordingly, a simplified correlation obtained by using the results from the present study is [26]

$$\varepsilon_r = 79.12 + 1.21 \times \left(1 - \frac{P_{ai}}{P_{si}}\right) + 4.37 \times \frac{m_a}{m_L} \tag{10}$$

where

$$P_{ai} = \frac{\omega_{ai} P}{(622 + \omega_{ai})} \tag{11}$$

The outlet desiccant temperature can be calculated from the temperature difference ratio [26]:

$$\pi = \frac{T_{si} - T_{so}}{T_{si} - T_{ai}}$$

$$T_{so} = (1 - \pi)T_{si} + \pi T_{ai} \tag{12}$$

Where π can be calculated by the following equation:

$$\pi = 0.5723 - 0.1179 \frac{m_L}{m_a} \tag{13}$$

Another effectiveness correlation including the effect of the solution temperature, flow rate and concentration was found in the literature [28]:

$$\varepsilon_r = 67.4 \times (m_a)^{-0.703} \times (m_L)^{0.762} \times (t_{si})^{-0.909} \times (X)^{2.001} \tag{14}$$

3. Groundwater and ground temperature

Barns and greenhouses require fresh water for domestic use, irrigation and cooling purposes. Groundwater is one of the available options in the region which is considered as brackish water. Most of barns and greenhouses treat the groundwater for such applications. The table below shows a typical test of a borehole water in the North of Qatar.

The ground temperature in the North of Qatar is predicted using the following formula [29]:

$$T_g = T_m - A_s e^{-z\sqrt{\frac{\pi}{365\alpha}}} \cos\left\{\frac{2\pi}{365\left[t - t_o - \frac{z}{2}\sqrt{\frac{365}{\pi\alpha}}\right]}\right\} \tag{15}$$

where;

T_m is the mean annual ground temperature at z = 0m in °C

A_s is the annual amplitude at z = 0m in °C

Z is the ground depth in m

t is year in days

t_0 is the phase constant –day of the year when the lowest ambient air temperature occurs

α is the thermal diffusivity of soil m^2/day

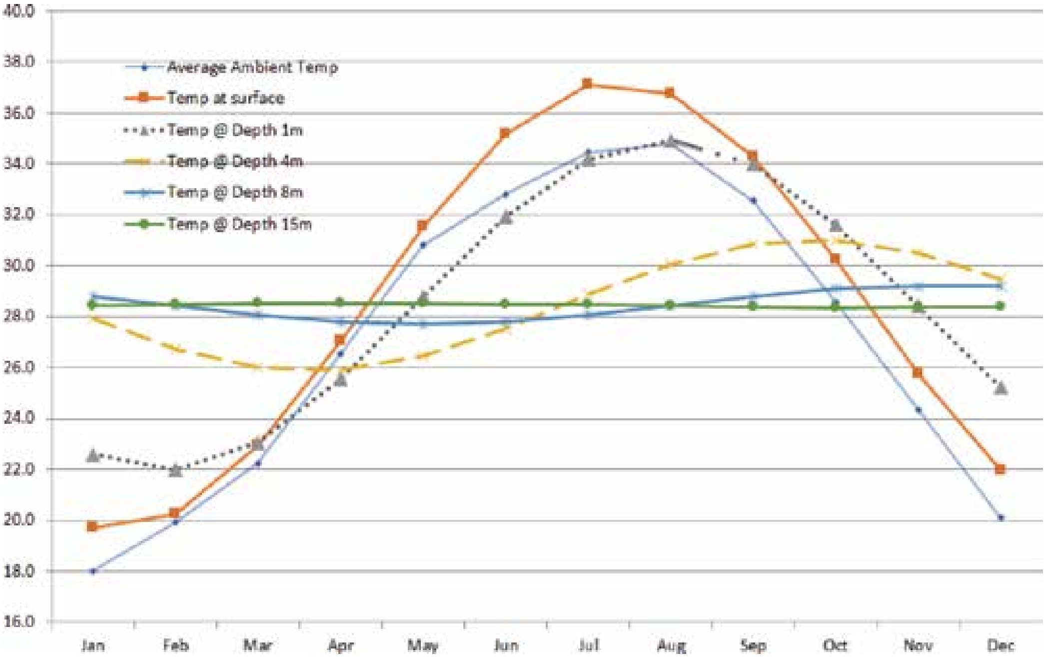


Figure 3. Ground temperature at different depths in Qatar.

Qatar weather data were inserted into Eq. 15 to produce the predicted annual ground temperature profile at different depths as shown in **Figure 3**.

It can be seen that at the surface (z = 0 m) the temperature profile is sinusoidal, but the soil temperature profile becomes more flat when the depth increase. At 15 m depth, the soil temperature is approximately constant, 28.5°C in Qatar, and its value is close to the annual average ambient air temperature.

The above results are very encouraging and provide clear guidelines about the water quality and thermal energy to utilize the groundwater for irrigation and cooling applications.

As mentioned above, maintaining a wet-bulb temperature 24–27°C can support the corp and dairy industry. The wet-bulb temperature of the ambient air can be controlled by recovering the geothermal energy by indirect evaporative cooling. In a humid climate, more control can be achieved by using desiccant dehumidification (**Table 1**).

Tests performed	**Results obtained**	**WHO/EPA/EU Guidelines**
pH Value @25°C	7.86	6.5–8.5*
Electrical conductivity @25°C (μS/cm)	8620	Max 1000*
Total dissolved solids (TDS) (mg/l)	4469	Max 500
Total suspended solids (TSS) (mg/l)	78	No guideline
Total alkalinity ($CaCO_3$) (mg/l)	202	No guideline
Carbonate (CO_3) (mg/l)	<1	No guideline
Bicarbonate (HCO3) (mg/l)	246	Max 30*
Total hardness ($CaCO_3$) (mg/l)	2435	Max 500
Calcium (Ca) (mg/l)	559	Max 100
Magnesium (Mg) (mg/l)	252	Max 50
Sulfate (SO_4) (mg/l)	3073	Max 250
Chloride (Cl) (mg/l)	2274	Max 250
Nitrate (NO_4.N) (mg/l)	0.21	Max 10
Iron (Fe) (mg/l)	<0.03	Max 0.3
Residual chlorine (mg/l)	0.03	Max 0.3
Turbidity (NIU)	5.02	Max 4
Appearance	SL cloudy	—
Odor	Acceptable	Acceptable
Taste	N/A	Acceptable
Color	10	Max 15
Bacteria (*E. coli*) (counts/100 ml)	0	Absent
Bacteria (total coliform) (counts/100 ml)	0	Absent

Table 1. Groundwater test analysis in the north of Qatar.

4. System description

Figure 4 shows the complete system setup. The main advantages of the proposed system are the utilization of the geothermal energy, the use of low-toxic desiccant extracted from desalination process (rejected brine) and the compact wall-mounted cooling and dehumidification panel.

The QGreen panel consists of a bundle of thin polymer tubes and cellulose pads. The pressure drop across the panel is shown in **Figure 5**.

The QGreen polymer heat exchanger requires less maintenance and do not require any chemical water treatment. The scale does not adhere to the polymer tubes in the exchanger; therefore, scale inhibitors are not necessary, eliminating the cost of chemicals and labor necessary for water treatment. The panel utilizes indirect-direct evaporative cooling technology and desiccant dehumidification coupled with open- and closed-loop systems.

The system operation can be divided into process air, desiccant and water cycles. The process fresh air enters the QGreen cooling and dehumidification panel in a cross manner to the desiccant flow. The groundwater can consistently flow through the micro polymer tubes effectively removing heat from the seawater bittern desiccant and the air. The magnesium-based desiccant absorbs moisture from the air. As a result, the air is dehumidified, and its wet-bulb temperature decreased. The cooled and dehumidified air is then evaporatively cooled by either evaporative pads, misting or fog system. The cooled air is then supplied to the greenhouse or barn. The circulated desiccant is stored in a tank. The regenerator maintains the desiccant concentration within the required levels. The desiccant temperature is raised via flat

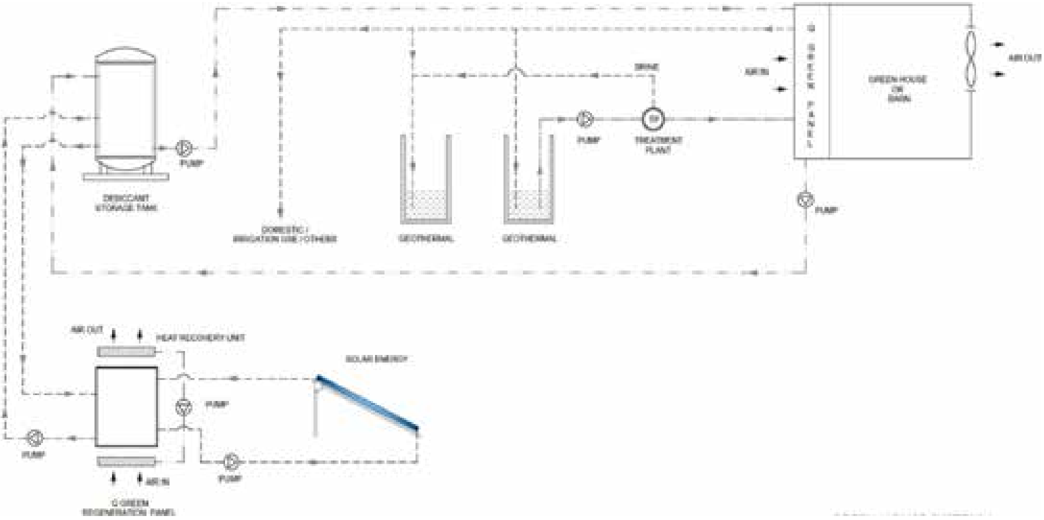


Figure 4. The proposed system schematics.

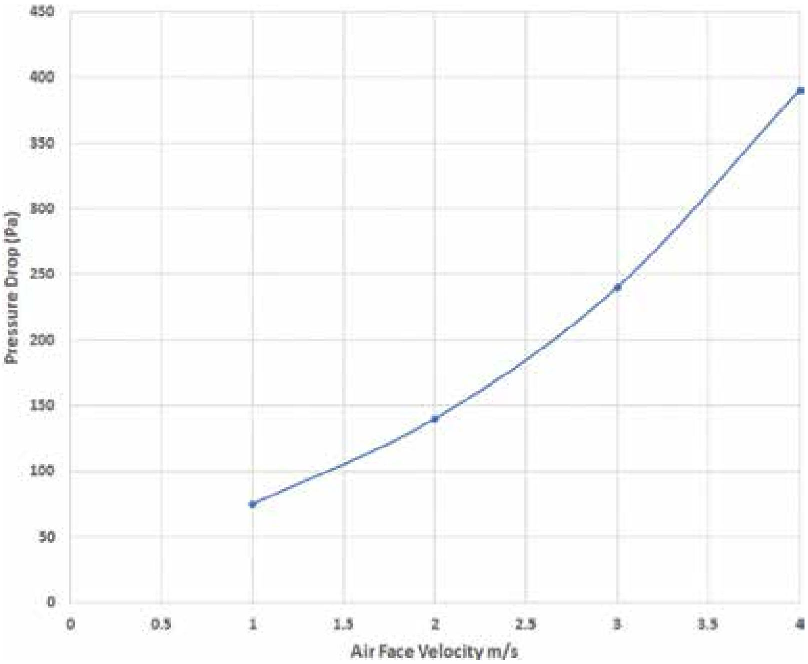


Figure 5. QGreen panel pressure drop (pa).

thermal collectors and hybrid photovoltaic thermal system. The average regeneration temperature is 50°C. The desiccant is sprayed over the QGreen packed regeneration panel. The scavenging air passes in a counter manner to the hot desiccant flow. As a result, the air is humidified, and the desiccant is concentrated.

5. Results and discussion

The rejected brine from the electricity water authority in Qatar is analyzed and enhanced by $MgCl_2$ to provide the sufficient concentration that will lower the process air wet-bulb temperature to the desired levels.

Figure 6 shows the relation between the equilibrium humidity and the minimum wet-bulb which can be obtained assuming that the effectiveness is 100% and the air temperature is equal to the solution temperature.

The QGreen polymer heat exchanger performance is vital. The relation between the geothermal water flow rate and the rate of heat transfer is depicted graphically in **Figure 7**. As shown, the heat transfer rate per panel is about 0.55 kW/(l/min).

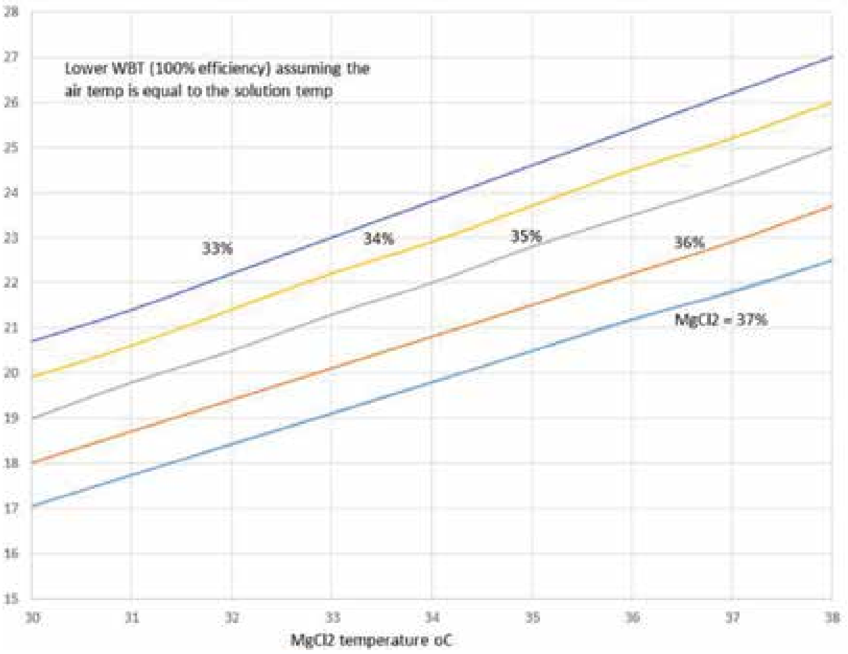


Figure 6. The lower wet-bulb temperature at different concentrations.

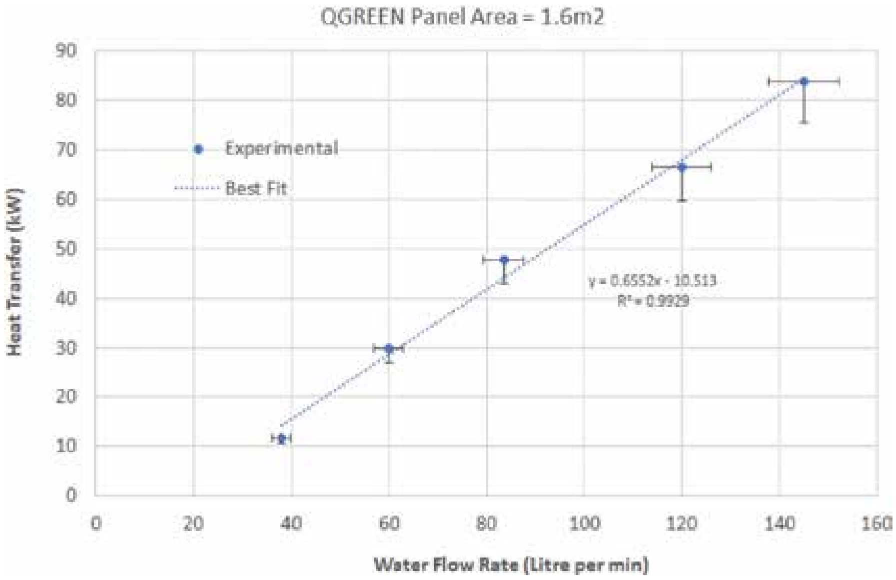


Figure 7. The QGreen geothermal polymer panel thermal performance.

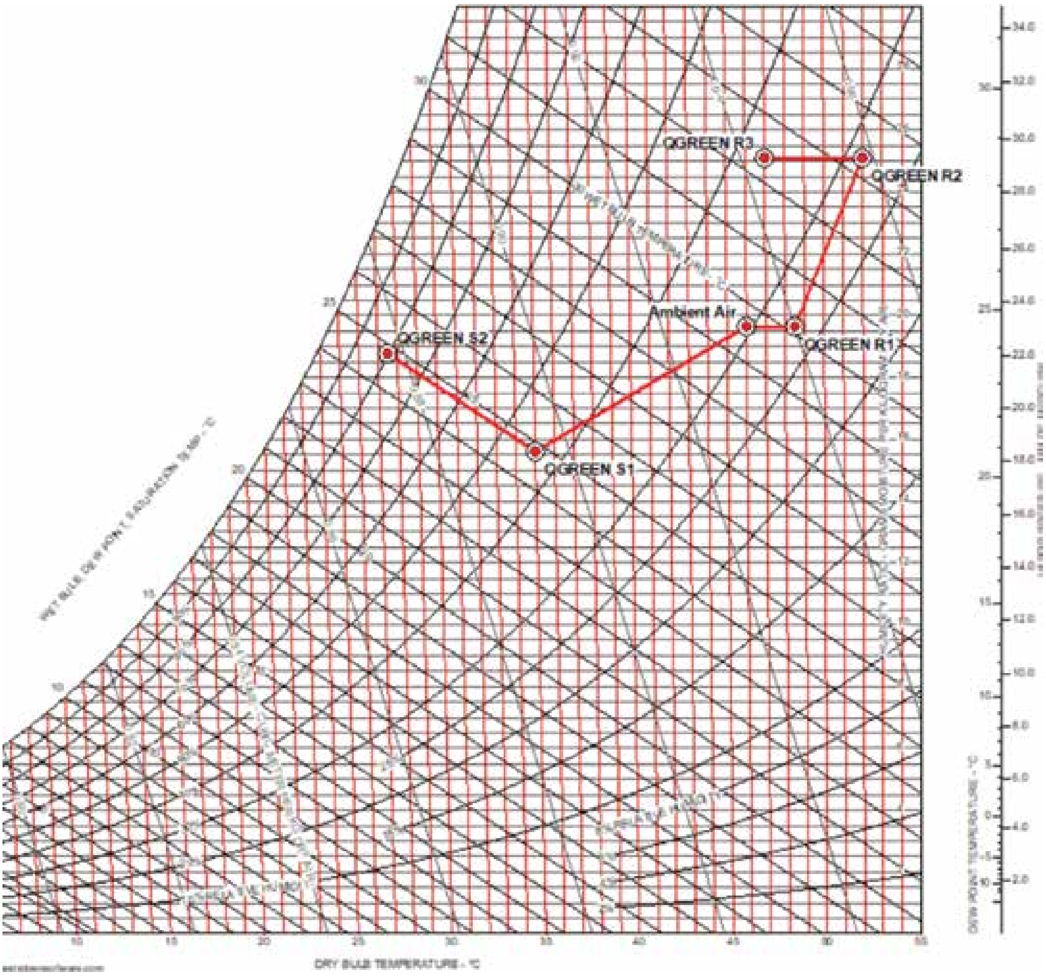


Figure 8. Cooling, dehumidification and regeneration cycle (case a).

Using the effectiveness method described above along with the psychometric model, the performance of the QGreen cooling and dehumidification panel can be predicted.

In order to design the system properly, three different weather conditions are used for analysis: (a) DB = 46°C, WB = 29.6°C; (b) DB = 35.5°C, WB = 31°C; and (c) DB = 35°C, WB = 24°C. The psychrometric cycle proposed by the authors is shown in **Figures 8–10**.

The ambient air passes the QGreen polymer heat and mass exchanger. As a result, the air is cooled and dehumidified. The wet-bulb temperature reduces; hence, the air will be evaporatively cooled in the second stage that integrated into the QGreen polymer panel.

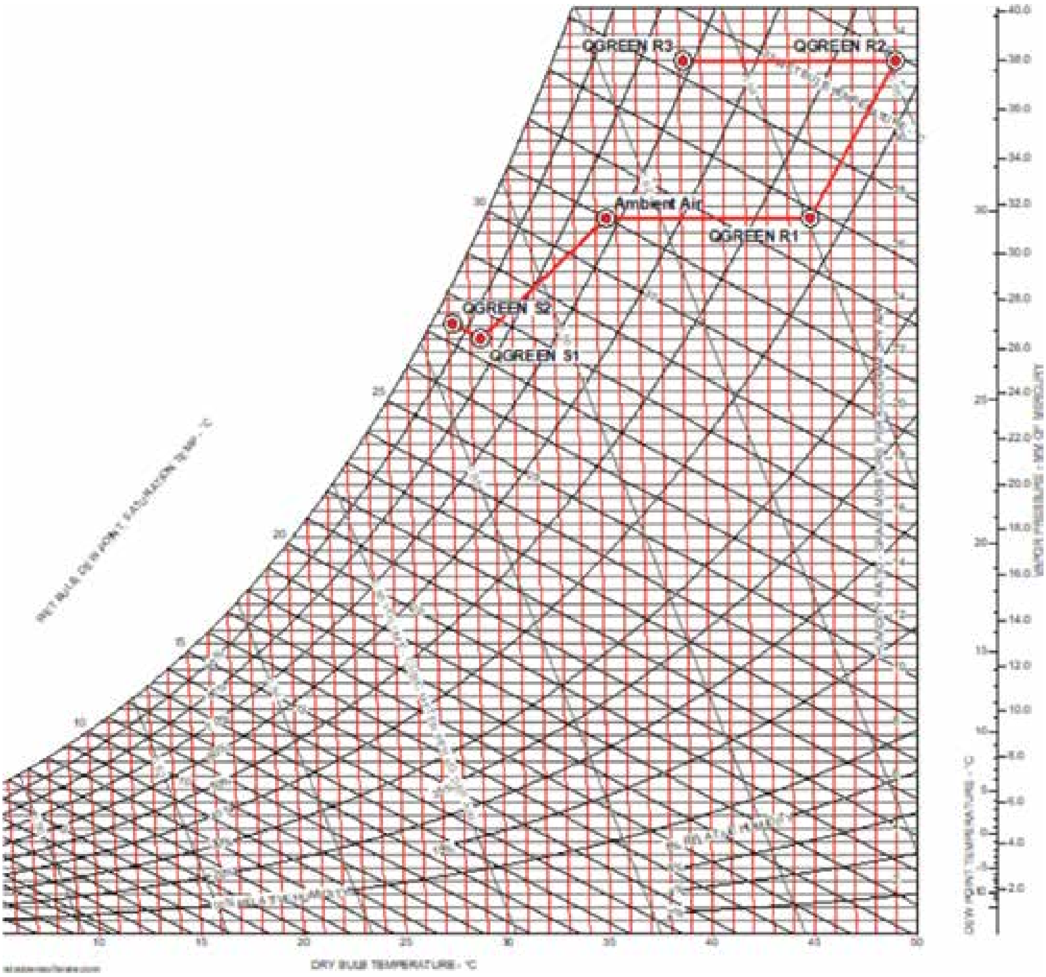


Figure 9. Cooling, dehumidification and regeneration cycle (case b).

The geothermal water could either be consumed or recirculated. The desiccant is regenerated by heating the desiccant to an average temperature of 55°C. Ambient air is initially preheated via a heat recovery system connected to the regenerator outlet and inlet. The hot air evaporates the absorbed water from the hot desiccant, and its temperature rises. The exhaust air is cooled via the sensible heat exchanger.

As shown in **Figures 8–10**, the supply air temperature can always achieve 28°C or lower.

Therefore, the geothermal desiccant system fits well such applications.

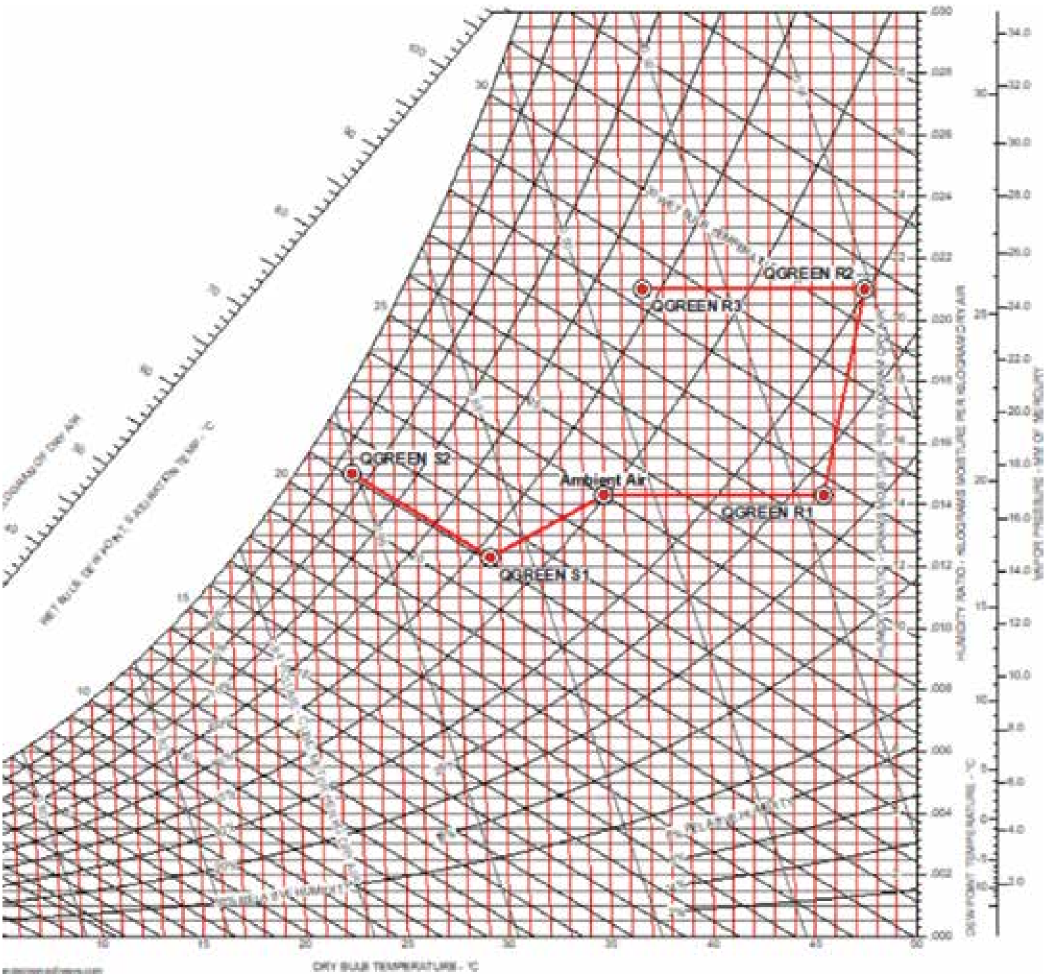


Figure 10. Cooling, dehumidification and regeneration cycle (case c).

6. Conclusions

With regard to food security, the Food and Agriculture Organization (FAO) requires all people to have access to sufficient, safe and nutritious food that meets their needs for an active and healthy life. However, in areas that have hot and humid climate and water scarcity, this remains a challenge. This chapter discussed one of the most interesting solutions that provide water source and climate control utilizing renewable energy. Qatar depends on desalination as a water source. The QGreen panel utilizes the rejected brine as a desiccant to dehumidify the air. The geothermal water cools the desiccant and air to the required temperature resulting in 2–4°C drop in the wet-bulb temperature. The thin polymer panel is corrosion and scale formation-free and can be installed within the greenhouse or barn boundaries. The results are promising and encouraging to be used in food security applications.

Acknowledgements

The authors acknowledge Qatar National Research Fund (QNRF) for supporting this research project through NPRP 7-332-2-138.

Nomenclature

a	Area of heat and mass transfer, m^2/m^3
a_t	Specific interfacial area of packing, m^2/m^3
Cp	Specific heat, kJ/kg.K
D_v	Diffusion Coefficient, m^2/s
d_{eq}	Equivalent diameter for structured packing, m
F_G	Gas phase mass transfer coefficient, $kmol/m^2.s$
F_L	Liquid phase mass transfer coefficient, $kmol/m^2.s$
h_G	Heat transfer coefficient, $kW/m^2.K$
K	Mass transfer coefficient, $kmol/m^2.s$
k	Thermal conductivity, W/m.K
Le	Lewis Number
m	Flow rate, kg/s or kg/h
m'	Superficial flow rate (mass velocity), kg/m^2s
M	Molecular weight, kg/kmol
N_v	Molar vapor mass transfer flux kg/m^2s
Re	Reynolds number
Sc	Schmidt number
T	Temperature, °C
X	Desiccant concentration, kg desiccant/kg solution
y	Water mole fraction, kmol water/kmol air
Z	Tower height, m

Greek

λ	Latent heat of condensation/vaporization, kJ/kg
ϕ	Density, kg/m^3
ω	Humidity ratio, kg water/kg dry air

Subscripts

a	air
c	condensation
e	equilibrium
G	gas phase
h	heat transfer
i	inlet or interface
L	liquid
m	mass transfer, mean
o	outlet
s	solution
v	vapor
w	water

Author details

Esam Elsarrag* and Yousef Alhorr

*Address all correspondence to: e.elsarrag@gord.qa

Gulf Organization for Research and Development, Doha, Qatar

References

[1] Elsarrag E, Alhorr Y. Towards Near Zero Energy Home Book chapter Energy Efficient Buildings. InTechOpen, ISBN 978-953-51-2876-2, Print ISBN 978-953-51-2875-5; 2017

[2] Rong L, Pedersen P, Jensen TL, Morsing S, Zhang G. Dynamic performance of an evaporative cooling pad investigated in a wind tunnel for application in hot and arid climate. Biosystems Engineering Elsevier Ltd;**156**:173-182. DOI: 10.1016/j.biosystemseng.2017.02.003

[3] Berman A. Predicted limits for evaporative cooling in heat stress relief of cattle in warm conditions. Journal of Animal Science. 2009;**87**(10):3413-3417. DOI: 10.2527/jas.2008-1104

[4] Fournel S, Ouellet V, Charbonneau É. Practices for alleviating heat stress of dairy cows in humid continental climates: A literature review. Animals. 2017;**7**(5):1-23. DOI: 10.3390/ani7050037

[5] Romantchik E, Ríos E, Sánchez E, López I, Sánchez JR. Determination of energy to be supplied by photovoltaic systems for fan-pad systems in cooling process of greenhouses. Applied Thermal Engineering. Elsevier Ltd. 2017;**114**:1161-1168. DOI: 10.1016/j.applthermaleng.2016.10.011

[6] Franco A, Valera DL, Peña A. Energy efficiency in greenhouse evaporative cooling techniques: Cooling boxes versus cellulose pads. Energies. 2014;**7**(3):1427-1447

[7] Aljubury IMA, Ridha HD. Enhancement of evaporative cooling system in a greenhouse using geothermal energy. Renewable Energy. Elsevier Ltd. 2017;**111**:321-331. DOI: 10.1016/j.renene.2017.03.080

[8] Xu J, Li Y, Wang RZ, Liu W, Zhou P. Experimental performance of evaporative cooling pad systems in greenhouses in humid subtropical climates. Applied Energy. 2015;**138**:291-301. DOI: 10.1016/j.apenergy.2014.10.061

[9] Abdel-Ghany AM, Goto E, Kozai T. Evaporation characteristics in a naturally ventilated, fog-cooled greenhouse. Renewable Energy. 2006;**31**(14):2207-2226. DOI: 10.1016/j.renene.2005.11.004

[10] Mirja AS, Misra D, Ghosh S. Study the performance of a fogging system for a naturally ventilated, Fog-cooled Greenhouse. 2016;**3**(1):19-23

[11] Katsoulas N, Savvas D, Tsirogiannis I, Merkouris O, Kittas C. Response of an eggplant crop grown under Mediterranean summer conditions to greenhouse fog cooling. Scientia Horticulturae. 2009;**123**(1):90-98. DOI: 10.1016/j.scienta.2009.08.004

[12] Perissinotto M, Moura DJ, Matarazzo SV, Mendes AS, Naas IA. Behavior of dairy cows housed in environmentally controlled freestall. CIGR. 2006;**8**(1989):1-11

[13] Ortiz XA, Smith JF, Villar F, et al. A comparison of 2 evaporative cooling systems on a commercial dairy farm in Saudi Arabia. Journal of Dairy Science. American Dairy Science Association. 2015;**98**(12):8710-8722. DOI: 10.3168/jds.2015-9616

[14] Titto CG, Negrão JA, Titto EA, et al. Effects of an evaporative cooling system on plasma cortisol, IGF-I, and milk production in dairy cows in a tropical environment. International Journal of Biometeorology. 2012;**57**(2):299-306. DOI: 10.1007/s00484-012-0554-6

[15] Davison TM, Jonsson NN, Mayer DG, Gaughan JB, Ehrlich WK, McGowan MR. Comparison of the impact of six heat-load management strategies on thermal responses and milk production of feed-pad and pasture fed dairy cows in a subtropical environment. International Journal of Biometeorology. 2016;**60**(12):1961-1968. DOI: 10.1007/s00484-016-1183-2

[16] Yadav B, Pandey V, Yadav S, Singh Y, Kumar V, Sirohi R. Effect of misting and wallowing cooling systems on milk yield, blood and physiological variables during heat stress in lactating Murrah buffalo. Journal of Animal Science and Technology. 2016;**58**(1):2. DOI: 10.1186/s40781-015-0082-0

[17] Brouk MJ, Smith JF, Harner JP. Effectiveness of Cow Cooling Strategies Under Different Environmental Conditions; 2003. Vol. 785. pp. 141-154

[18] Olorunnisomo OA, Adewumi AS, Oladimeji AO. Efficiency of Evaporative Cooling on Zebu Heifers Sprinkled. 2016. pp. 340-347

[19] Smith TR, Chapa A, Willard S, Herndon C, et al. Evaporative tunnel cooling of dairy cows in the southeast. II: impact on lactation performance. Journal of dairy science. Elsevier. 2006;**89**(10):3915-3923. DOI: 10.3168/jds.S0022-0302(06)72434-1

[20] Lychnos G, Davies PA. Modelling and experimental verification of a solar-powered liquid desiccant cooling system for greenhouse food production in hot climates. Energy. 2012; **40**(1):116-130

[21] Davies PA. A solar cooling system for greenhouse food production in hot climates. Solar Energy. 2005;**79**(6):661-668. DOI: 10.1016/j.solener.2005.02.001

[22] Abu-Hamdeh NH, Almitani KH. Solar liquid desiccant regeneration and nanofluids in evaporative cooling for greenhouse food production in Saudi Arabia. Solar Energy. Elsevier Ltd. 2016;**134**:202-210. DOI: 10.1016/j.solener.2016.04.048

[23] Elsarrag EM, Ali EE, Jain S. Design guidelines and performance study on a structured packed liquid desiccant air-conditioning system. HVAC&R Research. 2005;**11**:319-337

[24] Elsarrag E, Igobo ON, Alhorr Y, Davies PA. Solar pond powered liquid desiccant evaporative cooling. Renewable and Sustainable Energy Reviews. 2016;**58**:124-140

[25] Elsarrag E. Dehumidification of air by chemical liquid desiccant in a packed column and its heat and mass transfer effectiveness. HVAC&R Research. 2006;**12**:3-16

[26] Elsarrag E, Abdalla K. Effectiveness and performance of a Counterflow liquid desiccant regeneration tower in a hot-humid climate. ASHRAE Transactions. 2009;**115**

[27] Gao WZ, Liu JH, Cheng YP, Zhang XL. Experimental investigation on the heat and mass transfer between air and liquid desiccant in a cross-flow dehumidifier. Renewable Energy. 2012;**37**(1):117-123

[28] Liu XH, Jiang Y, Chang XM, Yi XQ. Experimental investigation of the heat and mass transfer between air and liquid desiccant in a cross-flow regenerator. Renewable Energy. 2006;**32**(10):1623-1636

[29] Kusuda T, Achenbach PR. Earth temperatures and thermal diffusivity at selected stations in the United States. ASHRAE Transactions. 1965;**71**(1):61-74

Chapter 3

Low/Zero-Carbon Buildings for a Sustainable Future

Erdem Cuce, Ahmet B. Besir and Pinar Mert Cuce

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.74540

Abstract

Fossil fuel-based energy consumption is still dominant in the world today, and there is a consensus on the limited reserves of these energy resources. Therefore, there is a strong stimulation into clean energy technologies to narrow the gap between fossil fuels and renewables. In this respect, several commitments and codes are proposed and adopted for a low energy-consuming world and for desirable environmental conditions. Sectoral energy consumption analyses clearly indicate that buildings are of vital importance in terms of energy consumption figures. From this point of view, buildings have a great potential for decisive and urgent reduction of energy consumption levels and thus greenhouse gas (GHG) emissions. Among the available retrofit solutions, greenery systems (GSs) stand for a reliable, cost-effective and eco-friendly method for remarkablemitigation of energy consumed in buildings. Through the works comparing the thermal regulation performance of uninsulated and green roofs, it is observed that the GS provides 20°C lower surface temperature in operation. Similar to green roofs, vertical greenery systems (VGSs) also reduce energy demand to approximately 25% as a consequence of wind blockage effects in winter. Therefore, within the scope of this chapter, GSs are evaluated for a reliable and effective retrofit solution toward low/zero carbon buildings (L/ZCBs).

Keywords: buildings, energy consumption, energy-efficient retrofit, green roofs and facades

1. Introduction

Since the beginning of the industrial revolution (roughly 200 years), the dramatic increase in world population and technological advancements led to remarkable rises in global energy demand [1]. Scientists address a relationship between the global energy demand and the consumption of natural resources through the economic growth across the world, especially over the last two decades. Uncontrolled energy consumption due to human activities plays a vital role in biodiversity decline. According to the latest report, the greatest part of the decline in biodiversity has taken place within the last 50 years [2]. Urbanization is another significant problem of today's world in terms of growing importance of environmental issues. The urbanization rate is to rise by 75% until 2030 as shown in **Figure 1** [3]. Urbanization-related environmental matters can be illustrated as pollution, the depletion of natural resources, climate change, and global warming. Especially climate change notably affects the biotic systems as it has cumulative impacts on the global environment such as terrible weather conditions and deterioration of natural ecosystem (serious decrease in fishery stocks and in the productivity of lands) [4].

The European Commission primarily aims to slow down the increase in greenhouse gas (GHG) emission to prevent the hazardous impacts on the environment. Based on the roadmap reported by European Commissions in 2010, the abatement in the EU GHG emissions is aimed to be 80% by 2050 (as compared to the 1990 level). The target of the decrease in GHG emissions takes place in the range 25–60% between 2020 and 2040. To reach this goal, the increase in the global temperature should be 2°C less than the pre-industrial era [5]. A similar, national plan underlying the significance of climate change is adopted by the Government of China. Based on this plan, carbon emissions are expected to be reduced by 40–50% until 2020 compared to the level of 2005 [6]. However, it is a clear challenge to achieve the said targets concerned with global warming and GHG emissions. In this respect, appropriate investments in energy, transport, industry, information technologies, and building sectors are required for the desired outputs. Among the relevant sectors, buildings stand for the most promising field in terms of eco-friendly-mitigating energy consumption levels. The reduction of energy consumed in buildings does not have any negative effects on the welfare of the dwellers [7]. L/ZCB strategy can be accomplished by constructing new environmentally friendly building or retrofitting existing buildings with low-cost, energy-efficient, and eco-friendly technologies. The retrofit

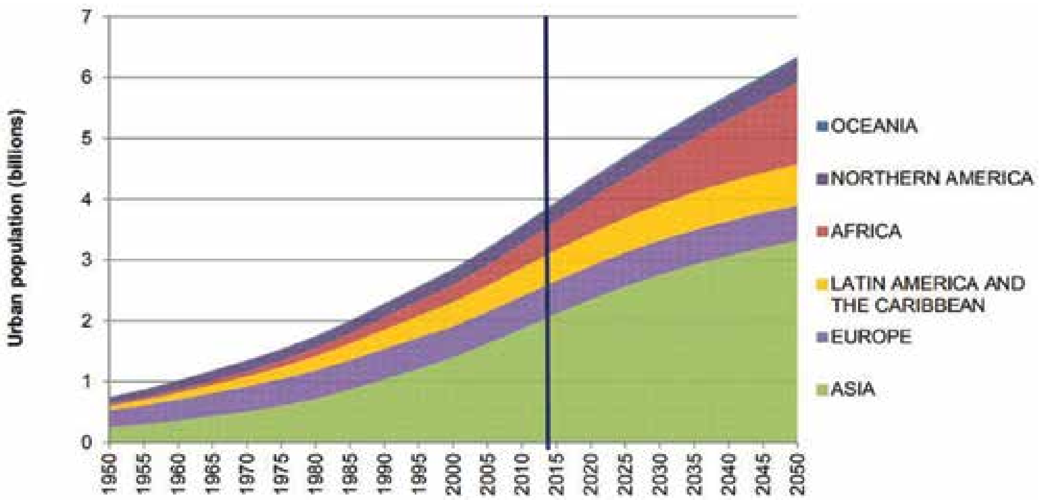


Figure 1. Urban population by major area, 1950–2050 [3].

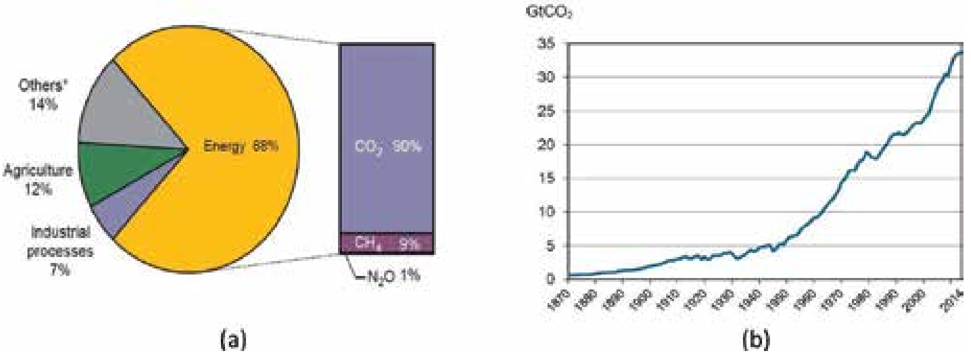
of existing buildings can remarkably reduce energy demands and carbon emissions, as well as mitigating the depletion of natural resources. GSs are considered as low-energy concept for buildings, and they can be deployed in existing buildings as retrofit applications [8, 9].

In this context, the main goals of this research can be illustrated as to explain the L/ZCB for potential reduction of energy demand in the building sector and to introduce the GSs as retrofit applications to existing buildings.

2. CO_2 emissions

With respect to consensus among scientists, CO_2 emissions in the atmosphere have a remarkably rising trend since industrial revolution. In comparison to pre-industrial revolution, the average rise in CO_2 concentration with 403 ppm is reported to be about 40%. Depending on the recent assessment report on climate change, human beings have a considerable influence on the climate system due to the energy consumption [10]. Therefore, the energy usage is admitted to be the greatest contributor to GHG emissions. **Figure 2a** illustrates the shares of global GHG based on human activity.

The level of CO_2 emission is represented in **Figure 2b**. It is clear from the data that the CO_2 emissions have a steadily rising trend from industrial revolution up to 2014 [11]. It is reported by Boeck et al. [7] that the emissions are expected to increase to 52% from 2005 to 2050 if no decisive measures are taken. During the said period, carbon emissions are predicted to increase by 78%, which is notable. Also the annual increase in GHG emissions between 2000 and 2010 is found to be 1 giga tone of CO_2 equivalent. When the emissions from 1970 to 2010 are analyzed, the growth is reported to be around 0.4 $GtCO_2eq$. Moreover, carbon emissions dramatically increase with the explosive growth in global economy and world population. On the other hand, within the last decade, the emissions have a decreasing tendency because of the global economic recession between 2007 and 2008 as shown in **Figure 2b** [7]. In 2015, global CO_2 emission level is predicted to be 32.3 $GtCO_2$, which is 0.1% lower than the level in



(a) (b)

Figure 2. Estimated shares of global anthropogenic GHG, 2014 (a), trend in CO_2 emissions from fossil fuel combustion, 1870–2014 (b) [11].

2014. For 2013 and 2014, the growth rate of CO_2 emission is given to be 1.7 and 0.6%, respectively. On the other hand, the annual rise of the emissions is reported to be 2.2% since 2000. From this point of view, it can be easily understood that the growth in global economy is independent of the reductions in GHG emissions [11].

As a consequence of rising welfare of the countries at growing economic indicators, global energy demand remarkably increases. Between 1971 and 2015, the rise of global energy demand is reported to be 150%. While expressing the energy demand, total primary energy supply (TPES) is widely used to determine the rates as shown in **Figure 3** [11]. With respect to the emissions from fuel combustion in 2015, the largest share of CO_2 emissions is attributed to coal. However, the percentage of coal consumption (28%) is lower than the oil consumption (32%) according to the TPES data.

The major CO_2 emission sectors are electricity and heat generation, which are responsible for 42% of the total emissions in 2015. Although the share of oil utilized in electricity and heat generation decreases, the coal and gas consumptions have an increasing trend in 2015 as compared to the year of 1990 as depicted in **Figure 4**.

2.1. Climate agreements

Kyoto protocol is known as the first agreement to mitigate GHG emissions and the protocol commitment covers the period between 2008 and 2012. The protocol indicates that 5% of reduction in the domestic emissions compared to the 1990 level is required to be fulfilled by the industrialized countries during the said period. Moreover, the countries are expected to reach the targets of Kyoto by mitigating emissions from fossil fuel consumption and emissions in other sectors such as direct industrial emissions. The second commitment period from 2013 to 2020 is defined as The Doha Amendment. The amendment was approved by 80 parties on August 9, 2017. The Kyoto target regarding the GHG emissions, approved by parties, is 19.3% mitigation in CO_2 emissions. Based on the data between 1990 and 2015, it is observed that the said target is already achieved with 20% reduction in the emissions. Paris agreement is defined

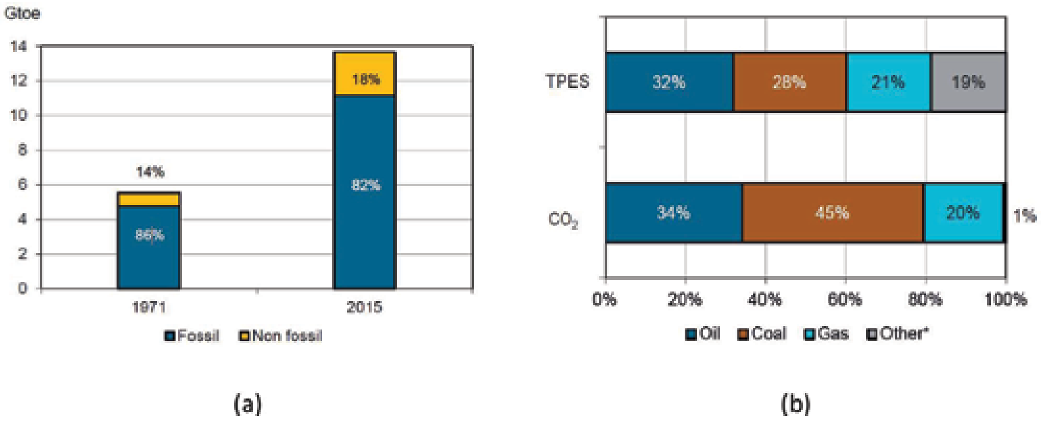


Figure 3. Energy supply by fossil and nonfossil fuels (a), world primary energy supply and CO_2 emissions: Shares by fuel in 2015 (b) [11].

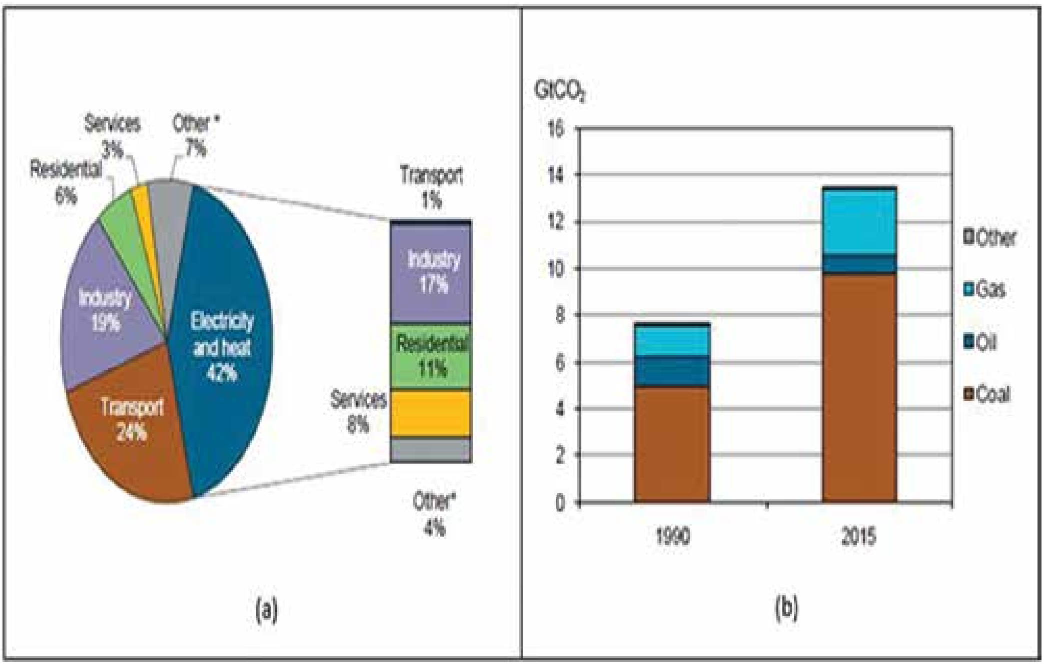


Figure 4. World CO_2 emissions from fuel combustion by sector, 2015 (a), CO_2 emissions from electricity and heat generation, 1990–2015 (b) [11].

as the first international obligatory climate agreement related to decisive reduction of CO_2 emissions. Both developed and developing countries ratified the agreement in 2016 [11]. Paris agreement covers the shift to low-carbon energy and emissions. For this reason, renewable energy technologies (RETs) are of crucial importance in developing low/zero-carbon technologies (L/ZCT) and green energy solutions. Owing to the improvements in these technologies, the cost of such systems remarkably decreases year after year, for instance, the cost of solar electricity is reported to reduce by 65% between 2010 and 2015 [12]. The target of this agreement is to provide the maximum 2°C change in global surface temperature (2DS) by 2050 [13].

3. Building sector

About 40% of the total energy consumption is attributed to the building sector in the world since both building construction and usage play a vital role in global energy use. In this respect, it is firmly believed that buildings contribute substantially to the world GHG emissions [14]. For instance, GHG emissions from buildings in the United States, China, the UK, and Australia are reported to be 43, 50, more than 50, and 23%, respectively [15]. The final energy consumption in European member countries is about 1104 million tons of oil equivalents (based on the data of 2012). A total of 26.2% of this amount is used in residential buildings. The amount of total buildings present in the EU27 overweighs by 25% compared to the residential buildings. Energy consumption in the residential buildings can be split into two major parts such as space heating (68.4) and heated water (13.6) [7]. As emphasized in a research, the rise of global space cooling is found to be about 60% between 2000 and 2010, and space cooling attributed 4% to the global energy consumption in 2010 [16].

The building sector plays a leading role in mitigating energy consumption with energy-efficient building concepts, which also reduce the amount of carbon emissions. Many countries implement new policies to reduce energy consumption based on building performance. However, the average amount of energy used in building per capita does not show a noticeable change for the last two decades in the world. Since 2010, the rise in CO_2 emissions is reported to be about 1% per year. Furthermore, the increase in CO_2 emission with regard to buildings is found to be 45%. While the natural gas consumption increases by approximately 1%, the rate of oil and coal consumptions seems stable. In addition, the expectation related to improving energy performance of the buildings is about 10% and more. In 2010, average energy use per capita seems to have peaked—that is roughly 12 MWh in the Organization for Economic Co-operation and Development (OECD) countries, and from this point, the consumption decreased gradually due to winters passing warmer regions in comparison with previous years. Also, it is observed that the share of space heating in buildings in terms of final energy consumption is 45% in OECD countries. In terms of non-OECD countries, the average final energy consumption increases almost 15% for a period of 15 years. While reaching 2DS target, the rate of average building energy consumption per capita should be at least 10% and the average consumption is not expected to exceed 4.5 MWh by 2025. **Figure 5** illustrates the amount of final energy demand and the share of final energy use by fuel and per capita [17].

The potential reduction in carbon emissions from the buildings is expected to be 30% by 2020 [18]. To be able to reach this target, measures to mitigate the energy consumed in residential buildings are primarily concerned as they are much more suitable to energy-efficient retrofitting. For this reason, various energy efficiency measures are adopted by the European Union

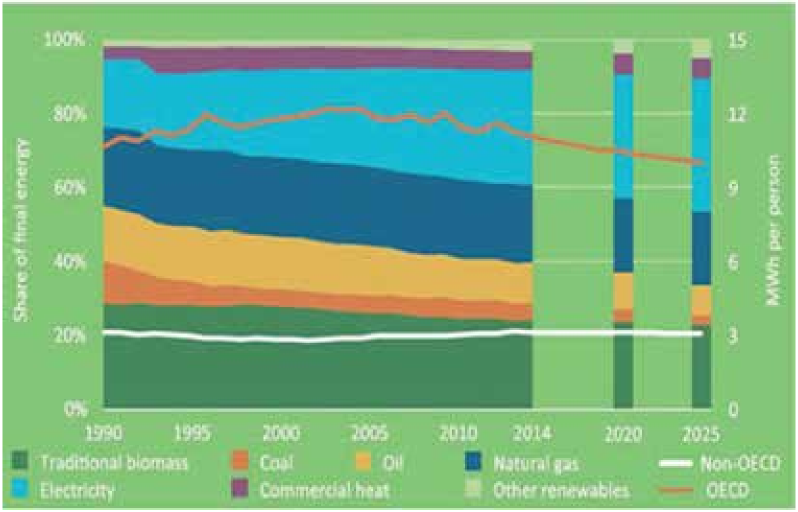


Figure 5. Final energy use by fuel and per person [17].

that can be implemented in the existing buildings. The commitments of the said agreements impose the member countries to implement energy performance certification and to improve the devices used in the buildings for providing space cooling and heating [19]. With regard to efficient building codes, the first five countries are Austria, Denmark, the UK, Finland, and France. Germany also follows the first five countries [20]. Through the directives of 2010/31/EU, the Energy Performance of Building Directive (EPBD) suggests the concept of nearly zero energy buildings (nZEBs) to improve energy performance with insulation properties, heating, ventilation, and air-conditioning (HVAC) systems, the building orientation, and comfortable indoor quality for both new and existing buildings in Europe [19].

Likewise, national governments take decisive measures to improve the building energy performance for the transition to the net-zero energy buildings [21]. Some European member countries including the UK implement the amendments regularly before the proposed date. According to Sustainable Homes Code introduced by the UK, the newly constructed building from 2016 is expected to consume less energy for heating, cooling, and lighting [22]. Similar to the UK, Italy also adopts a code which is inspired from the directive 31/2010/EU. The law embraces both energy performance of buildings in terms of particularly thermal features and HVAC systems (nZEB). For the new public buildings, the starting date is considered to be 2019, but the nonpublic buildings are planned to be built as nZEB from 2021 [23].

The American society of heating refrigeration and Air-conditioning Engineers (ASHRAE) code and the International Energy Conservation Code (IECC) emphasize new advancements in relation to the efficient use of energy in the building sector. Unlike the EU, the energy labeling in the building certification is not commonly used since it is not mandatory in the United States [24]. The US building energy codes address energy and cost savings of the buildings without underlining the abatement of CO_2 emissions [25]. Like ASHRAE, the design standard for Energy Efficiency of Public buildings is implemented to have noticeable improvements in the energy performance of buildings and accomplish a notable decline in energy demands in China [26].

In 2012, European Commission revised the advanced energy-efficient directive to be implemented by each member countries as a long-term project to enhance the energy performance of the existing buildings with low cost [22]. According to the report presented by International Energy Agency, the retrofit of the existing buildings improves overall energy performance, and this approach is approved as applicable and economically viable. The International Energy Agency (IEA) mentions that the energy-efficient building code is relatively important for forming net-zero energy houses [27]. Moreover, the energy demand in buildings can be decreased by improving building code and utilizing energy-efficient household appliances. Through the said phenomenon, the reduction in energy demand in both commercial and residential buildings is expected to be about 50% by 2050 when compared to 1990 [22].

4. Nearly zero energy buildings

Building sector has unequivocal effects on the economic growth and the employment rate of the countries. Buildings are also of vital importance in terms of growing significance of environmental issues [22]. Energy consumed in buildings is in the range of 25–40% for

OECD member countries. Buildings account for 40% of primary energy use in the United States and Europe. For China, the rate is given to be 30% of the energy consumption [28]. The energy demand related to buildings can be reduced by energy-saving technologies and energy-efficient regulation on the buildings. The increase in energy performance of the buildings leads to the concept of low energy building (LEB) or nZEB. In the literature, numerous studies define the concept of the nZE/CB. According to Esbensen and Korsgaard [29], a zero energy house is a concept which does not need extra energy demand for space heating and cooling through normal climate such as Denmark. Based on the definition of European Parliament [19], the nZEBs are expected to use renewable energy technologies (RETs) on-site or nearby to meet energy demands. The definition of EISA [30] consists of (1) reducing the energy demands, (2) meeting the energy needs from the non-carbon emission energy generations, (3) increasing the practice related to nZGHG, and (4) minimizing the installation and running cost. According to Riedy et al. [31] zero emission buildings can be defined as near zero energy, zero energy, passive house, 100% renewable, carbon neutral, climate positive and positive advancement, energy plus, and zero net energy. Moreover, some organizations such as IEA and solar heating and cooling programs highlight the net-zero energy building research, and these organizations promote the task 40 with respect to net-zero energy solar building since 2008 [28]. The task 40 formed by eight different definitions of Department of Energy in the United States supports the shift to net-zero energy commercial building for new buildings by 2030 [32]. In addition, the European Union also declares the target of net-zero energy building. The newly constructed buildings are aimed to have high-energy performance and to generate their own energy to consume on-site. The project is planned to be started at the beginning of 2019 [33]. The UK, Japan, and Canada also implement characteristic regulations to buildings related to net-zero energy.

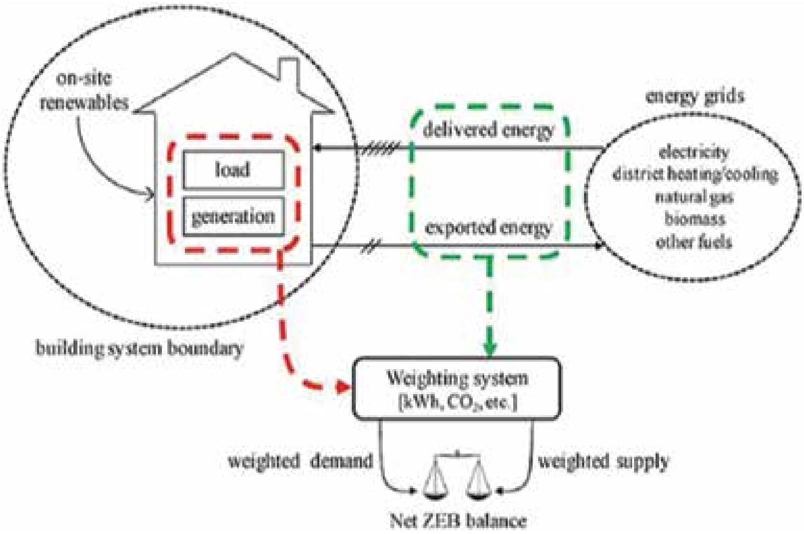


Figure 6. Systems structure and basic elements of nZEB [28].

The system structure of the nZEB is illustrated in **Figure 6**. Inside typical building systems boundary, the building consumes delivered energy on-site such as electricity district heating/ cooling, natural gas, biomass, other fuels, and finally renewable energy generation. Excessive electricity is also sent to the grids. The nZEB can be described as annual energy consumed by the building irrespective of the life cycle. The target of conventional nZEB provides the balance between loading and generating the energy within the buildings [34].

Figure 7 presents three different energy-efficient techniques such as passive service system and renewable energy systems. Passive systems consist of building orientation, envelope, airtightness, and shade. When implementing the passive systems to buildings, thermal and electrical energy consumption decreases effectively. In addition, in order to offer comfortable temperatures to the buildings, HVAC, domestic hot water systems, and lighting indoors can be reinvented to reduce energy loads. In this way, the performance of building energy systems is increased through integration of RETs. RETs are used not only to generate electricity but also to heat and cool the indoor environment via combined heating and cooling and power solutions (tri-generation systems) [28]. Through nZE/CB, thermally comfortable living spaces can be achieved for dwellers.

With respect to the roadmap (proposed by Sustainable Energy Authority of Ireland) aimed to provide 90% reduction in carbon emissions from the residential buildings, four essential measures are considered to enable this decrease in the building's carbon emissions. These measures are composed of energy-efficient retrofit (improving building energy performance), utilization of the RETs, low/zero energy technologies, and electricity generation with low carbon emissions [35].

There are many LE/CB standards adopted to mitigate energy consumption levels across the world. Some of the directives can be listed as Building Research Establishment

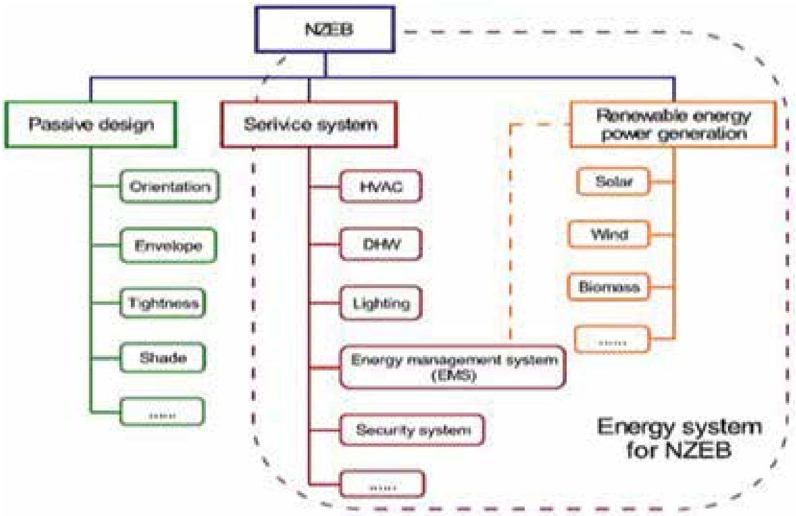


Figure 7. Design elements for nZEB [28].

Environmental Assessment Method (BREEAM), International Energy Conservation Code (IECC), Leadership in Energy and Environmental Design (LEED), Canada National Electrical Code (NEC), LEED Canada, Bureau of Energy Efficiency (BEE), Energy and Climate Studies (ECS), Comprehensive Assessment System for Built Environment Efficiency (CASBEE), Nationwide House Energy Rating Scheme NatHERS, and Internal Environmental Management–Environmental Performance (H1EE) [4]. **Figure 8** indicates some key parameters in the LEB standards. It can be easily observed that the requirements of thermal performance and airtightness for buildings dominate the other parameters. Major parameters of the L/ZEB standards are depicted in **Figure 8**.

The retrofitting of the existing buildings toward nZEBs is really important than the newly constructed buildings. Since the energy-efficient materials for the new buildings are commercially available on market, the main challenge comes from the existing buildings. By looking into reports, the buildings that existed from the 1960s in Europe are about 40% of all buildings in Europe nowadays. Newly constructed buildings in Europe are attributed to 1% of the building stock. It is predicted that the buildings existing in Europe today might be utilized until 2050. The energy performance of the existing buildings is relatively poor. Hence, the retrofits of these buildings are vital parts of the target of 2050. Along with improving energy performance of the building, the economic growth and the life quality also increase proportionally [5]. It is widely believed that the application of retrofitting the existing buildings will comprise a wide range of developments including thermal insulation of building facade and roofs, upgrading the space heating and cooling systems, renovation of electrical and electronic appliances, and utilizing RETs on-site or nearby [23]. Looking at the report presented by European Commissions, it is predicted that minimum energy saving can be targeted by 2020 and the amount saved would be in the range of 60–80 Mtoe/year [37]. Moreover, the study carried out by Williams et al. [4] focuses on the retrofit of the buildings in such a way that the expectation is considered to be 2.77 billion buildings in case the world population

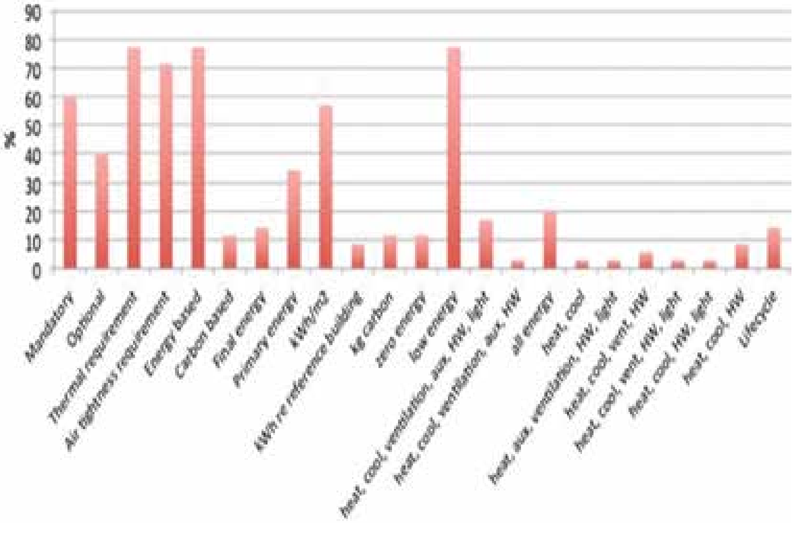


Figure 8. Major parameters of the 35 major low or zero energy building standards around the world presented as the percentage that are presented in terms of each parameter [36].

stays stable. So, to attain the target of near zero carbon world in 2080, 43 billion buildings would need to be constructed or retrofitted based on the zero energy standards per year [4].

The findings indicate that nZEB can reduce the environmental impacts with an energy-efficient building concept, and it is also financially viable. Although the initial investment cost is relatively high, the low energy consumption contributes to increasing the energy saving and reducing annual running cost [38]. The other study carried out by Kuusk and Kalamess [39] provides additional evidence to these problems by considering economic aspects of the renovation complying with net-zero energy buildings. As a result of the findings, the decline in both annual energy demand and energy expenditure is found to be 70% in comparison with the existing buildings in Estonia. But, for the owners of the buildings, the payback period is approximately 30 years and the period is really long. It is concluded that the nZEB retrofits do not seem economically viable. If annual rental income is increasing gradually, the payback period could be decreased as much as 8 years which may be considered as the best scenario.

The results from the case study conducted by Ferrari and Beccali suggest that there is an association between the building retrofits and primary energy consumption. The retrofitting of buildings reduces the GHG emissions by 40%. The increase in thermal performance of buildings with regard to roof and facade would diminish the emission proportionally. Also, the reduction in the energy consumption is found in the range of 2 and 6% depending on the thickness of thermal insulations [23].

Fraunhofer institution mentioned the reduction in the fuel consumption in the built environment with the application of energy-efficient measures was found to be 22 and 46% (compared to 2005) in 2020 and 2030, respectively [40]. Based on another study about mitigating GHG emission, the target of reducing GHG emission is planned to be 40 and 60% by 2020 and 2030, respectively. When these rates are designated by comparing to the data of 2005, RETs are applied to increase the energy saving of the buildings [41].

The retrofit of buildings presents two types of benefits such as co-benefits and direct benefits. Direct benefits are the reduction in energy consumption and carbon emissions. As for co-benefits, they consist of improving overall quality of the building, improving users' well-being, and financial benefits. In addition to these, macroeconomic benefits also are considered to be mainly composed of environmental economic and social subcategories. The economic benefits encompass a wide variety of opportunities such as lower energy cost, a decrease in unemployment rate, and setting up new business activities. In the same way, social benefits fully embrace the considerable improvement in productivity, social welfare, and comfort, the largest decrease in morbidity and mortality, and enormous advances in energy security. Environmental benefits are defined as a reduction in air pollution and waste reduction associated with constructing or renovating buildings [42].

Annual savings based on benefits resulted from the renovation of the existing buildings in Europe are estimated to reach approximately €104–175 billion by 2020. The savings are divided into three categories such as lower energy bills, suppression of carbon emission through energy generation, and enhanced indoor quality to provide healthier ambience. The resulting amounts are €52–75 billion, €9–15 billion, and €42–88 billion, respectively. Based on the growth estimation in economic activities, it is observed that approximately 760,000–1,480,000 people will have opportunities to work in new business sectors [43].

Furthermore, based on a research carried out by Stoecklein et al. [44] it is assumed that the benefits resulting from non-energy sectors are much higher (around 2.5 times) than energy-savings sectors occurring in the retrofit of existing buildings [44].

The main criteria for well-being of dwellers living in buildings are composed of thermal comfort, indoor air quality, internal and external sound level, natural lighting, and esthetic view. Thermal comfort is mainly dependent on temperature differences and air humidity. The indoor quality is associated with microbacterial contaminants resulting in hazardous conditions to residents. Internal and external noise can be decreased by using acoustic insulation materials, and so on, which are applied to both exterior and interior of buildings [42, 45, 46].

When constructing, renovating, and operating the buildings, both energy consumptions and GHG emissions are growing rapidly. Health threats due to environmental issues have damaging effects on a part of society, especially young, old, and poor persons. For instance, children and elders are in vulnerable groups that can be affected easily from tough weather conditions, especially during summer time. Since the mortality and morbidity are growing due to excessive heatwaves [47]. A research report shows the correlation between threshold temperature and mental and behavioral disorder. In order to provide better conditions, the indoor temperature must not be more than 26.7°C (threshold temperature) [48]. Moreover, these threats may cause inefficient resources including food, water, and power. While reducing energy consumption and air pollution, public health could be enhanced greatly [13]. The retrofit of the building provides not only less energy use but also positive contributions to the building and dwellers. These contributions consist of the value and life span of the building, more comfortable and healthier environment for the dwellers to live in, and work in the retrofitting building. By improving the ambient air quality of the building, the productivity and health of the dwellers are rising due to reducing undesirable conditions such as excessive moisture and mold [5]. To be able to achieve the said benefits, quick implementation of regulations on energy is necessary in the building sector.

Energy-efficient buildings consist of three main categories that present the impacts on suppressing energy consumption associated with buildings as follows [26]:

- Building envelopes including thermal insulation, thermal mass, windows/glazing, and roofs.
- Internal conditions consisting of indoor design conditions and internal heat loads.
- Building services systems divided main three subjects HVAC, electrical services, and vertical transportation used in buildings such as lifts and escalators.

4.1. Building envelopes

Nowadays, a large number of countries and local administrations are aware of the numerous impacts of building envelopes on the building energy performance. So, building energy codes released by policymakers are growing gradually on a yearly basis. Although this progression is conducted through the energy codes, two-thirds of the countries have not still implemented the energy codes for building sector. As per reports, building envelope performance has increased by approximately 6% in the last 5 years as shown in **Figure 9**.

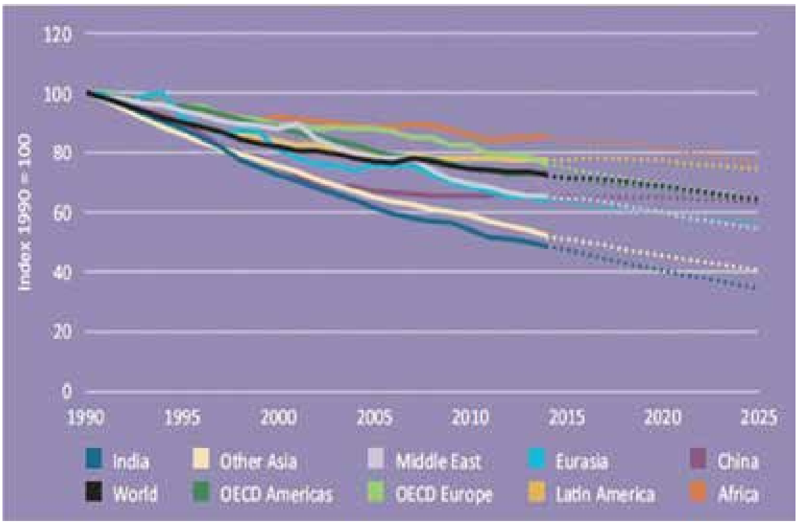


Figure 9. Change in building envelope performance [17].

The rates in the developing countries are greater due to rise in the floor areas and thermal comfort demands. The building envelope performance has considerable influences on the heating and cooling needs. It can, therefore, be assumed that high building envelope performance can be managed by deep renovation and retrofitting of the existing buildings. For this reason, the energy codes for building should be revised to meet the target of the building performance. The rate of retrofitting the existing buildings is in the range of 1–2% today, and the percentage is expected to rise by 2 and 3% per year up to 2025 [17].

5. Greenery systems

Greenery systems have a leading role to improve the energy performance of the buildings due to its relation with building envelopes. For this reason, GSs could be utilized to achieve zero energy or carbon buildings. While enhancing the energy efficiency of buildings, both energy consumption and carbon emission steadily decrease as well. The systems can cover both the surfaces of buildings, especially roof and wall. Also, it is mainly divided into two parts such as green roofs and green walls [8]. While contributing to energy efficiency and providing lower carbon emissions, the GSs applied in the existing building have substantial benefits to not only the environment but also economy and the society. In addition, these systems are used as passive design, which offers insulation, shading for heating, and cooling period for buildings, respectively. By applying the GSs to existing buildings, building dwellers could reach improved indoor microclimatic conditions by cost-effective and eco-friendly means [9, 49–51].

5.1. Green roofs

Building roofs occupy approximately 25% of total surface areas in the urban environment [52]. Green roofs have potential benefits associated with environment and society.

The environmental benefits consist of mitigating GHGs and threat of urban heat islands, decreasing the depletion of energy resources, improving urban life, and preventing devastation of wildlife [53–57]. Furthermore, green roofs also improve health of residents living in green roof buildings. The roofs, thus, provide better indoor air quality for dwellers, for instance, lower noise levels and ideal microclimatic ambience [56]. Among all, the main subject related to green roof is to improve energy performance of buildings. That is why energy-efficient buildings lead to reduction in energy consumption and carbon emissions as a result of heating and cooling the indoor ambience of buildings [8].

Figure 10 illustrates components of the green roof design that includes vegetation, substrate for growing, drainage element, protection layer, root barrier, insulation layer, membrane for preventing water leakage, and roof deck. Moreover, there are three categories in the design of green roofs such as extensive, semi-extensive, and intensive roof designs. The main differences between these categories depend on weight, system height, type of plants used in the roofs, maintenance, irrigation, and, surely, cost [52].

5.1.1. Thermal benefits of green roofs

Green roofs are considered as one of the primary solutions to mitigate energy demand with increasing energy efficiency in buildings [59]. According to a research in Italy, where traditional roofs were compared, temperature of the green roofs applied in buildings is found by 12°C lower in summertime. As for heating seasons, the green roofs are 4°C hotter than conventional roof systems [54].

Many studies highlight the thickness of growth substrate affecting thermal insulation performance of green roofs. The study considering optimization of thickness reveals that the increase in the thickness of growing media used in green roofs reduces energy consumption and heat transfer compared to conventional roofs. The reductions are estimated between 59

Figure 10. Schematics of different green roof components [58].

and 96% and in the range of 31 and 37% from the viewpoint of energy consumption and heat transfer, respectively [60]. Another research reveals that the increase in soil moisture reduces thermal resistance of green roofs. Briefly, thermal resistance of dry soil increases by 0.4 m^2K/W using 100-mm thickness of growing substrate [61].

5.1.2. Heat flux and energy saving

Green roofs are easy-to-use structures to increase energy saving by mitigating heat flux and improving shading effects. Shading effects have a key role to provide thermal comfort for the dwellers living in green roof buildings. Due to the substantial contribution to the thermal comfort, energy consumption and energy spending by dwellers tend to decrease after the installation of the green roof systems on the buildings [62]. Based on the studies with related leaf thickness and coverage thickness, these parameters play an important role in the thermal regulation for buildings. For instance, in comparison to bare soil, covering the building with plants reduces the temperature by about maximum 6°C during March and April. A further study, also, exposes that the features of vegetation have several effects on daily surface temperature, and it is found to be about 26°C [63]. Depending on the case study, temperature with respect to bare soil, uninsulated roof, and roof covering with GSs is determined to be 42, 57, 26.5°C [52]. Compared to black roof, the temperature falls from 80 to 27°C by deploying green roof systems on buildings [59, 63].

5.2. Vertical greenery systems

Many researchers mention about the advantages of VGSs such that they can provide energy-saving and ecological improvements for buildings placed in (sub)urban areas. Buildings integrated with these systems have potential benefits that cause the reduction in wall temperature arising from wind barriers and shading effect and thermal insulation based on growing media and vegetation [8]. In accordance with green roofs, the vertical systems can also affect both indoor thermal comfort and outdoor environment such as biodiversity and air quality. Some benefits are associated with thermal performance and environmental issues, but the rest of them are linked with architectural aspects and human psychology [64, 65]. The positive effects of VGSs on environment and buildings greatly outweigh in comparison to green roofs because of covered surface areas. The surface areas of VGSs are about 20 times wider than those of the green roofs [66].

In the literature, the VGSs are also called as vertical garden, green wall, vertical green, and bio walls [9, 49]. Green walls comprise green facade and living wall. The main difference between green facade and living wall is the growing style of vegetation such as naturally growing vegetation over building envelope and growing media placed on the ground for green facade [9].

5.2.1. Thermal benefits of green wall

Thermal performance of buildings can be improved by green walls due to shading effects and the effects depend on density of vegetation and coverage. Green walls are vital in mitigating energy demand and thermal comfort for dwellings. These advantages lead to reduced temperature differences between interiors and exteriors of walls due to shadowing and thermal insulation effects. Findings related to surface temperature under green walls reveal that average temperature is assessed by 8°C and the maximum effects on temperature differences between under vegetation and front of the plants are found to be 16°C [67]. According to the same research, the west-facing green walls exposed to solar radiation (189 W/m^2) absorbed 133 W/m^2 of overall radiation; 25 W/m^2 was reflected by foliage; and the rest of them passes through the vegetation.

In the literature, many researchers focus on the reduction in external wall surface temperature. There are some parameters such as location and period of the study, orientation, and foliage thickness which can directly affect the reduction in external wall surface temperature. For instance, several researches carried out by Sternberg found foliage thicknesses to be between 10 and 45 cm, and the reduction in temperature was found in the range 1.7–9.5°C [68]. **Table 1** illustrates some researches with respect to energy savings arising from shading effects.

5.2.2. Blockage of the wind

Previous literature focuses on the effect of VGSs on wind effects, since the wind effects have negative potential influence on energy performance of the buildings. Hence, the blockage of wind is of vital importance to mitigate energy demands on both cooling and heating periods for dwellings integrated with VGSs [69].

During the winter period, the decline in interior temperature of buildings occurs naturally because of the cold wind [73]. The wind blockage used in VGSs contributes to less energy consumption. The blockage feature can be improved by foliage density and characteristics and orientation of green walls, especially wind speed [74]. It is clearly illustrated in literature that energy consumption of buildings notably reduces by the decrease in wind strength. From this point of view, energy demands are mitigated by about 25% by applying VGSs on buildings [75]. The findings reported by another research reveal that when comparing with the bare wall, heating energy expenditure decreases by 8% for cold climates [66].

These findings mentioned earlier show that not only green roofs but also VGSs play a prominent role in mitigating energy demands and carbon emissions owing to having potential effects on energy performance of buildings. In addition to these, GSs provide indoor air quality and better productivity for dwellers. Moreover, the vegetation has an ability to absorb the sound and to reduce the noise level yielding to improved productivity [8, 76]. Furthermore, the excessive temperature increases the number of deaths among older people (≥65) and negatively affects sleep quality of residents [77]. The indoor temperature can be properly regulated by using GSs [78].

5.3. Cost

It needs to be reported that the maintenance and investment costs of green roofs and facades are required to be analyzed in detail. The previous studies indicate that the integration of green roofs

Authors	Orientation	Foliage thickness (cm)	External wall surface temperature reduction (°C)
Perini et al. [70]	North-west	20	1.2
Cameron et al. [71]	North-south	—	7–7.3
Yin et al. [72]	South	4	Max:4.67

Table 1. Green walls highlighting passive energy savings [8].

into existing buildings as a retrofit solution might not be commercially viable in some cases despite their notable beneficial impacts on energy saving [74, 79]. Thermal performance reports reveal that the buildings with full green roofs can provide an energy saving of about $215/year. However, it is underlined that GSs as a retrofit application still have challenges because of long pay-back periods of these systems. It is also reported that GSs might not be suitable for the buildings located in cold climate regions [8, 74]. In spite of the said challenges, there are numerous benefits of GSs such as economic, environmental, and social impacts on city life with mitigating urban heat islands effects, air pollution, and energy demands, as well as providing indoor environment quality [80, 81]. For these reasons, the cost of green roofs can be neglected to be used in the existing buildings.

6. Conclusions

Within the scope of this chapter, GSs are evaluated in terms of a potential energy-efficient retrofitting solution toward low/zero carbon economy. GSs are found to have a leading role to improve the energy performance of the buildings owing to several multifunctional benefits such as thermal regulation of building envelope, remarkable reductions in energy consumption figures, and greenhouse gas emissions, providing indoor air quality, and minimizing urban heat island effects. We can conclude from the results that the building surface temperature can be reduced by about 12°C with green roof retrofit. Moreover, GSs can provide up to 20°C of lower surface temperature in comparison with conventional facades. Furthermore, vertical greenery systems (VGSs) can reduce energy consumption in buildings by about 25% owing to the wind blockage effects in winter.

Author details

Erdem Cuce*, Ahmet B. Besir and Pinar Mert Cuce

*Address all correspondence to: erdemcuce@bayburt.edu.tr

Department of Mechanical Engineering, Faculty of Engineering, Bayburt University,
Bayburt, Turkey

References

[1] Wu J. Landscape sustainability science: Ecosystem services and human well-being in changing landscapes. Landscape Ecology. 2013;**28**:999-1023. DOI: 10.1007/s10980-013-9894-9

[2] Azevedo VG, Sartori S, Campos LMS. CO_2 emissions: A quantitative analysis among the BRICS nations. Renewable and Sustainable Energy Reviews. 2018;**81**:107-115. DOI: 10.1016/j.rser.2017.07.027

[3] UN. World Urbanization Prospects; 2014

[4] Williams J, Mitchell R, Raicic V, Vellei M, Mustard G, Wismayer A, et al. Less is more: A review of low energy standards and the urgent need for an international universal zero energy standard. Journal of Building Engineering. 2016;**6**:65-74. DOI: 10.1016/j.jobe.2016.02.007

[5] Becchio C, Corgnati SP, Delmastro C, Fabi V, Lombardi P. The role of nearly-zero energy buildings in the transition towards post-carbon cities. Sustainable Cities and Society. 2016;**27**:324-337. DOI: 10.1016/j.scs.2016.08.005

[6] Li D, Cui P, Lu Y. Development of an automated estimator of life-cycle carbon emissions for residential buildings: A case study in Nanjing, China. Habitat International. 2016;**57**:154-163

[7] De Boeck L, Verbeke S, Audenaert A, De Mesmaeker L. Improving the energy performance of residential buildings: A literature review. Renewable and Sustainable Energy Reviews. 2015;**52**:960-975

[8] Besir AB, Cuce E. Green roofs and facades: A comprehensive review. Renewable and Sustainable Energy Reviews. 2018;**82**:915-939

[9] Safikhani T, Abdullah AM, Ossen DR, Baharvand M. A review of energy characteristic of vertical greenery systems. Renewable and Sustainable Energy Reviews. 2014;**40**:450-462

[10] IPCC. Working Group I Contrubition to the IPCC Fifth Assessment Report, Climate Change 2013: The physical science basis, Summary For Policy Makers; 2013

[11] International EnergyAgency. CO_2 Emissions from Fuel Combustion; 2017

[12] International Energy Agency. Energy, Climate Change & Environment; 2016

[13] Wang N, Phelan PE, Harris C, Langevin J, Nelson B, Sawyer K. Past visions, current trends, and future context: A review of building energy, carbon, and sustainability. Renewable and Sustainable Energy Reviews. 2018;**82**:976-993

[14] Srinivasan RS, Braham WW, Campbell DE, Curcija CD. Re (de) fining net zero energy: Renewable emergy balance in environmental building design. Building and Environment. 2012;**47**:300-315

[15] Wang T, Seo S, Liao P-C, Fang D. GHG emission reduction performance of state-of-the-art green buildings: Review of two case studies. Renewable and Sustainable Energy Reviews. 2016;**56**:484-493

[16] Kampelis N, Gobakis K, Vagias V, Kolokotsa D, Standardi L, Isidori D, et al. Evaluation of the performance gap in industrial, residential and tertiary near-zero energy buildings. Energy and Buildings. 2017;**148**:58-73

[17] International EnergyAgency. Tracking Clean Energy Progress 2017; 2017

[18] Ürge-Vorsatz D, Novikova A. Potentials and costs of carbon dioxide mitigation in the world's buildings. Energy Policy. 2008;**36**:642-661. DOI: 10.1016/j.enpol.2007.10.009

[19] European Union. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings. Brussel, Belguim: European Union; 2010

[20] Annunziata E, Frey M, Rizzi F. Towards nearly zero-energy buildings: The state-of-art of national regulations in Europe. Energy. 2013;**57**:125-133

[21] Andrews-Speed P. Applying institutional theory to the low-carbon energy transition. Energy Research and Social Science. 2016;**13**:216-225

[22] Enker RA, Morrison GM. Analysis of the transition effects of building codes and regulations on the emergence of a low carbon residential building sector. Energy and Buildings. 2017;**156**:40-50. DOI: 10.1016/j.enbuild.2017.09.059

[23] Ferrari S, Beccali M. Energy-environmental and cost assessment of a set of strategies for retrofitting a public building toward nearly zero-energy building target. Sustainable Cities and Society. 2017;**32**:226-234

[24] Levine M, Zheng N, Williams C, Amann JT, SD. Building Energy-Efficiency Best Practice Policies and Policy Packages. Berkeley, CA, United States: Lawrence Berkeley National Lab (LBNL); 2012

[25] Livingston O, Cole P, Elliott D, Bartlett R. Building energy codes program: National benefits assessment. Tech. Rept. PNNL-22610. Pacific Northwest National Laboratory; 2014

[26] Li DH, Yang L, Lam JC. Zero energy buildings and sustainable development implications: A review. Energy. 2013;**54**:1-10

[27] Laustsen J. Energy efficiency requirements in building codes, energy efficiency policies for new buildings. International Energy Agency (IEA). 2008;**2**:477-488

[28] Deng S, Wang RZ, Dai YJ. How to evaluate performance of net zero energy building: A literature research. Energy. 2014;**71**:1-16. DOI: 10.1016/j.energy.2014.05.007

[29] Esbensen TV, Korsgaard V. Dimensioning of the solar heating system in the zero energy house in Denmark. Solar Energy. 1977;**19**:195-199

[30] EISA. CRS Report for Congress: Energy independence and security act of 2007: December 21. Washington, DC: US Government; 2007

[31] Riedy C, Lederwasch A, Ison N. Defining Zero Emission Buildings: Review and Recommendations; 2011

[32] Pless S, Paul Torcellini P. Getting to net zero. ASHRAE Journal. 2009;**51**:18

[33] European Parliament. All new buildings to be zero energy from 2019; 2009

[34] Hernandez P, Kenny P. From net energy to zero energy buildings: Defining life cycle zero energy buildings (LC-ZEB). Energy and Buildings. 2010;**42**:815-821

[35] SEAI. Residential Energy Roadmap: SEAI - Sustainable Energy Authority of Ireland; 2013

[36] PRP Architects. Zero Carbon Compendium: Who’s Doing What in Housing Worldwide. London: NHBC Foundation; 2009

[37] European Commission. Summary of the impact assessment. Accompanying to the Proposal for a Recast of the Energy Performance of Buildings (2002/91/EC). Brussels Belguim; 2008

[38] Becchio C, Bottero M, Corgnati S, Ghiglione C. nZEB design: Challenging between energy and economic targets. Energy Procedia. 2015:2070-2075. DOI: 10.1016/j.egypro.2015.11.226

[39] Kuusk K, Kalamees T. nZEB retrofit of a concrete large panel apartment building. Energy Procedia. 2015;**78**:985-990. DOI: 10.1016/j.egypro.2015.11.11.038

[40] Fraunhofer-Institute. Study on the energy savings potentials in EU member states, Candidate countries and EEA countries. Final Report for the European Commission Directorate-General Energy and Transport; 2009

[41] Ecofys. Sectoral Emission Reduction Potentials and Economic Costs for Climate Change (SERPEC-CC). Summary Report; 2009

[42] Ferreira M, Almeida M, Rodrigues A. Impact of co-benefits on the assessment of energy related building renovation with a nearly-zero energy target. Energy and Buildings. 2017;**152**:587-601

[43] Economics C. Multiple Benefits of Investing in Energy Efficient Renovation of Buildings: Impact on Public Finances. Renovate Europe: Copenhagen; 2012

[44] Stoecklein A, Zhao Y, Christie L, Skumatz L. The Value of Low Energy Technologies for Occupant and Landlord. ANZSEE Conference, Palmerston North, New Zealand; 2005

[45] Jakob M. Marginal costs and co-benefits of energy efficiency investments: The case of the Swiss residential sector. Energy Policy. 2006;**34**:172-187

[46] Edwards L, Torcellini P. Literature Review of the Effects of Natural Light on Building Occupants. Golden, CO, USA: National Renewable Energy Lab; 2002

[47] Berry S, Whaley D, Davidson K, Saman W. Near zero energy homes–What do users think? Energy Policy. 2014;**73**:127-137

[48] Hansen A, Bi P, Nitschke M, Ryan P, Pisaniello D, Tucker G. The effect of heat waves on mental health in a temperate Australian city. Environmental Health Perspectives. 2008;**116**:1369

[49] Manso M, Castro-Gomes J. Green wall systems: A review of their characteristics. Renewable and Sustainable Energy Reviews. 2015;**41**:863-871

[50] Pérez G, Rincón L, Vila A, González JM, Cabeza LF. Green vertical systems for buildings as passive systems for energy savings. Applied Energy. 2011;**88**:4854-4859. DOI: 10.1016/j.apenergy.2011.06.032

[51] Ichihara K, Cohen JP. New York City property values: What is the impact of green roofs on rental pricing? Letters in Spatial and Resource Sciences. 2011;**4**:21-30

[52] Raji B, Tenpierik MJ, van den Dobbelsteen A. The impact of greening systems on building energy performance: A literature review. Renewable and Sustainable Energy Reviews. 2015;**45**:610-623

[53] Coma J, Pérez G, Solé C, Castell A, Cabeza LF. Thermal assessment of extensive green roofs as passive tool for energy savings in buildings. Renewable Energy. 2016;**85**:1106-1115

[54] Bevilacqua P, Mazzeo D, Bruno R, Arcuri N. Experimental investigation of the thermal performances of an extensive green roof in the Mediterranean area. Energy and Buildings. 2016;**122**:63-79

[55] He Y, Yu H, Dong N, Ye H. Thermal and energy performance assessment of extensive green roof in summer: A case study of a lightweight building in Shanghai. Energy and Buildings. 2016;**127**:762-773

[56] Tang X, Qu M. Phase change and thermal performance analysis for green roofs in cold climates. Energy and Buildings. 2016;**121**:165-175

[57] Karteris M, Theodoridou I, Mallinis G, Tsiros E, Karteris A. Towards a green sustainable strategy for Mediterranean cities: Assessing the benefits of large-scale green roofs implementation in Thessaloniki, northern Greece, using environmental modelling, GIS and very high spatial resolution remote sensing data. Renewable and Sustainable Energy Reviews. 2016;**58**:510-525

[58] Vijayaraghavan K. Green roofs: A critical review on the role of components, benefits, limitations and trends. Renewable and Sustainable Energy Reviews. 2016;**57**:740-752. DOI: 10.1016/j.rser.2015.12.119

[59] Castleton HF, Stovin V, Beck SB, Davison JB. Green roofs; building energy savings and the potential for retrofit. Energy and Buildings. 2010;**42**:1582-1591

[60] Permpituck S, Namprakai P. The energy consumption performance of roof lawn gardens in Thailand. Renewable Energy. 2012;**40**:98-103

[61] Wong NH, Cheong DKW, Yan H, Soh J, Ong C, Sia A. The effects of rooftop garden on energy consumption of a commercial building in Singapore. Energy and Buildings. 2003;**35**:353-364

[62] Yan B. The research of ecological and economic benefits for green roof. In: Applied Mechanics and Materials. Trans Tech Publications; 2011. pp. 2763-2766

[63] Saadatian O, Sopian K, Salleh E, Lim C, Riffat S, Saadatian E, et al. A review of energy aspects of green roofs. Renewable and Sustainable Energy Reviews. 2013;**23**:155-168

[64] Wong I, Baldwin AN. Investigating the potential of applying vertical green walls to high-rise residential buildings for energy-saving in sub-tropical region. Building and Environment. 2016;**97**:34-39

[65] Marchi M, Pulselli RM, Marchettini N, Pulselli FM, Bastianoni S. Carbon dioxide sequestration model of a vertical greenery system. Ecological Modelling. 2015;**306**:46-56. DOI: 10.1016/j.ecolmodel.2014.08.013

[66] Pérez G, Coma J, Martorell I, Cabeza LF. Vertical greenery systems (VGS) for energy saving in buildings: A review. Renewable and Sustainable Energy Reviews. 2014;**39**:139-165. DOI: 10.1016/j.rser.2014.07.055

[67] Di HF, Wang DN. Cooling effect of ivy on a wall. Experimental Heat Transfer. 1999;**12**:235-145

[68] Sternberg T, Viles H, Cathersides A. Evaluating the role of ivy (*Hedera helix*) in moderating wall surface microclimates and contributing to the bioprotection of historic buildings. Building and Environment. 2011;**46**:293-297. DOI: 10.1016/j.buildenv.2010.07.017

[69] Hunter AM, Williams NSG, Rayner JP, Aye L, Hes D, Livesley SJ. Quantifying the thermal performance of green façades: A critical review. Ecological Engineering. 2014;**63**:102-113. DOI: 10.1016/j.ecoleng.2013.12.021

[70] Perini K, Ottelé M, Fraaij ALA, Haas EM, Raiteri R. Vertical greening systems and the effect on air flow and temperature on the building envelope. Building and Environment. 2011;**46**:2287-2294. DOI: 10.1016/j.buildenv.2011.05.009

[71] Cameron RWF, Taylor JE, Emmett MR. What's 'cool' in the world of green façades? How plant choice influences the cooling properties of green walls. Building and Environment. 2014;**73**:198-207. DOI: 10.1016/j.buildenv.2013.12.005

[72] Yin H, Kong F, Middel A, Dronova I, Xu H, James P. Cooling effect of direct green façades during hot summer days: An observational study in Nanjing, China using TIR and 3DPC data. Building and Environment. 2017;**116**:195-206. DOI: 10.1016/j.buildenv.2017.02.020

[73] Eumorfopoulou EA, Kontoleon KJ. Experimental approach to the contribution of plant-covered walls to the thermal behaviour of building envelopes. Building and Environment. 2009;**44**:1024-1038. DOI: 10.1016/j.buildenv.2008.07.004

[74] Feng H, Hewage K. Energy saving performance of green vegetation on LEED certified buildings. Energy and Buildings. 2014;**75**:281-289

[75] Dinsdale S, Pearen B, Wilson C. Feasibility study for green roof application on Queen's University campus. Queen's Physical Plant Services. 2006

[76] Payne SR. The production of a perceived restorativeness soundscape scale. Applied Acoustics. 2013;**74**:255-263

[77] Hoelscher M-T, Nehls T, Jänicke B, Wessolek G. Quantifying cooling effects of facade greening: Shading, transpiration and insulation. Energy and Buildings. 2016;**114**:283-290. DOI: 10.1016/j.enbuild.2015.06.047

[78] Fernández-Cañero R, Urrestarazu LP, Salas AF. Assessment of the cooling potential of an indoor living wall using different substrates in a warm climate. Indoor and Built Environment. 2012;**21**:642-650. DOI: 10.1177/1420326X11420457

[79] Francis RA, Lorimer J. Urban reconciliation ecology: The potential of living roofs and walls. Journal of Environmental Management. 2011;**92**:1429-1437. DOI: 10.1016/j.jenvman.2011.01.012

[80] Oberndorfer E, Lundholm J, Bass B, Coffman RR, Doshi H, Dunnett N, et al. Green roofs as urban ecosystems: Ecological structures, functions, and services. Bioscience. 2007;**57**:823-833

[81] Currie BA, Bass B. Estimates of air pollution mitigation with green plants and green roofs using the UFORE model. Urban Ecosystems. 2008;**11**:409-422

Section 3

Economic Assessment

Innovations for a Low-Carbon Economy in Asia: Past, Present, and Future

Venkatachalam Anbumozhi

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.76363

Abstract

Low-carbon technology development is crucial for country's economic and social transformation. It is often influenced by policy factors and multiple actors, both internal and external. This chapter explores the journey of low-carbon energy policymaking in four Asian countries: Based on critical analysis, three major conclusions are arrived in, about the dynamics of innovations in low-carbon energy policy making. First, a transition into a low-carbon energy economy involves distinguishable temporal and developmental phases, often characterized by hierarchy, aggregation, and space. In the initial period, technology policy choices are made to meet the growing concerns of energy security and access, later of reliability, and then of climate change. Past policies, technology-oriented top-down, are gradually being replaced or complemented by market-oriented policies. A second conclusion is that the ongoing low-carbon economic transition is enhanced by regional cooperation. Adoption of an action plan for regional energy cooperation created enabling environment for paradigm shifts in national energy policy making. Third, the flying geese model of economic integration points to a new way of regional cooperation to solve low-carbon energy policy dilemmas, with no formal involvement of policy institutions, but works according to market principles. To benefit as much as possible from that niche, developing countries need and create an environment more conducive to smooth the flow of low-carbon technology and services.

Keywords: climate change, energy security, low-carbon technology, regional cooperation

1. Introduction

Asian countries face a set of interconnected yet fundamental low-carbon technology and policy dilemmas. The region's rapidly industrializing economies, intensifying levels of urbanization, and Paris Agreement have created unprecedented demand for low-carbon energy services. This is occurring amidst rising demands from increasing prosperity of middle-class population. Average energy use per capita of the Asian countries remains quite low—about 0.61 metric tons of oil equivalent per person—compared to 4.67 for Japan and 1.69 for the world. Indeed, as of 2015, this region has at least 134 million people, or 22% of the population, without access to electricity [1].

By 2030, energy demand is expected to double in the region. According to several projections [1–4], the increase in regional demand will account almost 30% of the world total [5]. Policy makers in this region, face challenges in developing and distributing the low-carbon energy resources, from their remote locations to those urban centers of production and livelihood, where they are needed most. Moreover, the economic, energy, and emission geography of Asian countries is highly uneven. While the Southeast Asia region is of equal size as European Union and has a greater population as a whole than North America, its coal, oil, gas, and other renewable energy resources such as hydro and biomass are unevenly distributed, as are the stages of their low-carbon technology development.

The challenge of low-carbon technology deployment in this region is rivaled by the difficulties associated with improving energy security and protecting the environment. While Asia has major energy importing economies, namely, Singapore, Philippines, and Vietnam, it also has major energy exporters like Indonesia, Malaysia, and Brunei. This region is home to thousands of low-lying islands comprising major portions of Indonesia and the Philippines that are extremely disadvantaged in terms of energy access. The region's experience with growing natural disaster has also placed significant pressure on its energy security and the maintenance of the energy infrastructure and, in particular, fragile energy supply lines and transmission lines. Following on from Paris Agreement in December 2015, these countries' attention is also now increasingly fixed in advancing viable and scalable low-carbon energy transformation options. Asian countries have also announced plans to construct mega power grids and trans-regional gas pipeline, which are envisioned to bring affordable and available low-carbon energy resources in an acceptable and sustainable manner. Such regional cooperation efforts, challenges as they may be, will increasingly become a major driving force for national low-carbon technology policies.

Are the energy policy choices made in the past relevant in the long-term solutions for low-carbon economy? Are the new policies replacing the older one in a smarter way to support the future needs of low-carbon economy? Would current regional cooperation plans, actors, and stakeholder networks formed during the different stages of energy transition contribute to low-carbon economy? Is there any observed effects of policy path dependency resulted from greater Asian economic cooperation that is desirable and open up new window of opportunity for tackling multiple energy challenges? With these questions in mind, this chapter explores the low-carbon energy transition that is taking place in Indonesia, Malaysia, the Philippines, and Thailand that involve different temporal and developmental phases. The first two are fossil energy exporters, and the other three are net oil importers and preoccupied with concerns over energy security. Based on extensive literature review, drawing upon targeted information on policies and stakeholder networks, cooperation efforts evolved in these countries, and utilizing extensive analysis of governmental reports, this chapter examines the low-carbon energy policies of the past from a new angle of energy transition for sustainability.

The importance of such an exploration is threefold. First, the notion of transition provides an important lens through which we can understand the dynamics of low-carbon energy policy making and a host of other related issues related to low-carbon technology innovations. Relationship between economic development, industrialization, trade flows, and regional security all revolves around the basic access to and allocation of energy resources in a low-carbon way. Second, the prospects and challenges inherent with regional cooperation initiatives provide insights into the difficulties associated with large-scale low-carbon technology market transition. Third, an investigation on the path dependency in the transition low-carbon energy policy making that is associated with the other forms of economic integration such as flying geese industrial catchup paradigm helps to identify the key driving forces for modernizing the economies in a low-carbon way. Focusing on these three issues provide useful insights into how likely future low-carbon energy policies may evolve, to whether rhetoric of transition to low-carbon economy holds up under scrutiny.

2. Low-carbon energy policy development in Asia

2.1. Energy supply and demand outlook

With combined economic growth of 6%, the four economies Indonesia, Malaysia, the Philippines, and Thailand, which are rich in fossil energy rescues, have liberalized economic policies that have attracted many foreign investors. **Table 1** gives the energy profile of the countries.

Country	Oil reserve (billion barrels)	Natural gas reserve (trillion cubic feet)	Coal reserve (million MT)	Hydropower resource (GW)	Geothermal use (MWe)	Biomass (MT)	Per capita energy consumption (TPES/capita) (toe)	Population without access to electricity (%)
Indonesia	10	169.5	38,000	75	1,160	439	0.89	20%
Malaysia	3.4	84.4	1,025	25	—	137	3.00	1%
Philippines	0.26	4.6	346	9	1465	89	0.48	21%
Thailand	0.2	12.2	1,240	10	5	67	0.73	1%

Source: [6].

Table 1. Low-carbon energy resources and reserves in major Asian countries.

The use of high-carbon energy—coal, oil, gas, and electricity—has increased substantially in Indonesia, Malaysia, the Philippines, and Thailand, in the last 25 years, with an annual growth rate of 7%. The annual energy requirement of the countries is expected to increase by 4.2% over the next 25 years where the figure is just 1.7% for the world [4, 5]. Because of its large population, Indonesia is responsible for about half of the primary energy consumption of the region. The region is endowed with about 8% of the fossil fuel resources in the world. The diversity of available energy resources provides opportunity for cooperation. For example, nearly all of the coal reserves are located in Indonesia (83%) and Vietnam (10%); natural gas and oil are found in Brunei, Indonesia, Malaysia, and Vietnam. Indonesia and the Philippines possess substantial reserves of geothermal energy, ranking them as the second and fourth largest producers of energy from geothermal resources. Hydropower is abundant in Thailand, Indonesia, and Viet Nam. All the countries are endowed with biomass, a common noncommercial energy source for cooking, particularly in the rural areas.

In the Business-as-Usual (BAU) scenario, the total primary energy supply (TPES) of these countries is projected to increase steadily from 619 million tonnes of oil equivalent (Mtoe) in 2013 to 1685 Mtoe in 2040, growing at an annual rate of 4.7%. This projected growth is higher than the trends observed between 1990 and 2013, which averaged 4.2% per year [7]. Carbon emissions during the period are estimated to grow at the rate of 4.0% per year. The difference between TPES in the alternate policy scenario (APS) and the BAU scenario (**Figure 1**) shows approximately the potential of energy saving that could be achieved by these countries through the implementation of their advanced policies on energy efficiency in electricity power production and consumption, transport, residential, and industry sectors. Low-carbon technology policies such as energy efficiency improvement are expected to contribute to a reduction of energy demand of 13% by the end of 2035 [7].

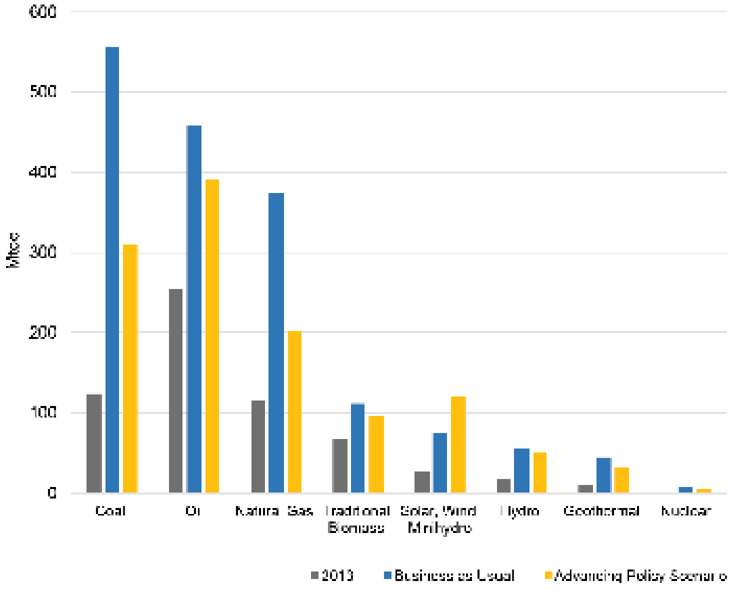


Figure 1. Comparison of future energy supply scenarios in 2030. Source: [8].

Coal and oil are cheaper and abundant compared with other sources of energy and hence going with the natural choice for the region to fulfill its sharp increase in the energy demand to support economic development. At the same time, they are the major source of air quality and greenhouse gas (GHG) emissions, accounting for 18% of carbon dioxide (CO_2) emission [9]. Further, the increasing energy security concerns as implied in **Table 2** have alarming implications for policy making. External costs related to air pollution from the combustion of fossil fuels will increase by 35%, from USD 167 billion annually in 2014 to USD 225 billion in 2025, which also equals to 5% of the regional gross domestic product (GDP) in 2025 [8]. Consequently, these countries will see rising costs for energy supply security and for controlling pollution.

2.2. The path of low-carbon energy policy development

Although these four countries are abundant in renewable energy resources, its low-carbon technology development and diffusion have been held back over a quite long period due to several economic, environmental, and social concerns and institutional constraints. There has been neither uniform strategy nor clear milestones for energy development prior to the 1950s, during which period, the choice of the policies was very much dependent on the framework conditions laid by colonial era governments. In Indonesia and Malaysia, the history of oil and mineral explorations was initially set by the Dutch and British governments. In the Philippines, it was under the influence of the USA. Currently coal and oil remain as the main energy sources, despite their efforts to diversify energy mix. Such dependency on fossil fuels began with the development of petroleum and mining industry, which took place in the nineteenth century. The extracted energy resources were mainly used to support industrial advancement of the colonial powers. Foreign entities played a major role in the exploration and extraction activities until the 1940s. Upon independence, with limited experience and expertise, the governments began to take over industry, including redirecting the trajectory of related policies and institutions. However, it was not easy to drastically deviate from the old institutional settings, industrialization patterns, shared economic beliefs, and sociopolitical values. Accordingly the transition path to low-carbon economy in Asia can be characterized by the following major stages.

2.2.1. Changing development perceptions and setting energy sector goals (1960–1980)

During this period, major economies in the region, especially Indonesia, Malaysia, Thailand and, the Philippines, have had stable energy policies, with the exploration of new

Countries	**Self-sufficiency (energy production/total primary energy supply)**			
	2000	**2005**	**2010**	**2015**
Indonesia	1.86	1.75	1.66	1.60
Malaysia	1.01	1.00	0.99	0.94
Philippines	0.57	0.58	0.53	0.43
Thailand	0.53	0.65	0.59	0.58

Source: [1].

Table 2. Energy self-sufficiency in major southeast Asian countries.

carbon-intensive energy sources, coal in Indonesia, oil and natural gas in Malaysia, hydro power in Thailand, and geothermal in the Philippines. This is due to shift from traditional agriculture to modern industrial economies, which increased the demand for energy. Both the accelerated introduction of high-carbon coal and oil into energy mix and experiences with differentiated tariff systems for industries, agriculture, and households led to changes in the policy perceptions of the national governments.

Governments of Thailand and Malaysia established central electricity authorities and provincial-level authorities to serve the new industrial units and fast growing towns. The functions of national monopolies such as Energy Generating Authority of Thailand, Perusahaan Listrik Negara (PLN) of Indonesia, Energy Development Corporation of the Philippines got strengthened over a short period of time. They were also instrumental in building modern electricity distribution systems that were integrated into the existing and expanded national power grids. This market niche allowed high profits for these state-owned enterprises. Offering stable energy supply at lower prices to large industries also helped the national governments to start luring several energy intensive industries. But this development is supported by external actors, outside the national regimes, namely, international financial institutional like Asian Development Bank (ADB) and World Bank, during which period the economic assistance to these five countries amounted to 121 billion USD [10].

Several technical cooperation studies were also initiated during this period with financial support by bilateral agencies like Japan Agency for International Cooperation (JICA) and German Technical Cooperation Agency (GTZ) with the aim of establishing effective energy policy at national level that have set targets for improving energy access, removing energy poverty and supporting industrial development. From the mid-1970s, the state-owned electricity utility companies also started adopting gas turbines and small renewable energy plants for peak load generation and off-grid electricity supply. This was the response to increasing number of power blackouts, when demand exceeded supply in urban centers, and to support mass electrification programs targeting the rural poor in Indonesia, Malaysia, and the Philippines. The expansion of electricity grid and economies of scale enabled the power generation and utility companies to expand their markets. The share of independent power producers such as large factories and industries was reduced to about 10 percent by the 1980s in Thailand [11].

The dominant actors in the network of carbon-intensive development regimes are the national governments, power generation, and utility companies, as well as international development partners (**Figure 2**). National governments, state-run power generation companies, and utilities form the core of energy policy making. The provinces, municipalities, and public are, nevertheless, kept at a distance from the energy policy regime and did not interfere with its functioning. With regard to the users, however, a distinction could be made between large power users, namely, industry, big factories, and small power users such as households. The latter was situated at the edge of the policy regime, not really exerting direct influence.

The oil crisis of 1973–1974 and 1979–1980 was an external shock to most of the Southeast Asian countries. Concerns over energy security were felt by entire network of actors. As a result, the Philippines established the national oil company in 1973; Malaysia passed the Petroleum Development Act in 1974, establishing its own national oil company PETRONAS. Thailand

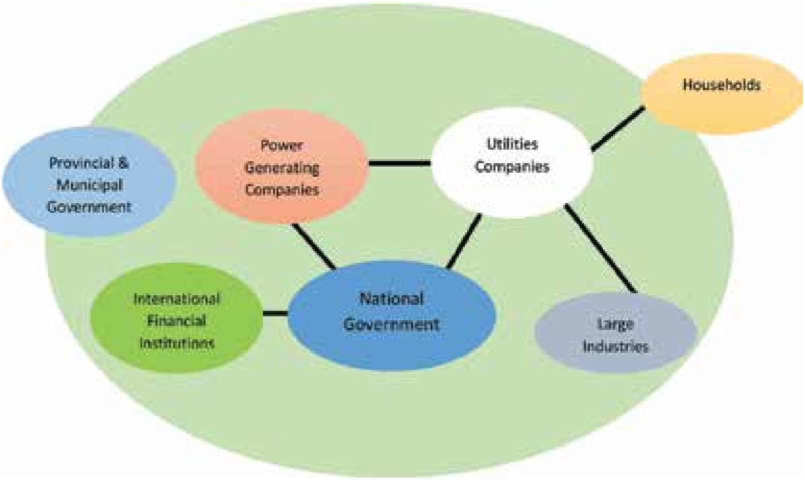


Figure 2. Actors and networks in the earlier carbon-intensive energy policy regime (mid-1970s).

took its first Energy Structural Adjustment Loan from the World Bank, and Indonesia started the first fuel subsidy program, which had profound implications on the economic systems in the coming years.

2.2.2. *Changes in energy sector objectives, rules, and privatization (1980–2000)*

Since the early 1980s, these countries have started witnessing high economic growth, and governments have gradually changed their energy policies in synchronization with industrial policies. The main approach to energy sector development has been deregulation, privatization of technology, and utility companies and market competition. This is partly attributed to countries like Indonesia, Thailand, Malaysia, and the Philippines becoming the part of the greater Asian economic integration process and the industrial production networks, as to be explained by flying geese pattern [12]. Most of the governments started to separate their legislative functions with regard to energy from the daily operation management, through formation-independent regulatory bodies or energy commissions. Under the build-own-transfer (BOT), build-own-operate (BOO), and joint venture mechanisms, the private sector has been encouraged to get involved in energy technology and infrastructure projects in terms of research, investment, construction, transmission, distribution, and daily operation management. In particular, Thailand and the Philippines have increasingly looked to private sector to finance energy developments. During mid-1990s, Thailand has privatized its energy development authority, deregulation of energy sector started in Malaysia, Indonesia permitted independent power producers (IPPs), and disinvestment of started in Philippines Energy Development Corporation. It has stared agreements with private companies to construct geothermal power plants.

On the other hand, energy efficiency has been low in production, distribution, and industrial sectors. For instance, in 1995 about 28% generated electricity was lost during transmission in the Philippines and 13% in Thailand. In order to improve the efficiency of their energy sectors and achieve better economic returns, many governments have reduced subsidies for energy production and consumption. The 1997 Asian financial crisis also found its impact on energy sector. After the crisis, energy prices have moved to being decided by market forces. Indonesia and Thailand, the countries most affected by 1997 financial crisis, were also under advice from international lenders to undertake structural reforms within the electricity sector to operate more efficiently by removing the subsidies.

With regard to energy efficiency policy, demand side management (DSM) has got increased attention in Malaysia and Thailand. Asian Development Bank (ADB), Economic and Social Commission of Asia Pacific (ESCAP), and Japan International Cooperation Agency (JICA) were instrumental in bringing many demonstration projects. On the other hand, privatization of electricity sector has required an increase of energy product sales to sustain the profits of newly privatized energy companies. Therefore, there has been little incentive for them to pursue DSM.

With regard to actors and networks, although the stakeholders remained the same, linkages in the social network changed, especially as a result of decreasing role of the national government on the energy policy regime, which has started a shift toward low-carbon development. The minor changes are illustrated in **Figure 3**. Provincial and municipal governments become part of core energy policy making. Community-based organizations had started influencing role, albeit indirectly. Subsequently, the pressure on the energy regime in countries like Indonesia and Thailand in the early 1990s came from increasing societal concerns about environmental impacts of large-scale private sector-initiated energy projects. This coupled with awareness on energy efficiency and the 1997 Asian financial crisis and its impact on high energy prices brought in the activities of international nongovernment organizations into the energy policy regime, though they are kept at the edge of the daily operational decisions (**Figure 4**).

2.2.3. Focus on renewable energy markets, social inclusion, and sustainability (2000–Present)

This was a dramatic time for all the four Asian countries, as energy supply security, economic integration, and climate change issues have started dominating the policy agenda

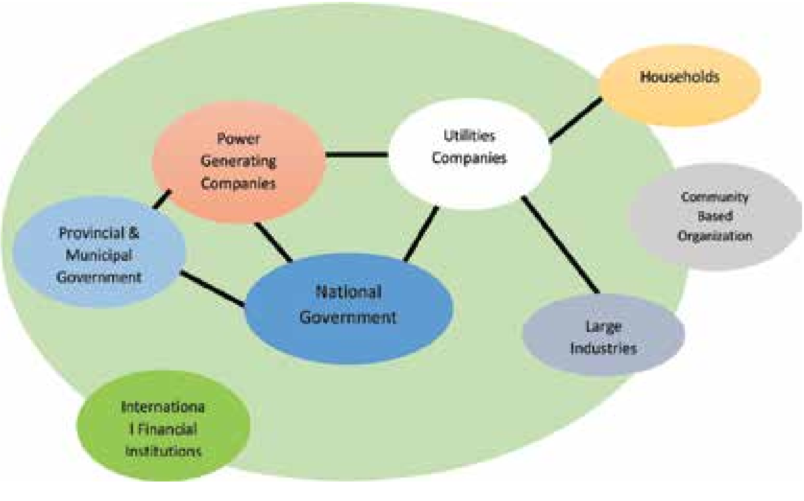


Figure 3. Actors and networks in the transition energy policy regime (mid-1990s).

http://dx.doi.org/10.5772/intechopen.76363

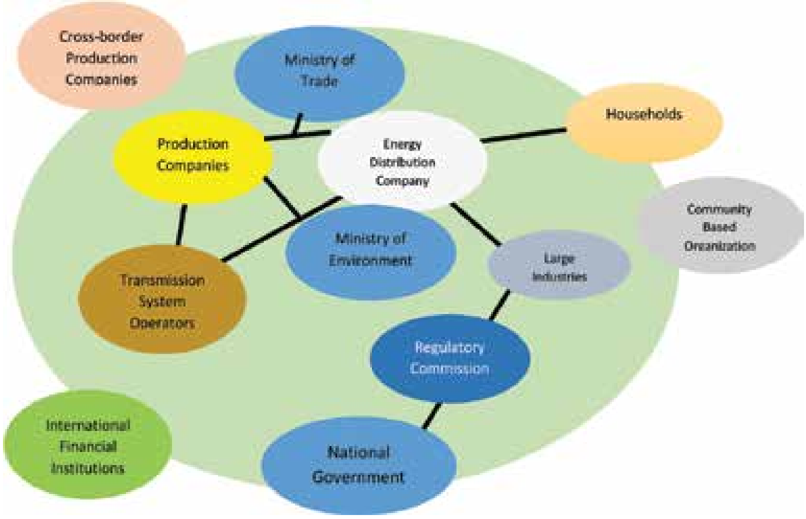


Figure 4. Actors and networks in the low-carbon technology policy regime (present). Source [17].

of national governments. The risks to energy security of supply became evident again during the food, fuel, and financial crisis of 2008. It had an effect on affordability of energy by low-income households, small-sized business, and other economic activities vulnerable to gasoline price volatility and high electricity tariff. Governments started finding niche in harnessing locally available renewable energy resources. Most of energy and electricity laws such as Thailand's establishment of Ministry of Energy (2002), Malaysia's National Biofuel policy (2006), Establishment of National Energy Council in Indonesia (2007), and the Philippines Renewable Energy Corporation (2008), helped to accelerate low-carbon energy deployment. **Table 3** illustrates the targets and policy instruments made available to increase the uptake of renewable energy in the study countries.

Renewable electricity production and supply to the grid by private actors, for example, solar and wind firms, are being accelerated, and a national standard-base tariff was established. The aim of these policy changes was to enhance market dynamism and efficiency.

Country	Renewable energy targets	Policy measures
Indonesia	23% share of renewable energy in the final energy mix	Feed-in tariff
Malaysia	4000 MW of installation capacity from renewable sources	Feed-in tariff, renewable energy standards
Philippines	38.6% share of renewable energy in the primary energy supply	Feed-in tariff Renewables Portfolio Standard, capital subsidies, tax incentives
Thailand	20% share of renewable energy in the power generation by 2036	Feed-in tariff, feed-in premium, biodiesel blending mandate

Source: authors.

Table 3. Renewable energy target and policy measures by 2030.

Country	Energy products subsidized	Energy policy reforms
Indonesia	Gasoline, diesel, kerosene for households and small business, LPG, and electricity	Increased price of gasoline by 44% and diesel by 22% in 2013. Promoting natural gas use in transport to reduce oil subsidies. Continuing successful kerosene to LPG conversion program in 2007. Electricity tariffs are set to rise by 20% in 2020, for all but consumers with the lowest level of consumption
Malaysia	Electricity, natural gas, and kerosene	Subsidies to gasoline and diesel were reduced in a bid to cut the budget deficit. Implemented a subsidy removal program in 2011 that gradually increase natural gas and electricity prices
Thailand	LPG prices controlled. Diesel and natural gas for vehicles. Electricity for poor households	Since 2013, increasing LPG prices every month for all but street vendors and consumers with the lowest level of energy consumption. Increased electricity tariff from 2013, which will be revised every 6 months

Source: authors.

Table 4. Fossil fuel subsidy reforms.

Removing pervasive subsidies is also a part of energy policy reforms being implemented during this period. In most of the countries, these fuel subsidies are targeted at gasoline and diesel as well as more socially sensitive products, namely, liquefied petroleum gas (LPG), kerosene, and electricity. As they were typically introduced to help improve the living conditions of the poor by making fuels affordable and accessible. However, they have resulted in market distortions while failing to meet their intended objectives. Fossil fuel subsidies in Southeast Asian countries amounted for $ 51 billion in 2012 [5]. Spending on subsidies has been significant in Indonesia and Malaysia, both of which are starting to become increasingly dependent on energy imports. Growing recognition that subsidies are not sustainable and are having many unintended consequences, the governments introduced specific reforms as listed in **Table 4**.

In particular, market-oriented subsidy policies are so politically sensitive in the region, the pace and ambition of reform efforts often accompanied by creation of social-safety net programs, which were found successful. For example, in 2015, when the government of Indonesia made a decision to abolish the subsidies to carbon-intensive gasoline and diesel, that policy was integrated with stronger social protection programs. When it reduced its energy subsidies and raised fuel prices, the government established a program to transfer unconditional quarterly payment of $30–15.5 billion poor households. The same move was undertaken when the fuel prices were raised in May 2008, with $ 1.52 billion being allocated as direct cash transfer to low-income households. The conditional cash transfer programs are intended to increase the levels of education and health of poor communities. These experiences show that it is possible to design successful low-carbon policies, with adequate social welfare programs and make the transition as inclusive as possible (**Figure 4**).

Parallel to these events, the international negotiation on a Post Kyoto regime called for urgent need to address climate change. The Bali Road map adopted at the 13th Conference of Parties (COP 13) in 2007 set off a forward-looking energy policy decisions that need to be undertaken by all the countries. Southeast Asian countries responded to these challenges by launching ambitious renewable energy and energy efficiency targets as they were obligated to reduce emissions on voluntary basis. On the other hand, the financial crisis of 2008 and the accompanied stimulus packages provided economic opportunities on tackling climate change actions that contributed for job creation, green growth, and increase competitiveness of small business. Despite the drop in oil prices in 2014, which provided enough political space for introducing subsidy reforms, it failed to improve energy efficiency, and climate change mitigation actions remained not high on the energy policy making priorities of these countries. At the same time, the formation of ASEAN Economic Community in 2015 paved the way for more integrated energy markets. Ratification of nationally determined contributions (NDC) as agreed in Paris-COP 21 by the governments provides another opportunity to work on a policy package with five mutually enforcing and closely interrelated dimensions of energy security, energy efficiency, a fully integrated regional energy market, a decarbonized economy, and financial innovations.

The actors and social networks have also changed substantially because of 2008 financial crisis and ongoing efforts on regional economic integration. The national governments become part of the regional economic policy landscape, as its formal powers and responsibilities to design energy policies with multiple objectives increased the policies of ministries of trade, environment, and infrastructure have started influencing energy policy making. And the growth of independent power producers and decentralized electricity systems of renewable energy producers and consumers, making them also part of the energy policy regimes to decide on environment and social priorities. The articles of association—Heads of ASEAN Power Utilities Authorities (HAUPA)— and the formal arrangement of the cooperation between the state-owned utilities promoted electricity trade across the borders. For example, the import of electricity by Thailand from Laos at lower prices has jumped from almost nothing in 1980 to 5000 MWh in 2000, which kept the push for further adjustments in the regulatory and institutional frameworks, to manage the complicated ownership between production companies and consumers located across the borders. New International transmission System Operators (TSO) responsible for the operation of balancing supply and demand and taking care of cross border connections also become part of the new energy policy regime.

2.3. Cross-country comparison on low-carbon technology policy pathways

Lessons from Indonesia, Malaysia, the Philippines, and Thailand taught that a number of factors mainly local renewable energy resource endowments, complex governance structures, and international players have combined effect on low-carbon economy transition. Taking a multilevel low-carbon energy transition analysis helped to identify two distinguishable patterns in technology policy pathways. Experiences from Indonesia and Malaysia show that numerous contextual factors shape the low-carbon technology policies. Both countries went through a process of decentralization from decades of monopoly or top-down policy making. On the other hand, countries like Thailand and the Philippines, which are very much dependent on imported oil, focused their efforts in integrating renewable energy technologies in the national energy mix. Unabated rise in oil prices and strains on public finance also helped this transition. This is reflected in the policy regime niches and market dynamics, as characterized in **Table 5**.

	Fossil fuel-rich countries (e.g., Indonesia, Malaysia)	**Resource poor countries (e.g., Thailand, Philippines)**	**Policy regime rules**
1980s	Wait-and-see attitude toward low-carbon energy transition	Active production by production companies because of economic and energy security concerns	Struggles over capacity and grid connection
1990s	Network fall apart, with small energy development companies become reactive	Increase in the renewable energy share in energy mix	Laws facilitate market liberalization independent power producers
2000s	Seen as a long-term option: large energy developing companies see it as an opportunity for low-carbon profiling	Close to dominant practice for attainment of energy security	Financial and regulatory incentives for scaling up the investment
2010s	Active production in local areas because of socioeconomic and environmental considerations	Tackling the grid-connection issues for accelerated deployment	Shift to high expectations on climate change mitigation and low-carbon green growth

Source: author.

Table 5. Policy regime influences on low-carbon energy technology market dynamics.

Renewable Electricity Power Act in the 1980s in Thailand and the Philippines marked starting point for radical reform that fastened the uptake of low-carbon energy technologies through liberalization and privatization. On the other hand, Indonesian and Malaysian energy markets are still dominated by state-owned enterprises. Attempts to shift the market conditions toward liberalization and low-carbon energy resource development are often stalled by administrative tribunals. Heavy fuel subsidies and regulated energy prices are dominant in the policy landscape until 2014. Nevertheless, nonsubsidized electricity prices in the Philippines is the highest in the region. With respect to incentives and support schemes for renewable energy, a comprehensive renewable energy act of 2008 in the Philippines and 2010 in Thailand embodied a set of policies and mechanism promoting renewable energy, although it took years for the national governments to implement its rules and regulations.

In contrast, only a few relatively weak-support policies for low-carbon technology diffusion exist, especially for geothermal in Indonesia and biofuel in Malaysia. The new institutions, the Directorate General for Renewable Energy and Energy Conservation (EBTKE), Indonesia, and Sustainable Energy Development Authority (SEDA), Malaysia, aims to further stimulate low-carbon technologies but is often with limited success. This has reflected in the fundamental difference in the energy mix, with high share of low-carbon renewables in the Philippines and Thailand, compared with a highly fossil fuel-dominated electricity production in Indonesia and Malaysia. Environmental issues and issues related to climate change are, at least rhetorically, more prominently articulated in the Philippines and Thailand, which are climate change hotspots.

Furthermore, there are commonalities in low-carbon energy policy making. The experience of the countries also shows that transformation in the policy regimes has been greatly influenced by external developments, such as oil crisis of the 1970s, the Asian economic crisis of the 1990s, and global financial crisis of the 2000s. The change has been nonlinear as there has been sometimes even complete reversal of previous regulations. In the 1960s and early 1970s, coal was phased out by oil. The strategy was to use oil and natural gas supplies rapidly, before maximization of hydro power. But after the first oil crisis, gas has come to be seen as a strategic source of energy to be used sparsely. But after the second oil crisis, this strategy was reversed; attention shifted to coal and to increasing energy efficiency. It goes with the aphorism, often termed Sali's law: "Bad times may produce good policies, and good times fervently the reverse" [13].

3. Regional cooperation approaches for developing affordable low-carbon energy system

3.1. ASEAN energy integration plan, targets, and patterns

Since the late 1960s, the Southeast Asian countries have recognized that energy security is an issue that affects the entire region. Multilateral energy cooperation and regional networks are thought to create an enabling environment for appropriate energy policies at the national level. In 1967, five countries in the region—Indonesia, Malaysia, the Philippines, Singapore, and Thailand—declared establishment of the Association of Southeast Asian Nations (ASEAN). Brunei, Cambodia, Lao PDR, Myanmar, and Vietnam joined later in the 1990s. At the 2003 ASEAN summit, the Bali Concord was signed, which agreed on establishing an ASEAN community comprising three pillars, namely, Political and Security Cooperation (ASEAN Security Community), Economic Cooperation (ASEAN Economic Community), and Socio-Cultural Cooperation (ASEAN Socio-Cultural Community) by 2020. In response to the increasing economic challenges, the ASEAN Economic Community was established in 2015, which oversees the energy cooperation shift to low-carbon economy among member countries.

Indeed, ASEAN energy policy cooperation dates back to the first meeting of ASEAN Economic Ministers on Energy Cooperation held in 1980. The meeting discussed energy policies, institutional arrangements, and energy cooperation within ASEAN and between ASEAN and other countries or international organizations. The first Energy Ministers Meeting held in 1988 agreed to formulate a framework for energy cooperation aimed at improving the social welfare and economic growth by ensuring affordable, reliable, and sustainable energy supply. From then to now, the progress of the regional energy policy cooperation can be divided into three periods, as shown in **Table 6**.

During that period, the studied countries witnessed a stepwise approach, whereby a coalition of countries took decisions on consensus basis to address the common challenge of how to plan and develop a secure and robust energy sector. Their common action plan for cooperation focuses on energy planning, energy efficiency, renewable energy, clean coal technologies, nuclear energy, electricity trade, and infrastructure. For each topic, working groups were formulated; work programs were agreed upon with a modest budget for implementation. Central to the work was the exchange of experiences on the happening in each country by annual senior officials meetings, seminars, and conferences as well as capacity building and training

	First phase 1980–1990	Second phase 1990–2000	Third phase 2000–present
Energy security	Long-term national planning, with the focus on oil, gas, and coal use	Reach neighboring countries for harnessing shared hydro-resources	Alignment of policies in the wider ASEAN context
Energy markets	Knowledge sharing on potential demand and supply	Plans for regional power grid, oil and gas pipelines, and liberalized markets	Action plan on investments for integrated markets
Energy efficiency	Knowledge sharing on support mechanisms	Plans for regional standards and performance targets	Technical assistance and monitoring around implementation of directives
Low-carbon technologies	Research and training programs on renewables and fossil	Research networking on renewables and nuclear	Market pull and tech push initiatives
Clean energy and environment	Increasing awareness	Collective renewable energy targets	Embedding in energy policy decisions
Regional energy governance	Energy Ministers Meetings and Committee of Senior Officials Permanent and ad hoc subsector networking and working groups Energy Cooperation Task Force ASEAN Centre for Energy (ACE) and Economic Research Institute for ASEAN and East Asia (ERIA)		

Source: authors.

Table 6. An overview of regional energy policy cooperation in ASEAN.

schemes for national energy policy planners and experts. The aim was to make the cooperation efficient and relying primarily on consensus-based bottom-up governance system.

This mode of operation was made from the very beginning and has not changed much over the years. But gradually, it has become an important catalyst for cooperation in its own right, to develop ambitious national level, targets, action plans, and other mechanisms to support a well-functioning integrated energy system within the region and across the borders. With the establishment of ASEAN Centre for Energy (ACE) in 1999 and Economic Research Institute for ASEAN and East Asia (ERIA) in 2008, the cooperation benefited from having institutions that could focus exclusively on regional energy policy issues. This cooperation has led to some success, particularly setting and achieving ASEAN's low-carbon renewable energy targets, visualizing cross border energy trade and implementing targeted energy policy research and training programs. It has also resulted in several vision documents and numerous policy statements.

The ASEAN 2020 is the first vision document adopted in 2007, which called for an ASEAN energy cooperation aimed at forging closer economic integration with the region. The vision highlighted the need for improved energy cooperation through electricity grid interconnection arrangements and natural gas pipeline across the region along with the promotion of energy efficiency, conservation, and renewable energy. In 1999, ASEAN formulated an ASEAN Plan of Action for Energy Cooperation (APAEC) 1999–2004 and subsequently updated versions for 2004–2009, 2010–2015, and 2016–2025, with the aim to enhancing energy connectivity and market Integration in ASEAN to achieve energy security, accessibility, affordability, and sustainability for all [4]. The adoption of such a vision represents a significant paradigm shift, elevating national policy efforts into realizing a single regional energy market within the framework of ASEAN Economic Community (AEC). They also created a policy framework for the AMS to achieve its overall low-carbon energy transition goals. In particular, electrical power integration offers a mechanism to further support renewable energy targets and to enable universal access to energy services for all its citizen in a low-carbon way.

3.2. Challenges to regional cooperation and low-carbon energy policy making

The ASEAN vision 2020 placed emphasis on the need to construct multilateral energy networks across the countries, and this priority was embodied in all subsequent decisions and plans. The ASEAN Power Grid (APG) was created as the flagship of such a vision with the purpose of delivering the main objectives of achieving long-term security, availability, and reliability of renewable energy supply, optimizing the region's energy resources and investments and allowing access to affordable energy to population across the region. APG consists of 14 bilateral and multilateral electricity interconnection projects. Since its inception in 1997, the APG has accomplished gradual progress, particularly through the deployment of several interconnections, many of which are fully operating on bilateral basis. However, the APG is yet to operate on multinational basis, so as to deliver its intended benefits.

Several studies [11, 14–16] of regional power integration have concluded that, regardless of the different types of models at work, some of the expected benefits from cross border energy infrastructure development are not realized, because they are not specifically targeted within the design of economic cooperation programs. The implication is that in designing regional cooperation programs, the challenge is to incorporate the proper mechanisms and incentives that would allow it to deliver its full benefits, notably for the deployment of low-carbon technologies, expansion of access to low-carbon electricity, and optimization of investments.

Nevertheless, these four countries have not yet identified appropriate indicators to measure the benefits of low-carbon development through completed interconnections. On the other hand, APAEC has set clear goals and quantitative targets for the year 2025. APAEC Phase II outlines seven main energy cooperation program areas: (i) the ASEAN Power Grid, (ii) the Trans-ASEAN Gas Pipeline, (iii) Coal and Clean Coal Technology, (iv) Energy Efficiency and Conservation, (v) Renewable Energy, (vi) Regional Energy Policy and Planning, and (vii) Civilian Nuclear Energy. While the program areas lay the foundation for greater regional energy cooperation and influence the rethinking on low-carbon energy policy making at national level, it remains unclear whether their implementation with current challenges relates to national interest, economic policy and institutional barriers, technical and financial capacity, as well as differing level of low-carbon energy development and security concerns among the countries.

The actors and governance structure of APAEC comprise a network of policy makers who work on consensus basis, with the rules and mode of operation determined by the council of ministers aided by senior officials from each country. The chairmanship of the ministerial council rotates annually as did the chairmanship of senior officials. The institutional networks are lean and rely on existing organizations with limited resources and human power. Hence, it is important that the process of regional cooperation is not done entirely behind the closed doors of the high-level taskforces. It must be coproduced and coenvisioned by the people in order to have buy-in from the public. A vision of regional energy cooperation that reflects the values and preferences of the community is a vision that the community will feel they have a stake in protecting, securing, and making sacrifices for. It is with collective best interests that the decisions on APAEC are made, priorities are selected, and risk–benefit tradeoffs are just, equitable, and acceptable.

While the purported low-carbon benefits of regional cooperation are tradeoffs, so are the challenges. Challenges arising from climate change become more and more embedded in regionally coordinated energy policies. Though energy sector is partly responsible for climate change, albeit also one of the solutions to mitigate carbon emissions, recently adopted Paris Agreement has shown that international cooperation has larger role to play in the short and long terms. Achieving the multiple benefits of low-carbon energy transition, gaining required technology spillovers, and attracting investments for cross border projects warrant new models of regional cooperation. These countries can see flying geese pattern of industrialization and economic integration from this point of view, to unleash the power of next-generation low-carbon technologies.

4. Regional economic cooperation and low-carbon energy policy path dependencies

4.1. Regional economic development through flying geese model

The pattern of East Asia's catchup economic growth and the process of industrial modernization and associated low-carbon energy policy path are chartered by "flying geese" model being the most well-known paradigm. It started in Japan; facilitated the emergence of production networks across Southeast Asia; permitted countries like Indonesia, Malaysia, the Philippines, and Thailand to catch up advancement in technology and skill up gradation; and narrowed the developmental gaps. This can be illustrated in **Figure 5**. In that framework, during the 1970s, newly industrializing countries, Korea, Taiwan, Singapore, and Hong Kong, followed Japan in developing industries that initially produced nondurable goods and then durable consumer goods and then capital goods. The ASEAN countries such as Indonesia, Malaysia, Thailand, and the Philippines followed the third tier in the 1980s. Japan is the leading goose in that model and used its technical and economic power to establish sophisticated industrial network with other Southeast Asian countries [18–19]. This is reflected in the export structure of Southeast Asian countries with Japan during that period.

In 1985, the order of the flying geese (FG) is clear; Japan is the leading goose, and Indonesia, Malaysia, Thailand, and the Philippines are catchup economies. However, by the year 2000, the slope of the FG becomes flatter. It seems that the FG pattern of economic integration has changed during 1985–1997, and Japan is now not a sole leading goose in the region, with Korea and China taking some part of the lead. The most prominent features of the gaggle of

Figure 5. Correlation of export structure of the second and third tier geese with the leading goose Japan. Source: [20].

flying geese are first, in the bid for regional integration, Japan relied solely on its economic power and technology prowess; second, Japan employed its Official Development Assistance (ODA) to consolidate its production network in East and Southeast Asia; and, third, the Japanese government made efforts to release the private capital to come up with Foreign Direct Investment (FDI) plans. The trade has increased from 2209 million USD in 1967 to 109,097 million USD. Foreign Direct Investment peaked in the 1970s, with the peak 30% in the 1970s and with an ODA constituting cumulative average flow of 1600 million/year during 1967–2002 (Ministry of Finance, 2005). The regional production network, established through FG model, is a form of informal economic integration. It involved no formal institution or intergovernmental agreement but worked according to the business logic of cross border activities.

5. Conclusion

The following conclusions about the dynamics of innovations in low-carbon energy policy making in Asia could be drawn.

First, a transition to low-carbon economy and shift in adaptation of new cleaner technologies have been unfolding in the last three decades. Major changes have occurred in the formal regulations, rules, actors, and networks of the policy regime that are initially planned to achieve long-term security, availability, and reliability of energy supply. Transition in low-carbon energy policy making in Indonesia, Malaysia, Thailand, and the Philippines involves three distinguishable temporal and developmental phases, often characterized by hierarchy, aggregation, and space. In the initial period, technology policy choices are made to meet the growing concerns of energy security and access, later of reliability, and then of climate change. These policy choices and institutional actors and networks, whether consciously or not, supported resource intensive growth. Guiding principles and drivers of energy policy making also changed over a period of time. Past policies, technology-oriented top-down, are gradually being replaced or complemented by participatory, market-oriented policies.

A second conclusion is that the ongoing low-carbon economic transition is enhanced by regional cooperation. Adoption of an action plan for regional energy cooperation created enabling environment for paradigm shifts in national energy policy making. ASEAN energy cooperation demonstrated two successes: the liberalization energy markets for low-carbon renewables—both developed far beyond knowledge sharing, exchange of experiences, best practices and learning, reaching a position as a role model for regional cooperation. By means of high political- and operational-level endorsements, the necessary frameworks are being developed step by step and country by country in a pragmatic way, gradually opening up for cooperation of the willing. Yet, regional energy cooperation has proceeded slowly in the actual implementation of plans. A lot has been said in the form of meetings and declarations, but many of the statements are declaratory in nature and nonbinding and have no legal force.

The Southeast Asian way of consensus building has posed real limits to institutional building and actual functional cooperation. This is due to barriers such as complex and diverse nature of energy needs, differing national interests, national sovereignty, and lack of trust and industrial structure of the states in the region. Indeed, the institutional frameworks and human capacity necessary for regional cooperation in most issues remain poorly developed. A clear understanding of the tradeoffs and plan for institutional and human capacity needed—skills, training, education, and capacity building—is urgently needed. A region-wide policy in the energy sector would be futile, if it is implemented across the board without specific considerations on the interests of the countries. A stepwise cooperation for low-carbon technology diffusion requires greater awareness and flexibility of it to support the goal of a one integrated energy market for low-carbon energy resources. Nevertheless, the current modus operandi allows the member countries to complement each other and thus remain as an enabler of making the shift from one equilibrium of policy making to another in a stable way. Accelerated energy market integration should remain of prime importance for the ongoing energy transition in the next decades.

Third, the flying geese model of economic integration points to a new way of regional cooperation to solve low-carbon energy policy dilemmas, with no formal involvement of policy institutions and intergovernmental agreements, but works according to market principles and with a policy dependency. Though the Greater Asia is no longer in the historical paradigm of flying geese, it provides conditions for competitive learning across many policy options and provides the capacity to take advantage of knowledge and low-carbon technology spillovers. Success in low-carbon energy policy making is the result of the governments making use of its existing production networks and sizable manufacturing sector to establish a stable foundation for the low-carbon technology requirements. As the increase of the Greater Asian integration depends on regional production networks, they should become the driving force for integrated planning on short-, medium-, and long-term basis. To benefit as much as possible from that niche, Asian countries need to continue integrating with other leading countries and create an environment more conducive to smooth the flow of low-carbon technology, products, and services.

The reality is that low-carbon technology and energy policy making anywhere are becoming more complex. Pretending that low-carbon technologies can be diffused in isolation from other social, environmental, and economic policies. There is a need to increase reform advocacy for multi-sectoral coordination, educate the stakeholders on the co-benefits of low-carbon technology, and support new models of energy cooperation. Asia should also remain engaged with other parts of the world, because the peer pressure for the next generation of low-carbon technology diffusion is likely to come from them.

Author details

Venkatachalam Anbumozhi

Address all correspondence to: v.anbumozhi@eria.org

Economic Research Institute for ASEAN and East Asia, Jakarta, Indonesia

References

[1] International Energy Agency (IEA). Southeast Asia Energy Outlook – World Energy Outlook Special Report. Paris: International Energy Agency; 2016. p. 131

[2] ADB. Asian Development Outlook. Manila: Asian Development Bank; 2013

[3] BP. Statistical Review of World Energy June 2016. British Petroleum; 2016

[4] ASEAN Centre for Energy (ACE). Renewable Energy Policies. Jakarta: ASEAN Centre for Energy; 2016

[5] International Energy Agency (IEA). World Energy Outlook. Paris: International Energy Agency; 2016

[6] ASEAN Centre for Energy (ACE). The 4th ASEAN Energy Outlook. Jakarta: ASEAN Centre for Energy; 2015. pp. 2013-2035

[7] Economic Research Institute for ASEAN and East Asia (ERIA). Energy Outlook and Energy Saving Potential in East Asia. Jakarta: Economic Research Institute for ASEAN and East Asia; 2016

[8] ASEAN Centre for Energy (ACE) and International Renewable Energy Agency (IRENA). Renewable Energy Outlook for ASEAN: A Remap Analysis. Jakarta: ASEAN Centre for Energy; 2016

[9] International Energy Agency (IEA). Energy & Climate Change. Paris: International Energy Agency; 2015

[10] Ministry of Finance, Japan Financial Statistics of Japan, various issues

[11] Tongsopit S, Kittner N, Chang Y, Aksornkij A, Wangjiraniran W. Energy Security in ASEAN: A quantitative approach for Sustainable Energy Policy; 2016. pp. 60-71

[12] Akamatsu K. A historical pattern of economic growth in developing countries. Journal of Developing Economies. 1962;**1**(1):3-25

[13] Hill H, Wie TK. Mohd Sadli (1922-2008). Economist, minister and public intellectual. Bulletin of Indonesian Economic Studies. 2008;**44**(1):151-156

[14] Lugg A, Hang M. Energy Issues in the Asia- Pacific Regions. Singapore: Institute for Southeast Asian Studies; 2010

[15] Shankar K, Mann MD, Salehfar H. Energy and environment in ASEAN: Challenges and opportunities. Energy Policy. 2005;**22**:4999-4509

[16] Yu X. Regional cooperation and energy development in the greater Mekong sub-region. Energy Policy. 2003;**31**:1221-1234

[17] Heads of ASEAN Power Utilities/Authorities (HAPUA). HAPUA Secretary-in-Charge report to the 34th ASEAN Ministers on Energy Meeting on the Progress of ASEAN Interconnection Project 2016. Nay Pyi Taw, Myanmar, 23 September 2016; 2016

[18] Kasahara S. The Flying Geese Paradigm: Critical Study of its Application to East Asian Regional Development: UNCTDA Discussion Paper No.169. United Nations Conference on Trade and Development: Geneva; 2004

[19] Kojima K. The flying geese mode of Asian economic development: Origin, theoretical extensions, and regional policy implications. Journal of Asian Economics. 2000;**11**:375-401

[20] Kumagai S. A Journey through the Secret History of the Flying Geese Model. IDE Discussion Paper No.158. Tokyo: Institute of Developing Economies; 2008

Chapter 5

Economic Impact of CO_2 Mitigation Devices in Sustainable Buildings

Chukwuemeka Ikedi

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.78960

Abstract

Recent innovations in residential and commercial buildings involve the integration of low-carbon devices for the purpose of mitigating CO_2 footprints. Photovoltaic (PV) modules are now commonly integrated into parts of the fabric of a building as roof tiles, asphalt shingles, facade materials or shading elements and usually blends with the aesthetics of applied buildings. This is referred to as building-integrated photovoltaics (BIPV), and when used in this way, the integrated PV modules replace conventional building envelope materials, thereby benefiting from capital cost reduction. One key aim of BIPV technology on applied buildings is sustainability, and according to recent research, ′sustainable buildings perform better than conventional buildings in terms of well-being of the occupants′. This study evaluates and assesses the economic impact of BIPV projects as a low-carbon technology on applied buildings for use by prospective BIPV investors in the building sector.

Keywords: economic impact assessments, CO_2 mitigation device, low-carbon technology, low-carbon economy, sustainable buildings

1. Introduction

This chapter provides an overview of the concept of low-carbon technologies and consequent economies of their applications. Most interestingly, a major issue with such technologies is that the curiosity to justify their economic or financial viability especially among prospective investors was elaborately treated via systematic methods of economic evaluations and experimental system monitoring/analysis. A framework of decision-making was developed based on the assessments.

1.1. Rationale behind the study

Climate change and global warming has become both scientific terms and political slogans and point to the same direction, namely the effect of industrialisation and urbanisation. At first instance, one may want to ask or find out if these are real or whether they are concepts driven by political motives towards policies and regulations in a desired inclination. Scientific investigations and research organisations like NASA have validated the reality and causes of these phenomena, a situation which now calls for effective low-carbon technologies and policies [1]. The application of such low-carbon technologies has therefore become a global recommendation by various governments as a key solution to mitigate the rising CO_2 emissions, while various governments have initiated strategic policies and guidelines towards achieving a low-carbon environment and economy. The UK Government policy paper on low-carbon technologies [2], for instance, stipulates a target of 80% reduction in greenhouse gas emissions by 2050. Meanwhile, statistics have shown that commercial/office buildings alone, account for 20% of the carbon dioxide (CO_2) emissions in the UK [3] and about 39% in the US for both domestic and commercial buildings. Also with the UK's existing building stock being replaced at a rate of 1–1.5% per annum [4], occupants of existing office buildings will need to respond to rising temperatures resulting from climate change with the possibility of temperatures exceeding comfort levels by as many as three to five working days by 2050 [3]. Therefore, there is an urgent need to extend the use of low-carbon energy technologies, and part of the strategies to encourage wider application of such technologies involves the introduction of policies [2] such as renewables obligation (RO), which provides incentives to support suppliers in the UK generate a proportion of their electricity from low-carbon renewable sources and the Feed-in Tariffs (FITs) scheme, which rewards users of small-scale, low-carbon electricity for the electricity they generate and use, and for excess electricity they export back to the grid.

Considering the level of attention at the moment on this global subject, questions and controversies begin to emerge regarding the economic viability, and one way to justify the continuous application of the technology in the building sector is by assessing their impact on applied buildings to find out whether they make economic sense with regard to initial investment cost, net benefit or payback period.

This research study assesses a low-carbon technology and evaluates its net benefit on applied building in order to find out whether the application makes an economic sense. The outcome or result of the research forms a vital decision platform for prospective investors and stakeholders.

2. Overview of low-carbon technologies and economy

An attention to both the technologies and the consequent economic outcomes on lives and the environment is very important for the present status and future trend.

2.1. Mitigation technologies

Low-carbon technologies simply refer to systems, which involve negligible or low amount of CO_2 in the process of generating a required form of energy, usually electricity for domestic and industrial applications. Several low-carbon energy technologies are available in the building sectors and the built environment at the moment for use in different parts of the world for mitigating carbon footprints. These include microwind turbines, building-integrated photovoltaics (BIPV), small hydro power generators and bio-tech systems. Although listed as a low-carbon energy source, categorising nuclear energy sources as low-carbon energy technology have been a bit controversial over time; however, the 2014 Intergovernmental Panel on Climate Change report identifies nuclear, wind, solar and hydroelectricity in suitable locations as technologies that can provide electricity with less than 5% of the lifecycle greenhouse gas emissions of coal power [5].

Besides the nuclear option, most other options can be applied to both domestic and commercial buildings usually for generation of electricity. It has been observed that when used in buildings, only building-integrated photovoltaics (BIPV) becomes aesthetically appealing and forms part of the applied building fabrics, while most other options could deform the building aesthetics and require large spaces for both installation and operation especially, the wind turbine.

Recent studies [6–9] and to mention but a few have involved research investigations on specific types or technologies: Ikedi, for instance, assessed the energy impact of a grid-connected, building-integrated PV (BIPV) in a commercial/office building in UK; Ronga, in a different study, conducted a comprehensive review for optimising poly-generation bio-tech systems in buildings; Santoli, in another study, conducted an energy and environmental analysis for a vertical-axis micro-wind turbine with a nominal electric power of 3.7 kW as a cost-effective energy technology for rural electrification, while Francisco reviewed small hydropower systems in Europe. These previous studies focused more on the power generation, while this present study focuses on the economic impact of such carbon mitigation devices.

2.2. Low-carbon economy

The topic of low-carbon economy can be considered as a new concept which dates from the inception of the matter of climate change with increasing carbon footprints. The logic behind this new concept lies in the fact or saying that health is wealth. In other words, a healthy environment implies a wealthy economy. Carbon emission has been identified globally as a key health challenge to lives and the environment. A low-carbon environment, therefore, implies a wealthy economy and referred to as a low-carbon economy.

Low-carbon economies offer various benefits to the environment, such as businesses, employment, health, energy security and industrial competitiveness [10].

Two different perspectives can be adopted to define or describe low-carbon economies namely:

(1) The expected economic value or benefit of low-carbon technologies on applied buildings or environment

This perspective which forms the basis for the economic evaluations in this study refers specifically to net benefit or financial savings achieved via the use of a low-carbon device to generate a particular type of required energy, which is usually electricity as in this research case study. Yearly monitoring for changes in cost of electricity before and after the installation of a low-carbon device is carried out to showcase or measure possible economic values or benefits.

(2) The projected contributions to the environment due to obtainable policies and practices

Based on this perspective, a low-carbon economy can be defined to be an economy that is an outcome of the introduction and application of low-carbon technologies, thereby resulting in some benefits such as the value of CO_2 reductions, the potential for good practice guidelines in energy production and use to minimise costs, opportunities for new knowledge and better scope of energy management [10].

The way a country or government manages the emission of carbon determines its ability to create a healthy and safe future. Countries with improved low-carbon energy production have the capacity to enhance their future economy and prosperity. How each government or country approaches and manages the challenge of carbon climate would depend to a large extent on awareness and investment towards carbon mitigation strategies. France, Japan, China, South Korea and the United Kingdom are currently best positioned in the trend of low-carbon economy. France retains the top ranking followed by Japan, South Korea and the United Kingdom. China's dramatic rise up the Index to third place is the result not only of its major investment in clean energy, but also growth in its high-technology exports. The earlier a country or government involves low-carbon technologies, the earlier they will experience greater benefits associated with sustainability and energy efficiency and so will be better positioned to provide healthier environment and wealthier economy in future.

3. Research methodology

This section explains the main research methodology applied in this study, as well as the assessment methods used. Firstly, the framework of economic assessment based on the most suitable economic method was explained. The researcher further explores and justifies the criteria for the selection of a case study and also explains the considerations adopted when selecting the most suitable and effective research methodology.

3.1. Economic assessment framework

Prior to this present study, there had been several similar attempts to develop some form of framework or method to assess the economic impact of low-carbon technologies on applied buildings. The summarised definition and principles of the process 'impact assessment' as provided by the IEA/IAIA best practice document (International Association for Impact Assessment [IAIA] and Institute of Environmental Assessment (IEA) [11] could be considered as a yardstick to weigh or compare such studies. The first criteria, for instance, could be the degree of compliance of the structure: aims, objectives and research methodologies of such studies with the definition standards. A further criterion could be the degree of fulfilment of critical areas of assessment required by prospective investors particularly in the areas of economy. Economic evaluations of low-carbon energy systems usually involve an assessment of the projected benefits compared to the estimated costs of the system, which implies that the actual financial benefit of a low-carbon energy system is in essence the value of energy generated.

Economic methods of evaluation considered include the following:

Payback period—The payback period is the minimum time it would take the mitigation device in the research case study to recover investment costs and can be calculated as:

Payback period = total investment cost divided by the first year

Net benefit analysis—net benefit analysis is an expression of the net difference between the benefits and costs of the technology relative to an alternative system. The low-carbon systems as applied in the case studies would be considered cost effective if the net saving or net benefit turns out positive.

Adjusted internal rate of return (AIRR)—the adjusted internal rate of return is a discounted cash flow technique, which can be used to measure the annual compound yield from the applied system in the case study, taking into account reinvestment of interim receipts at a specified rate. With this method, estimating the cost effectiveness of the low-carbon system involves comparisons of the calculated AIRR of the system to the investor’s minimum acceptable rate of return (MARR). The low-carbon system would be considered to be cost effective if the AIRR is greater than the MARR.

Lifecycle cost analysis—in life-cycle cost (LCC) analysis, all relevant present and future costs (less any positive cash flows) associated with the applied system are summed in present or annual value during a given study period (e.g., the life of the system). These costs include, but not limited to energy, acquisition, installation, operations and maintenance (O&M), repair, replacement (less salvage value), inflation, and discount rate for the life of the investment (opportunity cost of money invested).

One major barrier identified in this research assessment was how to gather and assess observable/measurable data and results associated with the BIPV system in such a way as to aid existing owners and potential investors decide whether the technology makes an economic sense or positive impact. However, because of the nature of data available in the selected case study, the economic assessment is based mainly on the net benefit analysis.

3.2. Selection of the research methodology for economic evaluation

In order to select an appropriate methodology, an extensive review of similar studies was carried out [[6–9]. The methods of assessments in the studies were also examined and compared. Most of the studies were found to focus more on power generation, while this present study focuses on the economic impact of such devices. Also, most of the previous studies focused their assessment on residential or non-commercial buildings with little or no consideration to commercial/office buildings. The present adopted the use of parametric analysis of intrinsic output characteristics of the applied device together with applicable economic methods to conduct the assessments.

3.3. Identification and selection of research case study

The first step adopted by the researcher in the research methodology was to identify an appropriate and suitable case study for the economic impact assessment. The main purpose of choosing a case study is to conduct a self-experimental assessment beyond mere evaluation of secondary data from a ready source.

Because of the wide application of BIPV due to its advantages of aesthetics and installation space, the case study selected for this assessment study is a BIPV system. One key requirement for the selection of a case study in this research study is that the applied system should have a comprehensive record of system monitoring for at least a period of 1 year. Another key requirement or criteria for the selection of a case study is that it must be grid connected, which is a basic requirement for economic analysis and assessment.

The BIPV system at the Kedleston campus of University of Derby was chosen—this case study comprises a BIPV roof array with an area of 204 m^2, consisting of 72 units of ND-170E1F (170 W), Si-poly Sharp PV modules and is of a commercial/office application. However, before evaluating the selected case study, it is important to have a brief background overview of BIPV systems.

3.4. Background behind BIPV

Photovoltaics refers to the science and engineering of converting energy from the sun to electricity with the aid of special configuration of modules, panels or arrays of cells referred to as photovoltaics or PV systems.

Two basic types of PV systems can be described namely: fixed PV and tracking PV.

The earth moves round the sun in an elliptical orbit, in a counter clockwise direction on an imaginary line called its axis, tilted with respect to the plane of its orbit at an angle of about 23.4°. Due to the movement of the earth around the sun and the consequent effect on solar radiation, tracking PV systems are designed to track the sun's movement and hence maximise solar incidence on the modules/arrays by maintaining an optimum orientation between the sun and the solar panels. The complex and usually delicate operations involved in tracking PV systems has meant that most PV applications are of the fixed category resulting in benefits of simplicity, least cost and convenience of operation.

Fixed PV systems are defined as such because the solar modules or arrays are permanently fixed at a particular angle towards the sun, with the aim of maximising solar capture. Fixed systems can be installed either as pole mounted, ground mounted or roof mounted systems.

Pole and ground mounted PV's are usually installed remote from building envelopes, while other types of PV systems are either installed on structured framework on the roofs of buildings or integrated with the building envelope in such a way that it is referred to as building-integrated photovoltaic (BIPV). These involve the integration of the PV modules into parts of the fabric of a building as roof tiles, asphalt shingles, facade materials or shading elements. Used in this way, the integrated PV modules replace conventional building envelope materials, thereby benefiting from capital cost reduction and hence improved payback period and life-cycle cost.

3.5. Methodological evaluation of the research case study

Post-commission data of the BIPV system in the selected case study were retrieved and recorded from the system with the aid of high-performance data logger systems networked to different input and output terminals of the entire BIPV system. The first set of monitored parameters here include mean values for grid current [A], DC current [A], grid voltage [V], DC voltage [V], operating time meter change [h] and feeding time meter change [h].

The second set of parameters monitored in the system include total yield meter change [kWh], power mean values [W] and specific inverter yield mean values [kWh/kWp], where A is ampere, V is volts, W is watts and h is hours, respectively.

The BIPV system, which involves the latest grid-feedback and SMA inverter technologies, was monitored with the aid of Kyoto platform software integrated into a state–of-the-art SMA data technology (Kyoto platform is an open text computer format, which has the capability to extract large volumes of texts and data in various computer languages and this formed the basis for using the software.)

Each of the parameters was monitored on a daily basis, and this was carried out for about 1 year in order to account for the different seasons of the year namely: winter and summer. The monitoring was commenced from July 2010 to July 2011. For simplicity and evaluation purpose, the data were subsequently compressed to monthly average values for the different months of the year.

Finally, graphical representations of the data were developed and applied to deduce and assess the economic impact of the system on the applied building.

Details of these graphical information and the subsequent assessment results are presented below.

4. Results of economic evaluations

The graphical results for the total system yield denote meter change values which represent the excess energy imported into the building grid supply by the BIPV system. The mathematical product of these values measured from the graphs with the unit tariff for electricity, provides the economic earnings or financial savings for each feed back into the grid system.

For simplicity and space, the graphs below (**Figures 1–4**) show the average daily values in kWh for the first months, only of each quarter of the 1 year research monitoring. Section 5 discusses the results in detail, while the economic evaluation of these parameters is presented in the section on economic impact assessment (Section 6).

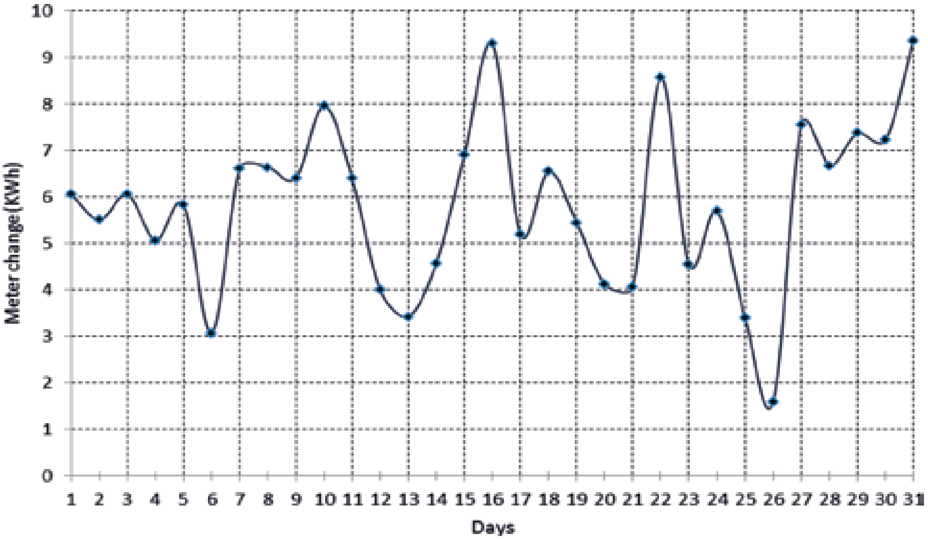


Figure 1. Total system yield—July 2010.

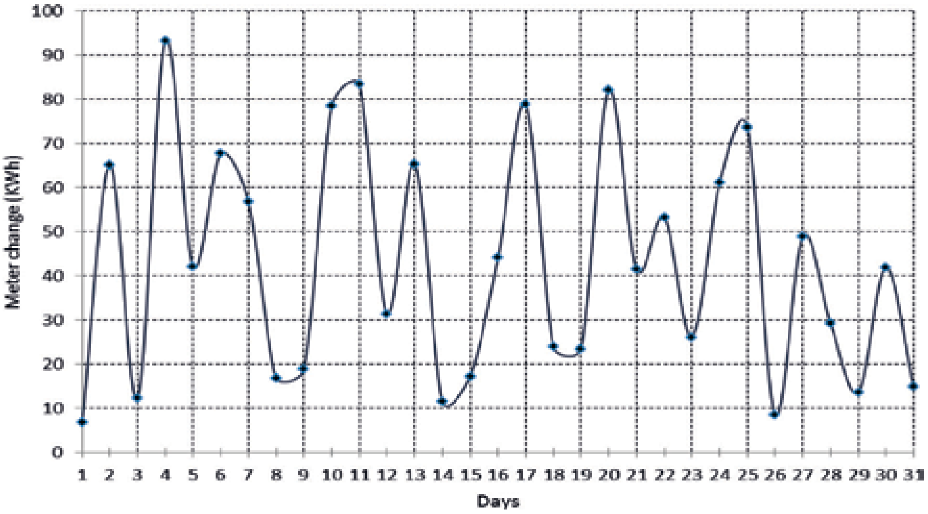


Figure 2. Total system yield—October 2010.

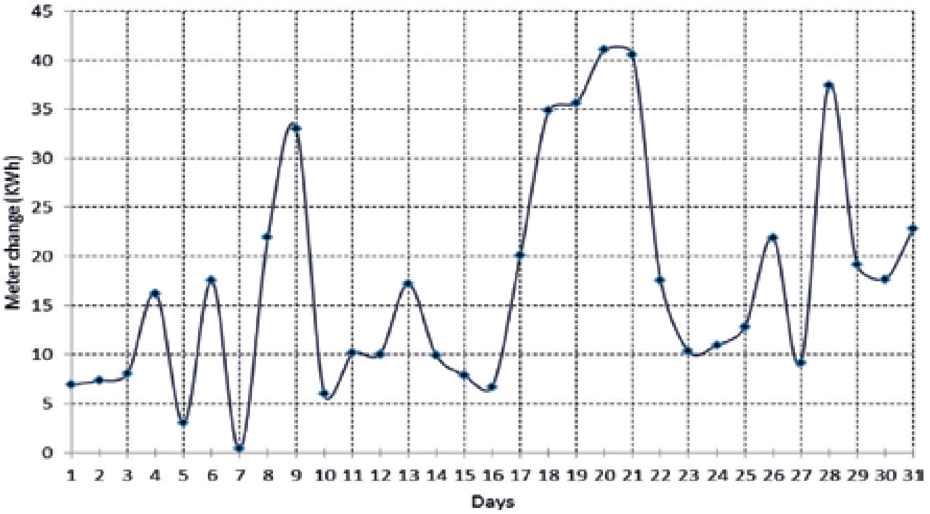


Figure 3. Total system yield—January 2011.

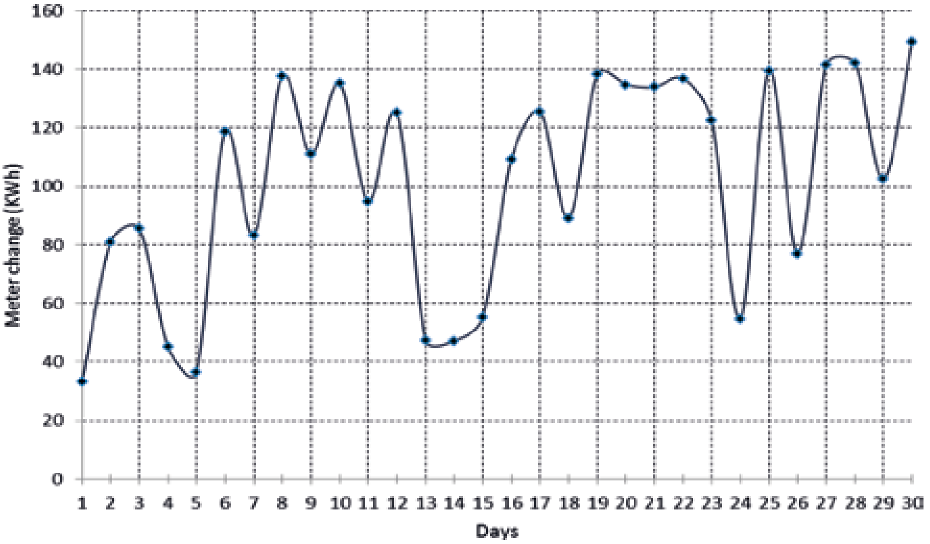


Figure 4. Total system yield—April 2011.

5. Discussion of the results of the economic evaluations

The total energy yield (**Figures 1–4**) deduced from monitored meter changes values and provides the excess energy imported into the building grid by the BIPV system. The unit for the total energy yield is kWh, while the mathematical product of these values measured from the graphs with the unit tariff for electricity provides the economic earnings or financial savings for each feedback into the grid system.

The total energy yield in principle is a product of the power contribution and time and can be expressed as:

$$\text{Total yield (Y)} = \text{power (P) kW} \times \text{time (t) h} \tag{1}$$

Substituting P for *IV*, then

$$\text{Total yield (Y)} = \boldsymbol{IVt}\ \text{(kWh)} \tag{2}$$

$$\boldsymbol{IVt}\ \text{(kWh)} \times \text{unit tarriff for electricity (£/kWh)} = \text{economic benefit (£)} \tag{3}$$

where *I* and *V* are the current and voltage, respectively.

From the graphical results for each of the respective months, it can be seen that the energy yield from the BIPV system is higher in the summer months than in the winter months. This is also explained based on the fact that the summer months are characterised by clear climatic solar conditions, which enhanced direct incident solar radiation on the BIPV panels, consequently maximising the system power and hence the total energy yield. The winter months, on the other hand, were characterised by cloudy climatic conditions resulting in diffuse solar radiations, which retard or impede the yielding capacity of the BIPV system.

The days in summer months namely May (5th and 6th), June (3rd), July (24th) 2011 recorded maximum daily energy yields of about 169.0, 180 and 175 kWh, respectively, from the BIPV, while the days in the winter months namely November (6th) 2010, December (25th) 2010 and January (20th) 2011 recorded about 51.0, 29.0 and 41.0 kWh, respectively, as the corresponding maximum in winter.

The energy yield from the BIPV system, therefore, shows a significant difference or margin between winter and summer months. This difference in the system yield at different seasons in effect has an implication on the economic or financial impact of the BIPV on the applied building at the respective periods. For instance, because the graphical results show significant increment in summer months, the excess energy imported into the building grid by the BIPV system was correspondingly high, thereby providing more economic earning or financial savings at such times.

The least recorded excess energy imported by the BIPV into the building grid within the 1 year monitoring period is approximately 0.01 kWh, which was recorded from the 1st to the 9th of the winter month of December 2010. A similar value of about 0.01 kWh was also recorded on the 7th of January 2011. In contrast, however, the highest excess energy imported by the BIPV into the building grid within the 1 year monitoring period is about 180.0 kWh, which was recorded from the system in the summer month of June.

Compared to the results of the power contribution, the BIPV system provided maximum power to the building in the month of May (**Figure 5**), while the maximum excess energy yield from the BIPV system was imported into the building grid in June.

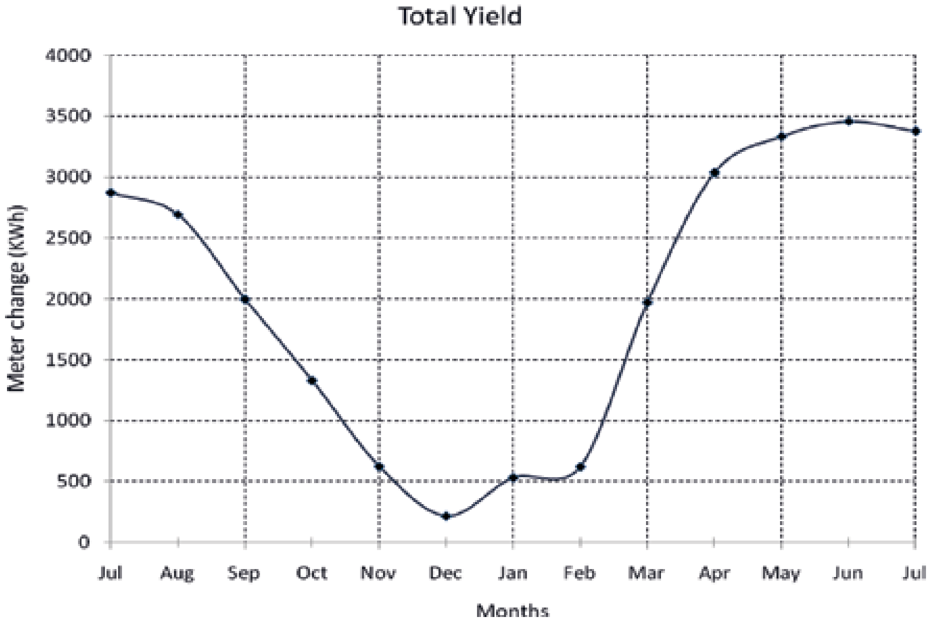


Figure 5. Monthly system total yield (University of Derby).

The graphs were based on daily values. These values were further computed into total monthly values for the purpose of the economic impact assessment in the research project (**Table 1**). The month of December with nine consecutive days recording the minimum daily energy export from the BIPV into the building grid had an overall total monthly yield of 219.59 KWh, resulting in the least financial savings of about £26.35 (**Table 1**).

Furthermore, from **Table 1**, it can be clearly seen that the system made a maximum yield of 3455.55 kWh in the summer month of June providing maximum economic benefit to the building with the highest financial savings of about £414.66 (**Table 1**). June 2011, therefore, was the most economic period of the BIPV project within the monitored period.

The explanation for the variations in the economic impact of the system at these periods obviously lies in direct relationship with the amount of direct solar radiation available to the BIPV panels at respective seasons or months of the year.

From this discussion and analysis, the following conclusions can be made:

- BIPV systems generate and feed back maximum excess energy into the building grid in the summer months. Regardless of the obtainable feed in tariff, the project, therefore, makes maximum economic returns at such times.
- It is advisable to carry out pilot or preliminary BIPV designs and base the design thresholds on the winter period when the atmospheric condition is usually cloudy and involves diffuse solar radiations. This will in practice ensure that the actual economic performance of the project does not operate below expectations.

Month	Total yield (kWh)	Financial value (£)
July	2871.04	344.52
Aug	2690.99	355.32
Sep	1997.92	239.74
Oct	1331.04	159.72
Nov	626.80	75.22
Dec	219.59	26.35
Jan	534.51	64.14
Feb	623.99	74.88
Mar	1971.33	236.55
Apr	3035.41	364.25
May	3333.16	399.98
Jun	3455.53	414.66
Total	22691.31	2755.33

Table 1. Monthly financial impact of BIPV system—University of Derby (July 2010 to June 2011).

6. Economic impact assessment

In general, two parameters were considered for use to assess the economic or financial impact of the system. The first is the 'energy cost produced', putting into account, the initial capital costs, maintenance costs and costs of changing parts of the balance of system (BOS) components like the inverters. The second is the 'value of excess electricity exported' by the BIPV system into the grid network of the building. The exported electricity can pay or make returns to the BIPV owners in either of two ways: reducing the overall cost of electricity imported from the grid company or generating direct cash as the selling price to the grid company.

On account of the nature of data monitored, the assessment in this study is based on the second approach, which in principle, falls under the net benefit analysis outlined in Section 3.1.

The direct financial benefit of the BIPV system can be described to be the value of excess electrical energy imported into the applied buildings. In simple mathematical notation, this can be expressed as:

$$\text{Projected benefits of BIPV systems} = \text{value of electricity generated} \tag{4}$$

In the same dispensation, the principal economic costs of the BIPV system can be expressed as:

$$\text{Estimated costs} = \text{initial costs} + \text{maintenance costs} \tag{5}$$

Because the photovoltaic (PV) components for the systems in the study are grid connected and used as part of the building components, its economic costs and benefits are, therefore, shared between the occupants and the utility company. Also, a further benefit to the building owners (University of Derby) is that the added costs of installing and operating the systems to generate electricity are offset by the avoided costs of purchasing electricity as well as the sale of surplus electricity yield to the utility companies. In effect therefore, the entire procedures for the economic impact assessment for the BIPV system can be used to develop frameworks for rates in the form of feed-in tariffs as well as to determine an equitable rate structure for exporting or importing electricity to and from the electricity grid, respectively.

Further economic benefits in the BIPV system lies in the structural performance of the BIPV modules as a building component (for instance, as shading devices, roofs or daylight devices).

The PV modules at the research case studies, in addition to generating electricity to the building, successfully provide roofing for a significant part of the building. On the other hand, although the PV modules in the high-rise building of the University of Derby are installed on the roof area of the applied building, there is no significant structural contribution to the building because of the underlying concrete roof.

Table 1 shows the results of the parametric analysis carried out for the assessment of the overall economic impact of the BIPV system.

Figure 5 is a graph of the monthly system total yield over the entire 1 year monitoring period of the research at the University of Derby, from July 2010 to July 2011.

From **Figure 5**, the monthly values of the total excess energy yielded or exported into the building were tabulated and multiplied in each case with the unit cost of electricity in UK estimated at about 12 pence per KWh. This gives the monthly economic impact or contribution from the BIPV system directly for each of the months (**Table 1**). The values in the last column of **Table 1** (financial values), which were obtained by multiplying the respective preceding total yield values by 12 pence in each month, give the respective economic values or benefits.

From **Table 1**, firstly, it can be clearly seen that the system yielded maximum economic benefit to the building in the summer months with the highest financial savings of about £414.66 in June 2011, while the winter months yielded minimum economic impact with the least financial savings of about £26.35 in December 2010.

It is interesting to note that the total financial savings or impact of the BIPV system over the one period of the research monitoring is approximately £2755.33 (**Table 1**).

The total capital installation cost of the BIPV systems at the University of Derby was £70.674.00 (incl. VAT).

The life expectancy of the BIPV system used in the project from the manufacturers (Sharp) is typically about 25 years.

Dividing the total capital cost of £70.674.00 by the life expectancy of 25 years implies an annual capital cost of about £2826. 96.

From the principles of life-cycle analysis (10.3), if the payback period of the BIPV system turns out to be significantly less than the expected system life, the BIPV project is considered cost effective.

£2826.96 ≤ £2992.49. This implies less payback period. Hence, the BIPV system applied in this case study is considered to be cost effective.

Finally, the percentage economic impact of the BIPV system based on the value of excess electricity exported into the building therefore becomes

[2755.33/70664.00 × 100]% = 3.90% with respect to the system capital cost.

In other words, the value of the excess electricity exported or yielded into the building grid by the BIPV system has the capability to provide financial savings of up to 3.90% of the original investment cost every year.

7. Conclusions

Having conducted and discussed the result of the assessment, key features of the research outcomes which contribute both to the aims of the study and knowledge are outlined below:

1. **Financial significance:** the results of the study has shown that the value of the excess electricity exported into the building grid by the BIPV system has the capability to provide financial savings of up to 3.90 of the original investment cost every year.
2. **Added value**: from the case studies, it can be seen that before the implementation of BIPV on applied buildings, most buildings could be considered as 'consumer–only' of energy. However, with the integration of the solar panels, the BIPV in addition to generating electricity into the building, replaced part of the building roof materials, thereby providing further economic savings equivalent to the cost of the area of roofing materials, replaced by the PV panel.
3. Besides the added value to the building, the system fulfils the second definition of low-carbon economy as implied in the study via the creation of opportunities for the installation contract or jobs in the project as well as business or sales outlet for companies supplying the equipment. Another indirect way to assess the economic impact would be to quantify the financial value of the quantity of CO_2 avoided by the device from the time it started operating.
4. **Decision-making:** finally, the entire information gathered from this study can be used to appraise or criticise the continued use or application of low-carbon technologies. Some potential or prospective investors sometimes go into the investments with exaggerated or overrated expectation and get disappointed after commitment to such investments. Such information as the outcome of this study provides a preliminary idea of post-investment expectations.

In conclusion, therefore, putting into consideration the outcomes of the assessments in the study, one can reach a conclusion that low-carbon technologies, in particular BIPV, have a relatively positive economic impact on applied buildings. A downside, which could be picked as seen from the parametric analysis in the economic evaluations, is the influence or dependence of the economic contribution of the system to seasons of the year. This forms a platform of critical comparison between BIPV systems as used in this research case study with other types of low-carbon technologies. Wind turbines can also be argued to depend on climatic wind current, micro-hydro-systems on water flow at any given point and bio-systems on the volume of bio-gas flow at any given point. Apart from nuclear source, it can be concluded that most other types are not absolutely stable with respect to the measure of economic contribution over a time trend but influenced by climatic conditions of applied locations. Meanwhile in addition to being controversial as a low-carbon technology, nuclear sources are not yet applied as building-integrated low-carbon technology.

Finally, it is important, however, to always adopt credible methods of economic evaluations as outlined and demonstrated in the chapter in which the net economic benefit of the technology was paralleled with the life expectancy before making decisions on the viability of the technology as a low-carbon energy option in today's built environment and the building sectors.

Author details

Chukwuemeka Ikedi[1,2]*

*Address all correspondence to: ikedienergy@yahoo.com

1 SunLab Technologies, London, UK

2 Energy Commission of Nigeria, Abuja, Nigeria

References

[1] The European Strategic Energy Technology Plan (SET-Plan). Towards a Low-Carbon Future. 2014. p. 6

[2] Government Policy: Low Carbon Technology. Department of Energy and Climate Change; 2015

[3] Barlow S, Dusan F. Occupant comfort in UK offices—How adaptive comfort theories might influence future low energy office refurbishment strategies. Energy and Buildings. 2007;**39**:837-846

[4] Lombard PL, Ortiz J, Pout C. A review of buildings energy consumption information. Energy and Buildings. 2007;**40**:394-398

[5] Warner ES. Life cycle greenhouse gas emissions of nuclear electricity generation. Journal of Industrial Ecology. 2012;**16**:S7. DOI: 10.1111/j.1530-9290.2012.00472.x. 73 - 92

[6] Francisco MA, Myriam T, Antonio ZS, Francisco GM. An overview of research and energy evolution for small hydropower in Europe. Renewable Energy. 2017;**75**:476-489

[7] Ikedi CU, Okoroh MI, Dean AM. Numerical assessment of energy contribution by building integrated photovoltaics in a commercial/office building refurbishment in UK. Low Carbon Technology. 2016;**11**:338-448

[8] Rong A, Su Y. Polygeneration systems in buildings: A survey on optimization approaches. Energy and Buildings. 2017;**151**:439-454

[9] Santoli LD, Albo A, Garcia DA, Bruschi D, Cumo F. A Preliminary Energy and Environmental Assessment of a Micro Wind Turbine Prototype in Natural Protected Areas, Sustainable Energy. 2014;**8**:42-56

[10] Presenting the benefits of low emission development strategies. Low Emission Development Strategies Global Partnership (LEDS GP); 2016

[11] International Association for Impact Assessment (IAIA), Institute of Environmental Ssessment (IEA), UK. Principles of Environmental Impact Assessment—Best Practice; 1998

Chapter 6

Bioelectricity's Potential Availability from Last Brazilian Sugarcane Harvest

Mirko V. Turdera and Marli da Silva Garcia

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.76251

Abstract

This chapter presents and discusses the potential of power generation from last sugarcane harvest (2016/2017), mainly by the combustion of two by-products; bagasse and straw. Bioelectricity production from the bagasse and the straw is possible through the grinding sugarcane, and both are available in the driest period of the year (May to September) and match with the water shortage in the reservoirs of hydroelectric power plants to the same period. Brazil is the largest producer of sugarcane of the world, in 2016/2017 reaped 657,189.900 tons, this crop is concentrated in four states that are responsible for over 90% of the bioelectricity production. Considering 2016/2017 harvest, we have foreseen that the availability of bioelectricity could reach 74,994 GWh, but if we aggregate straw to the combustion at the boiler, the electricity produced would reach 111,558 GWh. This power energy produced is almost 20% of total power energy supply in 2016, when power generation was 570,562 GWh. This way, Brazil could increase the share of the renewable resources at its power energy matrix and avoid greenhouse gas emission. Moreover, we present a deep discussion about the current federal regulatory scope of Brazilian electricity market and how bioelectricity fits into this competitive market.

Keywords: bioelectricity, bagasse, straw, sugarcane, gases, Brazil

1. Introduction

Electric energy is crucial to the economic development and welfare of mankind. Most developing countries have had a strong economic growth, which has demanded higher electricity consumption [1]. However [2], to increase power generation requires the use of technologies from renewable resources that pollute less in addition to mitigate the emission of CO_2. According to Furuoka [3], several countries around the world struggle to draw up effective policies aimed at reducing emissions of carbon dioxide (CO_2) that is the cause of more than 60% of the global greenhouse effect. Several studies have shown that when renewable energy is consumed less carbon is emitted [4]. For the Organization of Economic Cooperation and Development (OECD), the utilization of renewable energy is considered environmentally friendly and according to Jebli and Belloumi [5], renewable energy is an important resource for the development of economic and social activities.

Brazil is renowned for thriving agribusiness, and sugarcane is the crop that stands out in the Brazilian economy [6]. Brazil produces a significant amount of biomass, which is converted into ethanol and/or in the production of electrical energy. Brazil is the world's largest producer of sugarcane, the largest producer and exporter of sugar and the second largest producer of ethanol [7].

Before the Intended Nationally Determined Contribution- INDC, Brazil has undertaken to reduce greenhouse gas emissions to 43% below 2005 levels. For this, the country has undertaken measures to increase the participation of sustainable bioenergy in its energy matrix to approximately 18% until 2030, restore and reforest 12 million hectares of forests as well as reach an estimated 45% participation of renewable energies in the energy matrix in 2030 [6].

2. Bioelectricity generation in Brazil

Power energy installed capacity in 2016 was shared as follows: hydro 101,598 MW (71,5%), thermal (natural gas + liquefied natural gas) 12,414 MW (8,7%), wind 9,611 MW (6,8%), thermal (biomass) 7,640 MW (5,4%), thermal (fuel oil + diesel) 4,732 MW (3,3%), thermal (coal) 3,174 (2,2%), nuclear 1,990 MW (1,4%), others (waste + importation) 867 MW (0,6%) and solar 16 MW (0%) [7] (see **Figure 1**).

We can affirm that Brazilian power matrix still is clean, because renewable sources hold 84% of the installed capacity. The solar source has just 16 MW installed, but probably next decades it will be the source that will grow more. Nowadays, there is a strong stimulus to install photovoltaic (PV) panels at residential and commercial sectors as well as the combined heat and power (CHP) systems in the industrial sector. The goal is to become self-sufficient in electricity consumption. Factors such as a fall of PV's facilities installation cost, the sale of surplus electricity to the power grid and the increasing environmental pressure are leading to the expansion of the use of renewable sources.

2.1. Greenhouse gases

However, fossil fuels remain as the main source of the world's energy mix [8]. In global debates on climate issues there is the need for unanimous reductions in emissions of carbon dioxide (CO_2), arising from the massive use of petroleum, coal, and natural gas as fuels [9]. Thus, renewable resources such a solar, wind, biomass have emerged as an alternative in the production of electricity on a large scale, most of them in the mode of distributed generation, besides being less aggressive to the environment [10]. The vast majority of countries are aware

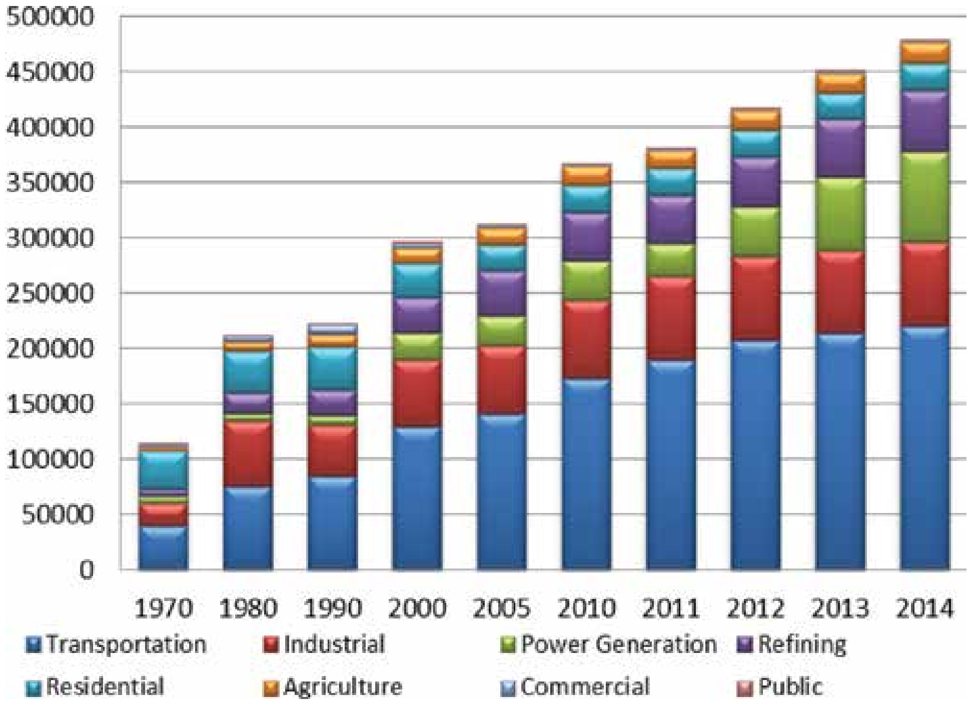


Figure 1. Brazilian-installed capacity of power energy. *Source – ONS 2017.*

of the strong dependence on fossil fuels in the energy production currently, its participation on the world energy matrix is 86% because of this, carbon dioxide emissions have reached the volume of 33.508 Gtons, or 0.1% more than 2015 [11].

To make matters worse, the transaction named "carbon credits" has emerged as an alternative to the developed countries and/or large enterprises, with appointments or goals of reduction of GHG emissions to be reached, acquires the "certified emission reductions" (carbon credits) and therefore promotes the implementation of energy projects that use renewable energy sources in developing countries. However, this market of carbon credits has not been consolidated as intended, since the value of the carbon credit did not reach attractive values expected. Thus, the initial enthusiasm about the commercialization of carbon credits goes through a phase of low motivation; therefore, the expectation of being a source financial for energy renewable projects has decreased substantially.

To be competitive developing countries are pressured to produce energy with sustainability and preserve natural resources, and that is just possible with the implementation of innovative technologies that reduce carbon emissions and environmental impacts [12, 13]. Sustainable production system is a global necessity which represents a competitive advantage and new market opportunities [14]. With the use of sugarcane waste to produce bioelectricity it is possible to soften the impacts of GHG and increase the share of renewable energy sources. According to the authors [15], this is a reality that makes it possible for energy crops to contribute significantly to the sustainability of the planet. The cultivation of sugarcane has a

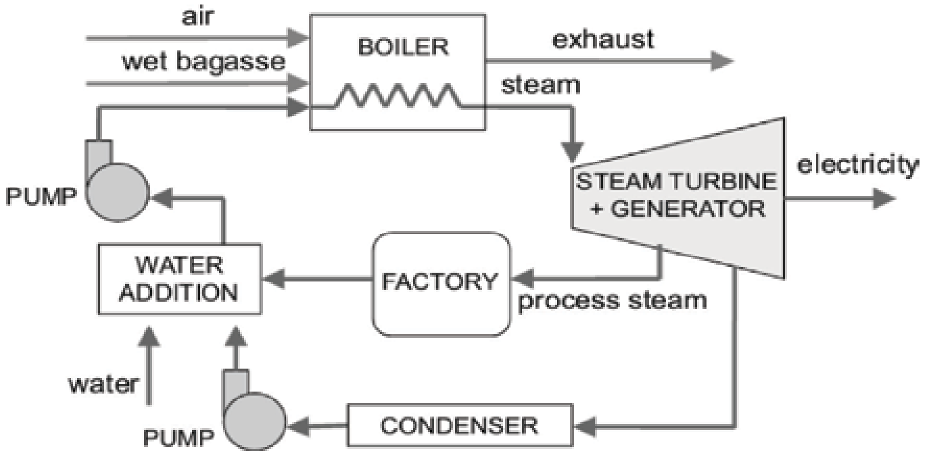


Figure 2. Brazil; $CO_{2\ eq}$ emissions by sector (kton).

great conversion efficiency of photosynthesis. As researched by Paula et al. [16], the production of a ton of biomass fixed minimum 0.42 tons of carbon, equivalent to mitigate 1.54 tons of carbon dioxide (CO_2) from the atmosphere. There are technologies already available to provide electricity from biomass-like energy sources. On the other hand, it is known that the bagasse burning in boilers emits pollutants in the atmosphere, the contents of which are particulates, carbon monoxide (CO), unburned hydrocarbons (C_XH_Y) and nitrogen oxides (NO_X). The researchers Teixeira et al. [58] affirm that the principal mechanism of NO_X formation is related to the "fuel mechanism" which overcomes the others.

The transportation sector is the greatest pollutant of GHG emission on Brazil with 46%. We can observe that from the year 2000 the power generation has increased its share of contribution of the CO_2 emission (17%). It is because the thermal power plants, by burning several fuels, have been activated to operate at the base and the intermediate part of the load curve and not only to meet peak demand. The electrification of rural areas has affected the fall in gas emissions from this sector, because the cooking is no longer made with firewood. Last 44 years, the emissions went from 114.26 to 479.1 Gton of CO_2 equivalent (**Figure 2**).

2.2. The sugarcane biomass

Lignocellulosic biomass is the renewable resource used in the production of bioenergy, where the goal is trying to reduce the massive presence of fossil fuels. Lignocellulosic biomass refers to plant dry matter, mainly composed of cellulose, hemicellulose and lignin [18]. The agricultural and industrial wastes are the most promising biomass for its use in the power generation because they are abundant and relatively low cost [19]. In Brazil, straw and bagasse are the renewable resources used by the combined heat and power (CHP) systems, both are derived from sugarcane. Other biomass resources known are black liquor, scraps of wood, rice husk, the elephant grass, and corn cob [20].

The ethanol production occurs in sugar mills. In the country, currently there are 520 factories operating in 23 states. Nowadays, there is a high concentration in the Southeast region, where more than two thirds of the plants are located, mainly in the State of São Paulo where are working 280 plants. The state of Minas Gerais with 45 power plants has the third position. In the last decade, the expansion of the sugarcane crops has occurred in the Midwest region of the country [21].

The energy contained in sugarcane is composed 1/3 in the form of sugars contained in the broth that is used in the production of sugar and ethanol, or 1/3 in the form of fibers contained in the thatched roofs and 1/3 in the form of leaf and stalk point. According to the national supply company [22] the production of Brazilian sugarcane 2016/2017 harvest was around 657,180,000 ton; harvested area has been estimated at 9,050,000 hectares. The sugarcane industry was destined primarily to produce sugar and ethanol, but sustainable production practices in the industrial process have led to the obtaining of two new by-products bagasse and straw, both used in the power production, ethanol from second generation bioplastics, xylitol and others [23].

Bagasse is the most important solid by-product of the processing of sugarcane. Maliger et al. [24] claim that the dry residue is composed of 32–48% of cellulose, 23–32% of hemicellulose, 19–24% of lignin, and 1–5.5% ash. According to the authors [25], these values can vary according to the variety and age of sugarcane, soil type and fertility and the harvest system. Saidur et al. [26] report that the lignin content of cellulosic fuel is strongly correlated with the caloric content. The straw is another by-product of sugarcane and its use is in the experimental stage, unlike the straw residue that must be collected from the field. The amount of bagasse generated in the process is in the range of 250–280 kg per ton of sugarcane crushed and has 50% humidity [27, 28, 29]. According to Pellegrini et al. [30], the need for cost reduction coupled with the recovery of by-products of sugarcane, and the environmental pressures have made a useful by-product residue to fuel CHP system. In fact, the generation of thermal and electric energy has been a practice routine at ethanol mills for decades and this use is not unique to Brazil. A ton of sugarcane produces on average 120 kWh using bagasse as fuel; this value can vary depending on the quality of the bagasse, crop season, the variety of sugarcane, kind of soil, CHP facilities, types of boilers and turbines, content humidity, and so on. [31].

The straw mixed with the bagasse is transported to the plant, where the separation of the vegetable and mineral impurities is carried out through the Dry Cane Cleaning System (SLCS). After separation, the straw together with the bagasse is transported in the same mat to the boiler or destined to the storage. According [32] if all the straw were left in the field can compromise the sprouting of the pests in large quantity, thus the removal of part of this vegetable waste is appropriate. The ideal is to collect 50% of the straw, which facilitates the management of fertilizer knuckle-dusters, favors the sprouting of sugarcane, inhibits the hosting of pests and reduces the risks with fires [33] to avoid the partial collapse of the straw, keeping an adequate amount to cover the ground. Therefore, this action protects the soil against erosion and direct radiation, increases the rate of water infiltration, reduces evaporation and perspiration and improves the control of plants weeds.

The straw added to the bagasse significantly increases the production of bioelectricity. Thus, in the case of the addition of 10% straw, with a moisture content of 15%, the production of electric energy would increase up to 23% and, when all the available straw is added, the power generation would increase by 102%. Inside the mills the consumption of electromechanical energy required to process 1 ton of sugarcane must be at least 28 kWh, but depending on the technology used up to 35 kWh may be required [34].

The mechanization of the harvest was made official with Act 11,241, dated September 19, 2002, gradually eliminating the use of fire as a facilitator of sugarcane cutting in areas susceptible to mechanization with declivity of less than 12% [35]. With the changes occurring, the mechanized harvest eliminated the emission of particulates and generated straw, which is now used as fuel in the generation of electric energy, if there is a surplus it is commercialized in the market.

2.3. CHP generation at sugar and ethanol mills

A study made by International Renewable Energy Agency [17] identifies three crucial factors to determine the use of biomass to power generation, they are: (1) the biomass storage, which can be in a variety of ways and has different properties impacting its use in generation of electrical energy, (2) biomass conversion; it comes from processes in which biomass is stocked in the form of chemical energy that will be used to generate heat and/or electric power and (3) power generation technologies.

The production incremental innovation of the sugarcane mills has come from genetic improvement technologies, modern machines and equipment, and energy efficiency measures allowed the development of the third product of sugarcane, the electric energy. The viability of biomass CHP plants is usually governed by the price of electricity and the availability and cost of the biomass feedstock. Although many sources of biomass are available for co-generation, the greatest potential lies in the sugarcane and wood processing industries, as the feedstock is readily available at low cost and the process heat needs are onsite [36]. Around the world, the rapid growth of the small-scale renewable market means that renewable power generation is rarely well-balanced.

Bioelectricity in Brazil has great challenges to face, but there are also great chances of establishing itself as a safe and reliable alternative in the supply of electric energy, especially to complement the drought season of the Southeast/Midwest region. The opportunity cost in the electricity market has been favorable, especially in the spot market. The rainfall regime in the mentioned region has been very irregular in the last 5 years, due to the climatic phenomenon called El Niño. Therefore, the useful volume or energy load in the form of water at hydroelectric plant reservoirs has decreased significantly and, with this, the threat of a blackout became more constant.

In Brazil, CHP facilities have bagasse as the main fuel used in sugar and ethanol mills. CHP systems are known as the simultaneous production of thermal, mechanical and electrical energy, in which a primary energy source feeds a thermal equipment that turns the chemical energy of the fuel into a mechanical shaft driven by the combustion reaction, which is then

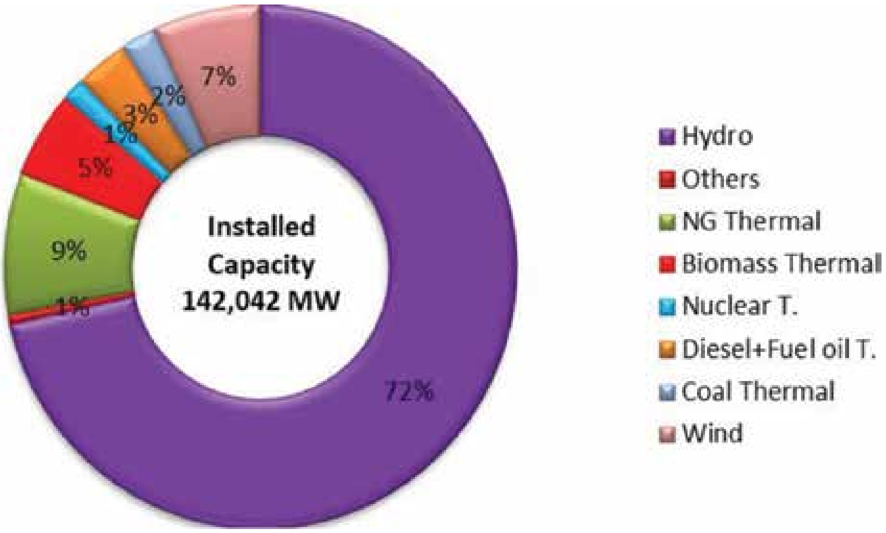


Figure 3. Rankine cycle in the CHP process at the Brazilian sugar and ethanol mills.

converted into energy through generators [37]. The technology adopted in the co-generation of the sugar-energy plants, the new denomination of the sugar and ethanol mills is the Rankine cycle [38, 30] due to the need for thermal, mechanical and electrical energy (**Figure 3**).

Carvalho and Pontes [39] complement that this technology uses water as the working fluid. The water is pumped to the boiler to release thermal energy in the form of steam; with temperature (1000–1300°C) and high pressure, the thermal energy goes through an expansion process in the turbines for the conversion of thermal energy to mechanical energy and after that to power energy. For authors such as Pellegrini et al. and [30], Ensinas et al. [40], the CHP system aiming only at self-sufficiency is of low efficiency because it uses boilers of 21 kgfcm^{-2} and 300°C, with backpressure turbines that are responsible for the industrial electromechanical demands of the plant. On the other hand, to produce surplus electric power, the units use boilers above 42 kgfcm^{-2} and extraction-condensation turbines.

The determinant factor for greater generation of electricity surplus is the configuration adopted by the CHP system, which Alves et al. [34] describe as the backpressure steam turbine (BPST) system. This system is designed to meet the energy demands of the process and operates only during the sugarcane harvest. Sugar and ethanol mills to produce surplus electric energy adopt the backpressure steam turbine system and condensing extraction steam turbine (BPS-C), which is indicated to generate steam of high pressure; thus, thermal and electrical energy are produced for meeting the demand of the plant and still have surplus electricity to trade at the market. This system operates with boilers above 67 bars with a steam outlet temperature of around 540°C. They are automatic control extraction-condensation turbines and the combination of backpressure steam turbines with axial flow condensation turbines. In modern boilers, the burning is made in suspension, with rotating grates, pin hole, tipper or fluidized bed, which allows biomass conversion efficiency. According to Bocci et al. [41], fluidized bed boilers allow greater efficiency in the conversion, generate more electricity due to the more complete burning of the fuel. According to Castro et al. [42], the use of high-pressure boilers and efficient steam turbines allows to increase power generation by providing surplus electricity .

2.4. Power energy generation from bagasse and straw

In Brazil, the production of electricity from alternative sources has been supported by Act 10,848 of March 15, 2004 [43]. This law provides for the sale of electric energy to increase the participation of wind, biomass and small hydroelectric power plants (SHPs) in the National Interconnected Electric System (NIS). The generation obtained from sugarcane biomass is managed by the Incentive Program for Alternative Energy Sources (PROINFA), described in Decree No. 5025 of March 30, 2004 [44].

Regarding the electric energy delivered by the national electric system operator (ONS), in 2016, it reached the value of 570,562 GWh. Hydroelectricity still prevails with the largest generation share, with 71.7% of the supply. Thermal plants have an 18.9% stake, of which 48% of them operate with natural gas, 38% with oil derivatives, 13% with coal and 1% with other sources. Biomass-fired CHP system accounts 8.9% of the electricity supply, 78% of which comes from the combustion of sugarcane bagasse, 20% from forest residues and 2% from others biomass. Power production from wind turbines is 3.6% and, finally electric energy supply from solar facilities is 0.2% (**Figure 4**).

The cost of power generation of a CHP plant is always much higher than a configuration of only one power plant. There are intrinsic factors to the CHP systems, installed at the sugar-energy mills, which increase the final cost of the kWh generated. Among them, the following can be included in the biomass storage system; in the case of bagasse, the cost usually varies between US$ 10.00/ton up and US$ 160 per ton [17]. The burning costs range in US$ 0.06–0.29/kWh. Other costs that can be considered are equipment costs, financing costs, operation, and maintenance costs (usually in the range of 20% of installed costs).

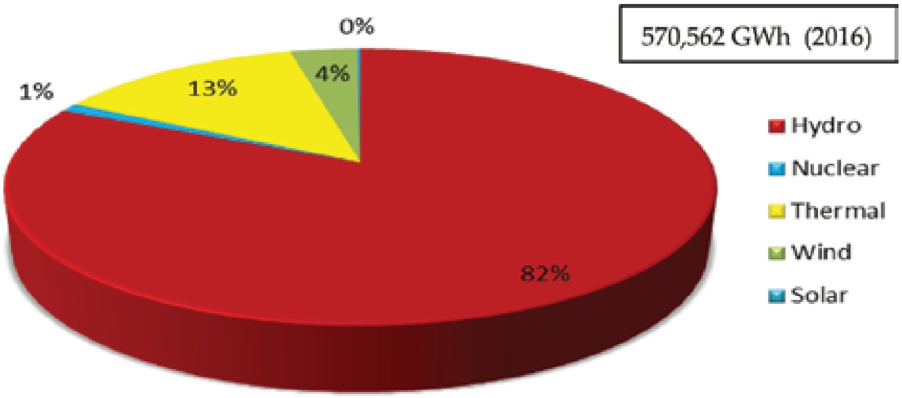


Figure 4. Power production by source.

Item	Unity	Quantity
Sugarcane harvested	Ton	657,184,000
Bagasse available with 50% humidity (280 kg per sugarcane ton)	Ton	184,011,520
Bagasse for starting in the boiler after maintenance or next harvest (5%)	Ton	9,200,576
Bagasse available for CHP generation	Ton	174,810,944
Straw available potential for CHP generation (310 kg per sugarcane ton)	Ton	101,863,520
Power generation potential using bagasse (0.000429 GWh/tonne of bagasse × 174,810,944 tonne bagasse)	GWh	74,994
Electric energy needed to meet internal demand of the mills (0.00003 GWh/ton of sugarcane) × 657,184,000 ton of sugarcane	GWh	19,715
Potential of electrical energy available from bagasse-fired	GWh	55,279
Potential of electrical energy available from straw-fired with 15% moisture	GWh	56,384
Total electric energy available (bagasse + straw)	**GWh**	**111,663**

Table 1. Potential of power generation based on the quantity of bagasse and straw of the last harvest 2016/2017.

Sugarcane production in the 2016/2017 harvest was 657,184,000 tons [22]. Based on the authors [27, 28, 34, 45], we estimated that 184,011,520 tons of bagasse and 203,727,040 tons of straw could be extracted. Of this total, 5% of the bagasse must be reserved for the sugar and ethanol plants to have bagasse stock required to start the boilers or the mandatory maintenance shutdowns. Therefore, 174,810,944 tons would be hypothetically available to produce power energy, aiming at the energy self-sufficiency of the plant and its commercialization at electric energy market. Then, of this amount of bagasse, it is possible to produce 74,994 GWh, of which 19,715 GWh are destined to meet the power demand of the mills, the remaining 55,279 GWh is destined for negotiation at electricity market.

About the straw, it is indicated by scientific literature to leave 50% of the biomass on the field; therefore, the amount of straw that can be harvested would be 101,863,520 tons. Modern boilers allow greater efficiency in conversion and would support the addition of 50% straw with a moisture content of 15%. The arrangement of the boilers into the CHP system would allow an increase of 36,669 GWh, this way the potential electric power generated by the biomass mix bagasse-straw would increase to 111,663 GWh. The current norms of electricity regulation in the world assume special relevance in the processes of environmental control needed to soften global warming and provide sustainable economic growth [13] (**Table 1**).

3. Structure of the Brazilian electricity sector

In Brazil, the structure of the electricity sector is hierarchical, and the Ministry of Mines and Energy (MME) is responsible for formulating policy adjustments for the energy sector. It is regulated by the National Electric Energy Agency (ANEEL), which supervises the electric sector, ensuring the quality of services rendered, the universalization of service and the establishment of tariffs for final consumers. Below ANEEL is the National System Operator (ONS) that coordinates and controls the generation and transmission of electricity from the interconnected system. The Electric Energy Trading Chamber (EETC), under the supervision of ANEEL, is responsible for contract management, short-term market (STM) liquidation and energy auctions.

3.1. The Brazilian electricity market

Institutional arrangements therefore define the way in which an economic system coordinates a specific set of economic activities. In the last decades, energy market players have made many agreements to address energy issues, ranging from increasing international energy exchange to reducing emissions and increasing flexibility in the distribution of electricity amid growing resources of intermittent renewable energy [46]. The institutional arrangements that regulate the commercialization of electric energy are important for development policies, especially for those that require cooperation of public and private agents. The Brazilian energy matrix diversified, with a variety of generation sources, to small-scale projects alongside those of large size, distributed in the geographic regions of the country [47] with increased participation of the private sector [48]. The Brazilian electric sector consolidated the rules trough Act No. 10,848 [43] and Decree No. 5163 [49]; both regulate the sale of electric energy between concessionaires, permit holders and authorized power services and facilities as well as of these agents with their consumers at SIN. The dynamic of the market occurs through regulated contracting or free agreement about electricity trading. In this specific context, contractual mechanisms have been developed to diversify the inflow of private capital investments.

3.2. Arrangement in the commercialization of electric energy

The commercialization of electricity in Brazil is carried out in two market spheres: The Regulated Contracting Environment (RCE) and the Free Contracting Environment (FCE); all contracting environments need to be registered in the EETC and serve as a basis for accounting and settlement of differences in the short-term market (**Table 2**).

	Free environment	**Regulated environment**
Participants	Power producers, marketers,	Power producers, distributors and marketers. Marketers can trade power energy only in existing energy auctions
Hiring	Free and special consumers	Held by means of energy auctions promoted by CCEE under ANEEL delegation.
Type of contract	Free negotiation between buyers and sellers	Regulated by ANEEL, called the Regulated Contracting Environment (RCE)
Price	Agreement freely established between the parties	Fixed in the auction

Table 2. Differentiating between the two marketing schemes.

3.3. Regulated contracting environment (RCE)

The bilateral agreements through Electric Energy Trading Contracts in the Regulated Environment are opened according to the national energy planning and in two modalities, current electric energy and new power generation [50]. At the end of the auctions, the commercialization of electric energy inside the RCE is done through standardized bilateral contracts, entered between each seller and all concessionaires, permit holders and authorized public service providers [51]. According the Federal Law 10,848 [43] current electric energy agreements have a duration of 1–15 years, while new power generation contracts can be from 15 to 35 years. Decree No. 6048, dated February 27, 2007 [52], regulated the auctions of renewable sources like wind, biomass, and electric energy from small hydroelectric plants—with a term of 1–5 years in the start and duration of 10–30 years.

3.4. Free contracting environment

The commercialization of electricity in the Free Contracting Environment is carried out through the purchase and sale of electric energy between concessionary agents, permission holders and generation-authorized buyers and sellers, traders, importers of electric energy, on the one hand, and free or special consumers, on the other hand [51]. All contracts negotiated in the ACL have their conditions of service, the price and other contractual clauses freely negotiated between the parties. Free consumers are considered those whose contracted demand is equal to or greater than 3000 kW, serviced at a supply voltage above 69 kV. These customers can acquire electric energy from any incentive and/or conventional source [53]. According to Araujo et al. [54], the special consumers are those whose contracted demand is greater than or equal to 500 kW, individually or by actual communion (same address) or law. In Brazil, the environment that allows producers and traders to freely sell electric energy is the short-term market [51].

3.5. Short-term market

The EETC measures the amount produced or consumed by each agent. The differences determined are settled in the short-term market (STM), or spot market, at the settlement price of differences (SPD) that is determined weekly for each load level, limited by the maximum and minimum price of each assessment period of the market [51].

To trade electricity in the short-term (spot) market, agents must inject into the SIN the electricity produced, which is accounted by EETC. The Electric Energy Trading Chamber performs three tasks: (1) manages all contracts for the purchase and sale of energy, (2) records the daily measurement of what is generated in the plants and consumed by all agents participating in the system, (3) accounts for amounts payable and receivable based on purchase and sale agreements and effective generation and consumption. With the amounts calculated, the EETC carries out the liquidation, which is the settlement of accounts between the creditors and debtors' agents. These differences are determined by the amount of the settlement price of differences (SPD) [51]. This price is used to value the energy not contracted among the agents of EETC (leftovers or differences) in the short-term market. The credits and debits resulting from this contracting are settled between the agents in a centralized way in the EETC. The sale or purchase price of the energy that exceeds or is lacking in the contracts is added to the system service charges (SSC) [54]. The settlement price of differences reflects the marginal cost of new electricity in the system. In the rainy season, when supply and demand for electricity in the country are balanced, the price of electric power is lowered and, consecutively, the SPD as well. When the water reservoirs are low, there is a lack of energy and the thermal plants are linked to a high marginal cost, pushing up the energy price and the SPD [55].

The crisis in the Brazilian electricity supply, which occurred due to climate issues, lack of planning and investments by the federal government, has been causing losses to the public coffers and society. During the period from December 2013 to April 2014, the market value of the SPD in the Southeast/Midwest region increased from US$ 0.09232 to US$ 0.26121 per kWh. This increase was due to the entry into operation of many thermal power plants caused by the low level of water in hydroelectric reservoirs [56]. Between 2015 and November 2017 there was no contracting of new energy from biomass, wind and solar. During the period from 2015 to August 2017, the behavior of SPD prices was lower than US$ 0.07936/kWh, but in November 2017, prices reacted and reached US$ 0.16946/kWh [51].

4. Conclusions

Hypothetically, the amount of carbon dioxide absorbed could reach 276.03 million of CO_2 equivalent tons, resulting from 657,184,000 tons of sugarcane harvested in 2016/2017. Regardless of installed capacity, all sugar and ethanol plants produce energy to be self-sufficient, in terms of thermal, mechanical and/or electrical energy. Discounting this domestic demand, the electric energy produced is injected and sold in the National Interconnected System (SIN). The most commonly used fuel in the boilers of sugarcane plants is bagasse, the straw is a potential fuel in the experimental stage. The energy potential of the straw should be considered with caution, since the sugar-alcohol boilers are limited to the addition of this fuel to the bagasse; in some cases the mixture is made up to 30% straw. Therefore, the possibility of using the full potential of the electric energy through the burning of bagasse and straw requires the adaptation of the boilers and the selection of the best straw collection system in the field, considering the economic viability.

The potential power generation from the combustion of bagasse and straw will be 111,558 GWh; this energy would be equivalent to 20.4% of the electric energy delivered by the national electric grid operator (ONS) in 2016. Nowadays, discussing energy security has another nuance that of preventing the market from collapsing, especially by the eventual lack of electricity supply, whether due to climatic issues or armed conflicts [57, 59]. Brazil suffers more with the first question, the dependence of the availability of water in the hydro basins makes it very vulnerable. Fortunately Brazil has several renewable sources that could hold the matrix of the power energy supply clean. As for the electric energy market and the way to market bioelectricity, we may claim that there are endogenous risks such as the technology chosen, the quality of biomass, tax exemptions, but, there are exogenous risks too, such as the performance of the country's economy, the volatility of electric energy prices, the political context, and so on. However, in Brazil, bioelectricity comes definitively to stay; therefore, its competitiveness should be put to the test, but the prospects of success seem to be attractive.

Author details

Mirko V. Turdera[1]* and Marli da Silva Garcia[2]

*Address all correspondence to: eduardoturdera@ufgd.edu.br

1 Federal University of Grande Dourados, Dourados, Brazil

2 Don Bosco Catholic University, Campo Grande, Brazil

References

[1] Rehman MU, Rashid M. Energy consumption to environmental degradation, the growth appetite in SAARC nations. Renewable Energy. 2017;**111**:284 A-28294. DOI: https://Doi-Org.Ez50.Periodicos.Capes.Gov.Br/10.1016/J.Renene.2017.03.100

[2] Sinha A, Shahbaz M, Balsalobre D. Exploring the relationship between energy usage segregation and environmental degradation in N-11 countries. Journal of Cleaner Production. 2017;**168**:1217 A-121229. http://Dx.Doi.Org/10.1016/J.Jclepro.2017.09.071

[3] Furuoka F. The CO_2 emissions – Development Nexus revisited. Renewable And Sustainable, Energy Reviews. 2015;**51**:1256-1275. http://Dx.Doi.Org/10.1016/J.Rser.2015.07.0 49

[4] Dogan E, Seker F. The influence of real output, renewable and non-renewable energy, trade and financial development on carbon emissions in the top renewable energy countries. Renewable and Sustainable Energy Reviews. 2016;**60**:1074-1085. DOI: https://doi.org/10.1016/J.Rser.2016.02.006

[5] Jebli MB, Belloumi M. Investigation of the causal relationships between combustible renewables and waste consumption and Co_2 emissions in the case of Tunisian maritime and rail transport. Renewable and Sustainable Energy Reviews. 2017;**71**:820-829. DOI: https://doi-org.Ez50.Periodicos.Capes.Gov.Br/10.1016/J.Rser.2016.12.108

[6] Catherine A, Livia K. La Contribution Du Brésil À La Cop21: L'agrobusiness Du Futur. Brésil(S) Sciences Humaines Et Sociales. 2017;**12**. DOI: http://Journals.Openedition.Org/Bresils/2154

[7] Garcia MS, Vilpoux OF, Cereda MP. Distributed electricity generation from sugarcane for agricultural irrigation: A case study from the Midwest region of Brazil. Utilities Policy. 2017;**50**:207-210. A-1 4. DOI: https://doi.org/10.1016/J.Jup.2017.09.010

[8] Afonso TL, Marques AC, Fuinhas JA. Strategies to make renewable energy sources compatible with economic growth. Energy Strategy Reviews. 2017;**18**:121-E126. DOI: https://Doi.Org/10.1016/J.Esr.2017.09.014

[9] Carpio LGT, Souza FS. Optimal allocation of sugarcane bagasse for producing bioelectricity and second generation ethanol in Brazil: Scenarios of cost reductions. Renewable Energy. 2017;**111**:771 A-77780. http://Dx.Doi.Org/10.1016/J.Renene.2017.05.015

[10] Ripoli MLC, e Gamero CA. Palhiço de cana-de-açúcar: Ensaio padronizado de recolhimento por enfardamento cilíndrico. Revista Engelharia agrícola. Botucatu. 2007;**22**(1):75-93

[11] British Petroleum Statistical Report. https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review-2017/bp-statistical-review-of-world-energy-2017-full-report.pdf

[12] Aghion P, Hepburn C, Teytelboym A, Zenghelis D. Path-Dependency, Innovation And The Economics Of Climate Change. Supporting Paper For New Climate Economy. Grantham Research Institute On Climate Change And The Environment, School Of Economics And Political Science, London; 2014

[13] Alvarez-Herranza A, Balsalobre-Lorente D, Shahbazc M, Cantos JM. Energy innovation and renewable energy consumption in the correction of air pollution levels. Energy Policy. 2017;**105**:386-397. http://Dx.Doi.Org/10.1016/J.Enpol.2017.03.009

[14] Alexopoulos I, Kounetas K, Tzelepis D. Environmental performance and technical efficiency, is there a link? The case of Greek listed firms. International Journal of Productivity and Performance Management. 2012;**61**(1):6-23. DOI: 10.1108/17410401211187480

[15] Hassuani SJ, Leal MRLV, Macedo IC. Biomass power generation: sugar cane bagasse and trash. Piracicaba: PNUD Brasil, Centro de Tecnologia Canavieira; 2005. p. 216

[16] Paula M, Pereira FAR, Arias ERA, Scheeren BR, Souza CC, Mata DS, Fixação De Carbono EA. Emissão Dos Gases De Efeito Estufa Na Exploração Da Cana-De-Açúcar. Revista Ciências E Agrotecnologia. 2010;**34**(3):633-640. http://Dx.Doi.Org/10.1590/S1413-70542010000300015

[17] IRENA. International Renewable Energy Agency, Renewable Energy Technologies: Cost Analysis Series, Volume 1, Power Sector, Biomass for Power Generation; 2012. p. 60

[18] Arshad M, Ahmed S. Cogeneration through bagasse: A renewable strategy to meet the future energy needs. Renewable and Sustainable Energy Reviews. 2016;**54**:732-737. DOI: https://Doi-Org.Ez50.Periodicos.Capes.Gov.Br/10.1016/J.Rser.2015.10.145

[19] Dogan E, Inglesi-Lotz R. Analyzing the effects of real income and biomass energy consumption on carbon dioxide (Co_2) emissions: Empirical evidence from the panel of biomass-consuming countries. Energy. 2017;**138**:721. E-72727. http://Dx.Doi.Org/10.1016/J.Energy.2017.07.136

[20] Caia J, He Y, Yu X, Banks SW, Yang Y, Zhang X, Yu Y, Liu R, Bridgwater AV. Review of physicochemical properties and analytical characterization of lignocellulosic biomass.

Renewable and Sustainable Energy Reviews. 2017;**76**:309-322. http://dx.doi.org/10.1016/j.rser.2017.03.072

[21] Carpio LGT, Souza FS. Optimal allocation of sugarcane bagasse for producing bioelectricity and second generation ethanol in Brazil: Scenarios of cost reductions. Renewable Energy. 2017;**111**:771-780. http://dx.doi.org/10.1016/j.renene. 2017.05.015

[22] CONAB, Companhia Nacional de Abastecimento. https://www.conab.gov.br/

[23] Clauser NM, Gutiérrez S, Area MC, Felissia FE, Vallejos ME. Small-sized biorefineries as strategy to add value to sugarcane bagasse. Chemical Engineering Research and Design. 2016;**107**:137-146. DOI: https://Doi.Org/10.1016/J.Cherd.2015.10.050

[24] Maliger VR, Doherty WOS, Frost RL, Mousavioun P. Thermal decomposition of bagasse: Effect of different sugar cane cultivars. Industrial and Engineering Chemistry Research. 2011;**50**(2). DOI: 10.1021/Ie101559n

[25] Jebli MB, Bellouimi M. Investigation of the causal relationships between combustible renewables and waste consumption and CO_2 emissions in the case of Tunisian maritime and rail transport. Renewable and Sustainable Energy Reviews. 2017;**71**:820-829. https://doi-org.ez50.periodicos.capes.gov.br/10.1016/j.rser.2016.12.108

[26] Saidur R, Abdelaziz EA, Demirbas A, Hossain MS, Saidur MS. A review on biomass as a fuel for boilers. Renewable and Sustainable Energy Reviews. 2011;**15**:2262-2289. DOI: https://Doi.Org/10.1016/J.Rser.2011.02.015

[27] Nogueira MAFS, Garcia MS. Gestão Dos Resíduos Do Setor Industrial Sucroenergético: Estudo De Caso De Uma Usina No Município De Rio Brilhante, Mato Grosso Do Sul. Revista Eletrônica Em Gestão, Educação E Tecnologia Ambiental – Reget. 2013;**17**:3275-3283. http://Dx.Doi.Org/10.5902/2236117010444

[28] Satyanarayana KG, Arizaga GGC, Wypych F. Biodegradable composites based on Lignocellulosic fibers—An overview. Progress in Polymer Science. 2009;**34**:982-1021. DOI: https://Doi.Org/10.1016/J.Progpolymsci.2008.12.002

[29] Nakanishi EY, Villar-Cocinab E, Santos SF, Rodrigues MS, Pinto PS, Savastiano Jr, H. Tratamentos térmico e químico para remoção de óxidos alcalinos de cinzas de capim elefante. Química Nova. 2014;**37**(5):766-769. http://dx.doi.org/10.5935/0100-4042.20140123

[30] Pellegrini LF, Oliveira Júnior S, Burbano JC. Supercritical steam cycles and biomass integrated gasification combined cycles for sugarcane Mills. Energy. 2010;**35**:1172-1180. DOI: 10.1016/J.Energy.20 09.0 6.011

[31] Deshmih R, Jacobson A, Chamberlin C, Kammen D. Thermal gasification or direct combustion. Comparison of advanced cogeneration system in sugar cane industry. Biomass and Bioenergy. 2013;**5**(5):163-174. DOI: https://Doi.Org/10.1016/J.Biombioe.2013.01.033

[32] Marques TA, Pinto LEV. Energia Da Biomassa De Cana-De-Açúcar Sob Influência De Hidrogel, Cobertura Vegetal E Profundidade De Plantio. Revista Brasileira De Engenharia Agrícola E Ambiental. 2013;**17**(6):680-685. http://Dx.Doi.Org/10.1590/S1415-43662013000600015

[33] Hassuani SJ, Leal MRLV, Macedo IC. Biomass Power Generation: Sugar Cane Bagasse and Trash. Piracicaba: PNUD Brasil/Centro De Tecnologia Canavieira; 2005. p. 216

[34] Alves M, Ponce GHSF, Silva MA, Ensinas AV. Surplus electricity production in sugarcane mills using residual bagasse and straw as fuel. Energy. 2015;**91**:751 E-75757. DOI: https://Doi.Org/10.1016/J.Energy.2015.08.101

[35] SÃO PAULO. Lei N°. 11.241, de 19 de setembro de 2002. Dispõe sobre eliminação gradativa da queima da palha da cana-de-açúcar. Disponível em: < http://www.al.sp.gov.br/repositorio/legislacao/lei/2002/lei-11241-19.09.2002.html>. Acesso em: Jan 2018

[36] Rego EE, Parente V. Brazilian experience in electricity auctions: Comparing outcomes from new and old energy auctions as well as the application of the hybrid Anglo-Dutch design. Energy Policy. 2013:**55**. https://doi-g.ez50.periodicos.capes.gov.br/10.1016/j.enpol.2012.12.042

[37] Costa MHA, Balestieri JAP. Viabilidade De Sistemas De Cogeração Em Indústria Química. In: Congresso Brasileiro De Engenharia E Ciências Térmicas. Vol. 1; Rio De Janeiro; 1998. pp. 358-363

[38] Potter MC, Scott EP. Termodinâmica. Editora Thomson; 2006

[39] Carvalho MS, Pontes LAM. Soluções de cogeração para uma planta industrial utilizando o ciclo Brayton. Revista Eletrônica de Energia. 2014;**4**(1):53-64

[40] Ensinas AV, Nebra SA, Lozano MA, Serra LM. Analysis of process steam demand reduction and electricity generation in sugar and ethanol production from sugar cane. Energy Conversion and Management. 2007;**48**:2978-2987. DOI: https://doi.org/10.1016/j.enconman.2007.06.038

[41] Bocci E, Di Carlo A, Marcelo D. Power plant perspectives for sugarcane mills. Energy, n 34. 2009. p. 689-698. https://doi.org/10.1016/j.energy.2009.02.004

[42] Castro NJ, Brandão R, Dantas GA. A Bioeletricidade Sucroenergética Na Matriz Elétrica. Etanol E Bioeletricidade: A Cana-De-Açúcar No Futuro Da Matriz Energética. Coordenação E Organização Eduardo L. Leão De Souza E Isaias De Carvalho Macedo. São Paulo: Luc Projetos De Comunicação; 2010. 144 A 14147

[43] Brasil - Lei N° 10.848 De 15 De Março De 2004. Dispõe Sobre A Comercialização De Energia Elétrica. Brasília; 2004

[44] Brasil. Decreto N° 5.025 De 30 De Março De 2004. Regulamenta O Inciso I E Os §§ 1o, 2o, 3o, 4o E 5o Do Art. 3o Da Lei No 10.438, De 26 De Abril De 2002, No Que Dispõem Sobre O Programa De Incentivo Às Fontes Alternativas De Energia Elétrica - Proinfa, Primeira Etapa, E Dá Outras Providências. Presidente Da República; Brasília; 2004

[45] Ripoli MLC. Ensaio De Dois Sistemas De Obtenção De Biomassa De Cana-De-Açúcar (Saccharum Spp.) Para Fins Energéticos. 235 F. 2005. Tese, Faculdade De Ciências Agronômicas, Unesp; 2005

[46] Silvast A. Energy, economics, and performativity: Reviewing theoretical advances in social studies of markets and energy. Energy Research & Social Science. 2017;**34**:4-12. DOI: https://Doi-Org.Ez50.Periodicos.Capes.Gov.Br/10.1016/J.Erss.2017.05.005

[47] Vahl FP, Ricardo Rüther R, Casarotto FN. The influence of distributed generation penetration levels on energy markets. Energy Policy. 2013;**62**:226-235. DOI: https://Doi-Org.Ez50.Periodicos.Capes.Gov.Br/10.1016/J.Enpol.2013.06.108

[48] Rego EE, Parente V. Brazilian experience in electricity auctions: Comparing outcomes from new and old energy auctions as well as the application of the hybrid Anglo-Dutch design. Energy Policy. 2013;**55**. DOI: https://Doi-Org.Ez50.Periodicos.Capes.Gov.Br/10.1016/J.Enpol.2012.12.042

[49] Rego EE. Decreto N° 5.163 De 30 De Julho De 2004. Regulamenta A Comercialização De Energia Elétrica, O Processo De Outorga De Concessões E De Autorizações De Geração De Energia Elétrica, E Dá Outras Providências. Brasília, 2004

[50] Camara De Comercialização De Energia Elétrica - CCEE. Contratos – Regras De Comercialização. Versão 2017

[51] Ursaia GC, Guerra JBA, Youssef YA, Lordemann JA. O Quadro Político E Institucional Do Setor Energético Brasileiro. Revista Jurídica Da Universidade Do Sul De Santa Catarina. 2012;**2**(4):27-56

[52] Coutinho PC, Oliveira AR. Trading forward in the Brazilian electricity market. International Journal of Energy Economics and Policy. 2013;**3**(3):272-287

[53] Souza FC, Legey LFL. Dynamics of risk management tools and auctions in the second phase of the Brazilian electricity market reform. Energy Policy. 2010;**38**:1715-1733. DOI: https://Doi-Org.Ez50.Periodicos.Capes.Gov.Br/10.1016/J.Enpol.2009.11.042

[54] Araujo JLRH, Costa AMA, Correa T, Melo E. Energy contracting in Brazil and electricity prices. International Journal of Energy Sector Management. 2008;**2**(1):36-51. DOI: https://Doi.Org/10.1108/17506220810859088

[55] Dalbem MC, Brandão LET, Gomes LL. Can the regulated market help Foster a free market for wind energy in Brazil? Energy Policy. 2014;**66**:303-311. DOI: https://Doi-Org.Ez50.Periodicos.Capes.Gov.Br/10.1016/J.Enpol.2013.11.019

[56] Agencia Nacional de Energia Elétrica. Banco de Informações de Geração – Aneel/BIG. Capacidade de Geração. Brasília, 2017. http://www2.aneel.gov.br/aplicacoes/capacidadebrasil/capacidadebrasil.cfm

[57] National Operator of Power Grid System – ONS. http://ons.org.br/

[58] Teixeira FN, Lora E. Experimental and analytical evaluation of NO_X emissions in bagasse boilers. Biomass and Bioenergy. 2004;**26**:571-577

[59] Yerginm D. The Quest, Energy, Security, and the Remaking of the Modern World. New York: The Pinguin Press; 2011

Section 4

Policy and Environmental Analysis

Chapter 7

A Societal Life Cycle Costing of Energy Production: The Implications of Environmental Externalities

Yemane W. Weldu

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.77188

Abstract

Alberta's electricity market is deregulated; consequently, it does not recognize the benefits of renewables. This research applied a novel societal life cycle costing approach to estimate the economic values of environmental damages to society that result from coal and biomass fired electricity generation. Although coal fuel is cheaper to produce electricity, yet its societal life cycle costing (LCC) is significantly higher than bioenergy systems. Mainstreaming of environmental externalities creates market advantages for low carbon energy sources. Coal power plants cause Alberta to lose at least $117.8 billion per annum due to externalities. Ending electricity from coal with wood pellet can save 53.7 billion USD per year. The societal life cycle cost per year of coal power plants in Alberta represents 15.8% of the province's GDP and 343.7% of the total expenditure on health. The transformative potential presented by carbon pricing toward a cleaner future is limited. Externalities for health and ecosystems should also be priced and included in the retail price of electricity.

Keywords: externality, electricity, human health, ecosystem, societal life cycle cost

1. Introduction

Alberta's electricity grid is fossil-intensive that more than 80% of the electricity supply is sourced from fossil fuels [1]. The provincial *Climate Leadership Plan* aims to transform the electricity generation from fossil fuel coal to a more sustainable low carbon energy source. Bioenergy is a low carbon renewable energy source that can contribute to the supply of more clean energy [2, 3]. So much as electricity transformed human well-being, it has also caused significant human health, ecosystem, and climate change damage [4–7]. Human health and ecosystems damage are external costs because the power plant does not take full account

IntechOpen

when deciding how to generate electricity [8, 9]. New investments on renewable energy sources are challenged by the province's deregulated electricity market system that does not appreciate the societal benefits of clean energy sources [10, 11]. Recognizing the societal external costs of energy production in energy planning could create a better playing field for low carbon electricity supply.

The Paris Agreement on climate change was ratified by the several nations to retain global warming below 1.5°C. This crucial agreement demonstrated that the world is committed to fight climate change. Pricing environmental externalities is a mechanism that supports the prospects for energy transition and transformation. For example, carbon pricing has been an effective way of promoting cleaner energy production for addressing global climate change in Quebec's transportation sector. By implementing a carbon price in its transportation system, the province of Quebec is able to reduce greenhouse gas (GHG) emissions and create economic revenues. To this effect, carbon credit auctions raised $1.2 billion, in which over $800 million of the money generated is used in the transportation sector.

The increased production of fossil fuels has increased Alberta's GHG emission by 47% since 1990 [12]. Alberta contributed 35.7% of the national total 700 $MtCO_2eq$ (million tons of carbon dioxide equivalent) GHG emissions in 2012. With only 11.2% of the total population, Alberta ranked second next to Saskatchewan in terms of emissions per capita, when compared to other provinces of Canada. Alberta introduced emission trading system and carbon taxes to reduce emissions from large GHG emitters in 2007. Large GHG emitters are required to reduce emissions by buying offsets, investing in technological innovations, or trading verified emission reduction from other cleaner industries. For example, the provincial government has mandated 2% biodiesel and 5% ethanol content in transportation fuels with 9 cent per liter tax exemption for biofuel producer [13]. However, current government policies do not encourage clean electricity and heat producers.

Electricity producers are less motivated to invest on renewables because environmental externalities do not appear in the electricity pricing system. Additionally, the negative impacts of environmental externalities are mare primarily born by society and not by producers. Accounting for environmental externalities is more effective than environmental regulation because it supports informed decision-making for meaningful climate change mitigation [14, 15]. The pool price of electricity from fossil fuel is higher than cleaner energy sources, when the economic value of environmental impacts resulting from air emissions is considered [16]. Previous studies on the externalities of electricity have largely focused on the damages caused by air pollution or global warming only [17, 18], and damage to ecosystems quality is ignored. Additionally, the assessment of environmental externalities at the power plant alone would underestimate the total economic impact [10, 19]. Studies have examined the implication of environmental externalities at power plant. However, the entire life cycle of the product must be examined for accurate societal life cycle cost (SLCC) damage by including the feedstock production and transport life cycle stages. On the other hand, previous studies focus mainly on solar and wind, whereas studies on the societal cost of bioenergy are limited [20]. Societal cost is usually quantified using specific models tailored for a specific product or jurisdiction. Few studies have applied the societal life cycle costing (LCC) method to determine the economic implication of environmental externalities in waste management [21]. The economic value of environmental externalities is traditionally estimated based on epidemiological studies, and the concept of life cycle costing has not been used to quantify externality. Rating the cost per the damage-adjusted life-years (DALY) of human health, and the potentially disappeared fraction of species on 1 m^2 of earth surface during 1 year (PDF.m^2.year) of ecosystems impact is controversial in the literature.

Incorporating the environmental externalities of products creates cost-effective and environmentally friendly solutions by promoting clean energy development [22, 23]. Alberta has implemented a carbon price in order to mitigate climate change [2]. However, the course of map for addressing the energy sustainability of the province has ignored bioenergy source. On the other hand, the externalities for ecosystem and human health damages must be also accounted into the pool price for most accurate total SLCC assessment. A societal life cycle costing method was applied to compare the economic value of environmental damages caused by coal fuel with bioenergy for the case of Alberta. In addition, the SLCC per kWh electricity generation was quantified in order to examine the retail costs of electricity.

2. Method

A societal LCC method was applied to investigate the policy-relevance of accounting environmental externalities. Societal LCC is a proven approach for measuring the cost–benefit of alternative investments due to the relatively larger set of costs included in the analysis. The most important aspect of the societal LCC lies the fact that the monetized environmental effects of societal costs are incorporated in the analysis [24, 25]. In such analyses, the economic and environmental impacts are integrated to compare alternative production systems. As a result, a societal LCC is a stand-alone method, and it is not followed by environmental or economic impacts results. This study used a model for environmental life cycle costing [26] to generate the economic impact of societal costs per kWh. The model developed in this study accounts the external cost for climate change, ecosystem, and human health damages. As such, the costs for climate change, human health, and ecosystems impacts were summed up with the environmental life cycle cost impact in order to yield a monetized total impact.

It is difficult to measure the costs for environmental externalities because they do not have a direct input/output counterpart like in the case of life cycle assessment (LCA) or life cycle costing (LCC) methods. Nevertheless, the monetary valuation of societal costs can be easily related to the notion of externalities in welfare economics. There are various approaches and methods of monetary valuation. The budget constraint method provides a better contribution for applications in LCA [27, 28]. In this study, the external cost of environmental impacts per unit of DALY and per unit of PDF.m^2.year was quantified based on the cost factors estimated by Weidema [27].

2.1. Electricity production scenario

The installed electricity generation capacity of Alberta is a mix of 40% of natural gas, 43% of coal, and 17% of combined renewable sources. Clean energy from hydrocarbon is the prime focus of Alberta's electricity strategy; however, the potential of bioenergy sources is ignored [29]. Therefore, the scope of this research was limited to understand the significance of bioenergy based on pellet in the transition and transformation of coal-fired electricity. Wood pellet feedstock was assumed for bioenergy production because it can be easily integrated into coal power plant technologies and infrastructure with minimal retrofitting. The prevailing scenario of coal-fired electricity was compared with three alternative bioenergy scenarios for a study period of 29 years, beginning from 2017 to 2046. This study period is in line with the lifetime for the best available power plant technology operating in Alberta.

2.1.1. Electricity production reference scenario

The reference scenario was modeled to represent business as usual of burning coal fuel for electricity supply. A sub-bituminous coal from High Vale mine area is direct-fired to produce electricity.

2.1.2. Electricity production transformation scenario

The transformation scenario, that is Scenario 2, represents a complete substitution of coal plants with 100% direct-mono-combustion of pellet biomass in existing coal power plant. This scenario ends the consumption of coal beginning from 2017.

2.1.3. Transition scenario

The *Climate Leadership Plan* of Alberta calls for electricity transition until 2030 and forces a complete transformation of coal power plants after 2030. Therefore, co-firing of coal with pellets until 2030 and the direct-firing of coal until 2030, both followed with pellet mono-combustion in the years 2031 through 2046 represented Scenario 3 and Scenario 4, respectively. Minor retrofitting of current power plants is required for co-firing of pellet with coal only [30, 31]. Direct co-firing with separate feed systems for pellet and coal was assumed for the analysis.

2.2. Data collection and handling

Primary data and Alberta specific settings were used to represent the environmental modeling of energy scenarios. The intermediate upstream and downstream unit processes of the life cycle were represented by generic data.

On the other hand, economic factors that are specific to Alberta's setting were used to model the life cycle cost (LCC) impact. Generic cost factors were considered for parameters that are similar across technologies.

2.3. System boundary

The system boundary and process flow diagram for energy pathways was drawn as shown in **Figure 1**. Biomass feedstock was assumed to be harvested from the *Division No. 13* and *Division No. 14 West* region of Alberta. Processes involved with biomass feedstock production are silviculture, felling, skidding, road construction, biomass preparation, and pelletization. The two recently commenced new coal plants in Alberta, *Genesee Thermal* and *Keephills*

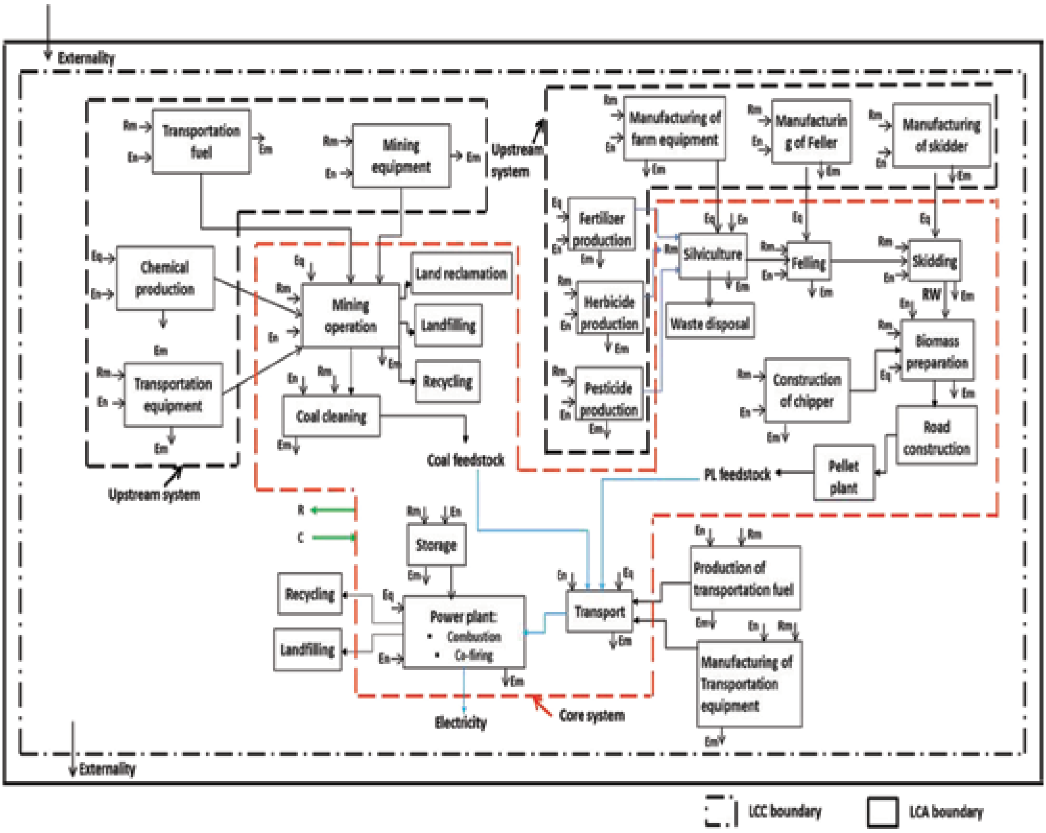


Figure 1. System boundary of energy pathways [26]. Note: R: Revenue; C: Cost; En: Energy; Rm: Raw material; Em: Emission; Eq: Equipment.

Thermal, electric power generating stations consume sub-bituminous coal from *Highvale mine*. The coal mine in *Highvale* operates a surface mining [32]. The basic processes for surface mining include mine fracturing, resizing the coal, coal preparation, and cleaning. Clean coal is hauled using trucks to the power plant for electricity generation [33].

The transportation subsystem accounted the transportation of chemicals, feedstock (coal or pellet), and other items between the boundaries of the forest field or coal mining, and the plant. Coal is combusted in a supercritical pulverized boiler to generate electricity. The inventory for the power plant subsystem begins at the plant gate of the power plant and ends with the production of electricity. *Genesee 3* is the first power plant in Canada to use supercritical pressure pulverized coal combustion technology [29]. Supercritical boilers operate at high temperature and pressure and employ a high-efficiency steam turbine. Coal and pellet are crushed, pulverized, and burned to create a high-pressure steam that turns a turbine shaft for electricity generation. The option for co-firing depends up on the co-firing level and the type of biomass feedstock. Direct co-firing is a proven combustion system for pulverizing pellet and coal feedstocks together. In this study, a heat rate of 20% pellet and 80% coal was considered for co-firing to produce 1 kWh of electricity. The power plant efficiency for supercritical pulverized boiler was estimated at 35.5% based on the annual electricity generation and coal consumption inventoried for the new power generation units in Alberta.

Pellet substitution and co-firing of pellet with coal require only minor retrofitting for integrating biomass to existing coal-fired power plants. Direct co-firing with separate feed systems for coal and pellet was considered for analysis. All of the life cycle activities from resource extraction and feedstock production, transportation, to the production of electricity, and any necessary waste disposal were considered. The environmental impact of electricity generation scenarios was quantified using a functional unit of 1 kWh for the case of Alberta. The IMPACTWorld+ impact assessment method was used to quantify the impacts on human health, ecosystem, and climate change.

The costs of electricity generation can be categorized into investment costs, operating costs, and externalities costs. LCC refers to all costs associated with the life cycle of the product system, including internalized cost of external effects, over a given study period [24, 25]. A LCC was conducted, with the same system specification as for LCA, to quantify the cost per functional unit of 1 kWh electricity generation [26]. The study period has been assumed to be 29 years based on the life-time for coal plants, as determined by the government of Alberta, and it begins at the same time with the base date. The study period of each system elapses from a base date or service period of 2017 through 2046.

The present-value method was used to quantify the economic impact of electricity production scenarios. Future costs were discounted from the end of the year they occur to the base date and summed up with the investment costs to give the total LCC. Only costs to be incurred on or after the base date were included in the base case. The constant dollar method was used in the study to estimate future money flows as it has the advantage of avoiding the need to project future rates of inflation or deflation. The value of dollar was fixed to 2016 US dollars as a reference to express all future amounts.

2.4. Calculation

2.4.1. Cost of environmental externality

Monetary valuation is used to determine the economic value of nonmarket goods. It can be applied in LCA, especially in the weighting phase, to compare the cost benefit between different impacts [28]. The willingness to pay by an individual for a small change in his/her quality of life (e.g. prolonging one's life by 1 year) can be valued monetarily [34, 35]. According to Weidema [27], the price rate for environmental damages ranged from \$USD2.01 to \$USD5.95 per pdf.m^2.year and \$USD89399.73 to \$USD135482.06 per DALY. In this study, the societal LCC of alternative electricity production scenarios was quantified by assuming an average rate of \$USD4.0 per pdf.m^2.year and \$USD 112440.9 per DALY.

The external cost of electricity generation was calculated using Eqs. 1 and 2.

$$\mathit{Externality\ of\ Health}(\$/kWh) = (\mathit{Health\ impact}\ (DALY))/(\mathit{Functional\ unit}\ (kWh)) * \mathit{Price\ rate\ for\ Health}(\$/DALY) \tag{1}$$

$$Externality\ of\ Ecosystem(\$/kWh) = \left(Ecosystem\ impact\ (pdf.m2.year)\right)/(Functional\ unit\ (kWh)\ ) * Price\ rate\ for\ Ecosystem\left(\$/(pdf.m2.year)\right) \tag{2}$$

2.4.2. Societal LCC of energy scenario

The environmental life cycle cost impact and the monetized value of externalities are summed up to produce the societal life cycle cost of electricity production scenario. The fraction of human health and ecosystem impacts caused due to global warming per functional unit of 1 kWh electricity was subtracted from the total environmental damage in order to avoid the double counting of externality due to climate change. The environmental life cycle cost analysis considered a discount rate of 0.1% [26]. The societal LCC was calculated using Eq. (3).

$$\text{Societal LCC } (\$/\text{kWh}) = \text{Environmental LCC } (\$/\text{kWh}) + \text{Externality } (\$/\text{kWh}) \tag{3}$$

where the environmental LCC figures were drawn from a previous research which applied the same system boundary [26].

2.4.3. Economic benefit of energy transition and transformation scenarios

Economic benefit is achieved by saving a sum of money through averting the conventional scenario of coal-fired electricity using a more clean electricity production scenario. Eq. 4 was applied to quantify the benefit of Alberta's electricity grid transformation and transition scenarios.

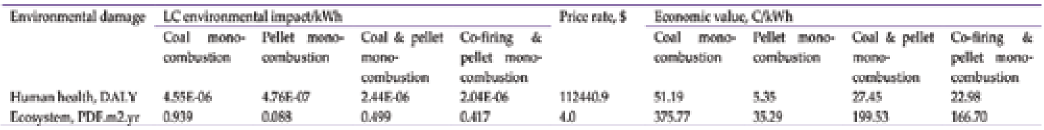
$$\text{Benefit of scenario } (\$/\text{kWh}) = \text{SLCC of scenario 1 } (\$/\text{kWh}) - \text{SLCC of alternative scenario } (\$/\text{kWh}) \tag{4}$$

3. Results and discussion

3.1. Economic value of externalities

The economic value of an environmental externality was quantified by multiplying the environmental impact per functional unit of 1 kWh electricity with the respective price rate. As shown in **Table 1**, coal-fire electricity scenario has the highest economic value of environmental externalities. For all energy scenarios, the economic value of damage to ecosystem was 559–634% higher than the economic value of damage to human health. The transformation scenario of pellet mono-combustion demonstrated the lowest economic value for all environmental damages.

As shown in **Figure 2**, Scenario 1 exhibited the highest social cost when compared to alternative wood-biomass based electricity generation scenarios. The external cost of Scenario 2 is only 9.5% of the external cost of Scenario 1. On the other hand, Scenario 3 and 4 demonstrated 44–53% of the external cost of Scenario 1.



Environmental damage	LC environmental impact/kWh				Price rate, $	Economic value, ¢/kWh			
	Coal mono-combustion	Pellet mono-combustion	Coal & pellet mono-combustion	Co-firing & pellet mono-combustion		Coal mono-combustion	Pellet mono-combustion	Coal & pellet mono-combustion	Co-firing & pellet mono-combustion
Human health, DALY	4.55E-06	4.76E-07	2.44E-06	2.04E-06	112440.9	51.19	5.35	27.45	22.98
Ecosystem, PDF.m2.yr	0.939	0.088	0.499	0.417	4.0	375.77	35.29	199.53	166.70

Table 1. Economic value of environmental impact (¢: Cent).

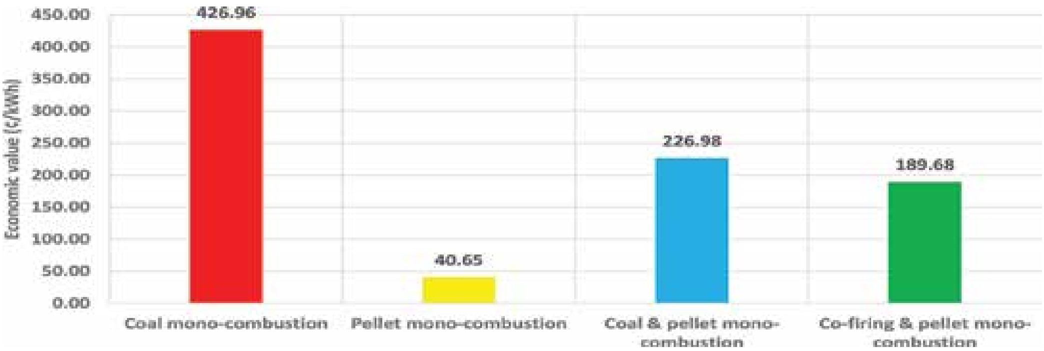


Figure 2. Social cost of electricity generation.

3.2. Societal LCC of electricity

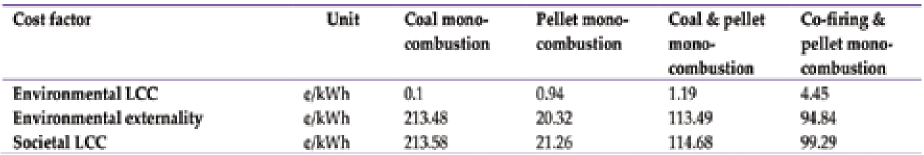
The societal LCC of electricity is a sum of the environmental externality cost and the economic impact (i.e., environmental LCC). Coal power plants caused the highest environmental externality of electricity generation (**Table 2**). On the other hand, the transition scenarios caused higher economic impact (i.e., environmental LCC), but resulted in lower environmental externality, when compared to coal-fired electricity generation. As shown in **Table 2**, coal-fired electricity caused the highest SLCC, when compared to alternative electricity production systems. Although coal fuel combustion is the most cost effective scenario, its SLCC was nearly 10 times higher than electricity transformation scenario based on biomass pellet. Therefore, transitioning and transforming the coal power plants in Alberta with bioenergy systems has greater economic benefit. As a result, decarbonizing of Alberta's electricity grid to phase out the coal plants would significantly reduce the SLCC. Transitioning of the coal plants in Alberta also would result in lower aggregated cost.

The average price for electricity observed maximum values ranging from 10.8 to 14.05 ¢/kWh and minimum values ranging from 2.4 to 3.4 ¢/kWh [36]. As per to *Alberta Utilities Commission*, the generation of electricity covers nearly 50% of the total pool price for electricity. Thus, the societal life cycle cost of Scenario 1 amounted 7908–25,121% higher than the cost of electricity generation, and at times higher.

There is always uncertainty on the results for SLCC analysis because there is no one way of modeling a reality. Subjective choices made related to willingness to pay can influence the study results. Therefore, a sensitivity analysis was carried out to see the influence of the societal price rate assumed for environmental damage on the SLCC results (**Table 3**). The

Cost factor	Unit	Coal mono-combustion	Pellet mono-combustion	Coal & pellet mono-combustion	Co-firing & pellet mono-combustion
Environmental LCC	¢/kWh	0.1	0.94	1.19	4.45
Environmental externality	¢/kWh	426.96	40.65	226.98	189.69
Societal LCC	¢/kWh	427.06	41.59	228.17	194.13

Table 2. Societal life cycle cost per kWh.



Cost factor	Unit	Coal mono-combustion	Pellet mono-combustion	Coal & pellet mono-combustion	Co-firing & pellet mono-combustion
Environmental LCC	¢/kWh	0.1	0.94	1.19	4.45
Environmental externality	¢/kWh	213.48	20.32	113.49	94.84
Societal LCC	¢/kWh	213.58	21.26	114.68	99.29

Table 3. Sensitivity analysis: variation of SLCC cost per kWh for 50% increase in social cost of environmental externality.

sensitivity analysis demonstrated that a 50% decrease of price rates per DALY and PDF would not change the overall outcome.

3.3. Economic benefit of electricity transformation

The energy balance of each scenario was analyzed based on the near term electricity generation outlook by AESO (*Alberta Electricity Systems Operator)* [29]. AESO has taken into account several factors, including technology development; environmental goals; availability of resources; and investment finance in forecasting future electricity production. According to this outlook, the coal-fired electricity installed capacity is expected to decrease from 5900 MW in 2017 to 2876 MW in 2032 [29]. To fit the purpose of Alberta's *Climate Leadership Plan*, we assumed that the province's installed capacity would achieve 2876 MW in 2030 (**Figure 3**).

The annual potential of sustainably available forest wood biomass supply for energy in Alberta is estimated at 165.04 PJ [13]. The amount of wood pellet delivered at the power plant was estimated to be 149 PJ, by assuming a 10% of haul loss during feedstock transportation.

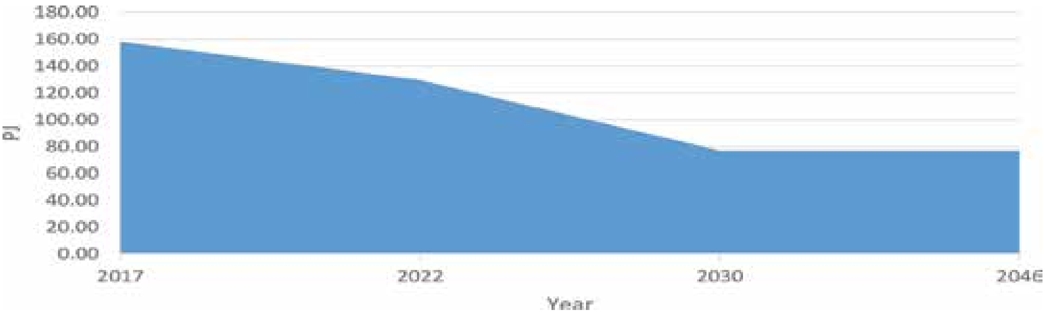


Figure 3. Projection of electricity generation from coal fuel.

Considering a power plant efficiency of 33.73%, the energy content of pellet would yield approximately 50.1 PJ of electricity. To phase-out the coal-fired electricity, this same amount of pellet feedstock was fed annually to the power plant. The coal power plants in Alberta have a capacity factor of 85%. Consequently, pellet alone cannot completely transform the current coal-fired installed capacity before the year 2046 (**Figure 4**). It is worth noting that the difference amount of electricity capacity will be addressed by other renewables.

A total of 13,916.67 GWh per year was considered for energy balance analysis. This implies that approximately 403,583.3 GWh (or 1452.9PJ) of electricity is produced during the projected 29 years study period. Given $4.27 per kWh for the societal life cycle cost of electricity generation from coal fuel, coal power plants are costing on average 130.5 billion USD per year. As shown in **Table 4**, ending electricity from coal with wood pellet can save 53.7 billion USD per year. Therefore, the societal life cycle cost per year of coal power plants in Alberta represents 15.8% of the province's GDP and 343.7% of the total expenditure on health. To this effect, bioenergy has the potential to finance Albert's expenditure on health with a huge surplus going for technology development or other clean energy incentives. Therefore, the transformative potential presented by carbon pricing toward a cleaner future is limited.

Canada's total expenditure on health per capita was $4641.0 in 2014, which is equivalent to 10.4% of its gross domestic product (GDP) [37]. In contrast, Alberta's total expenditure on health care was nearly $17,291.8 million, and a total GDP of $375,756 in 2014 [38, 39]. For a population of 4,120,900 the total expenditure per capita and total expenditure on health as percentage of GDP was estimated to be $4196.1 and 4.6% respectively [40]. This demonstrates that Alberta has lower expenditure per capita as compared to the national average

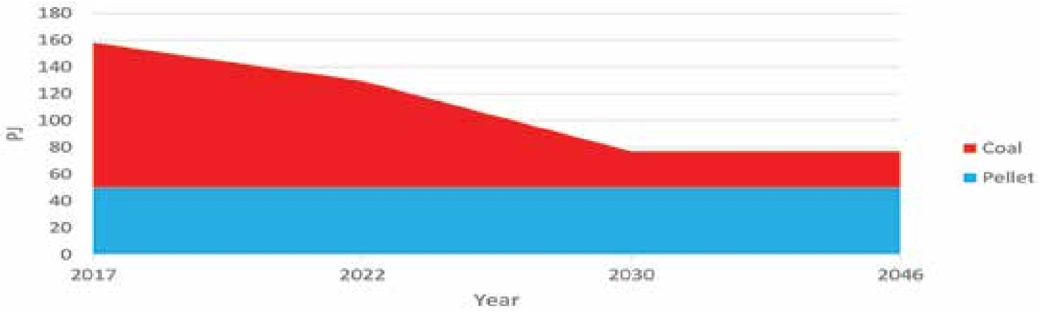
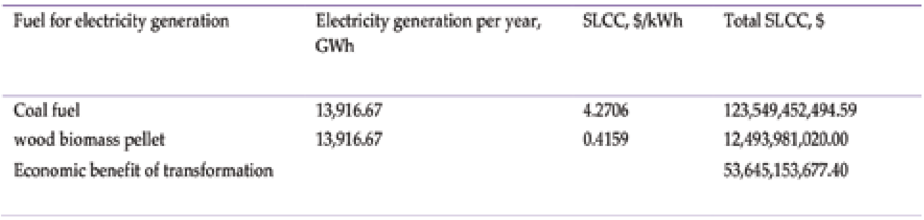


Figure 4. Projection of annual electricity generation for the transformation scenario.



Fuel for electricity generation	Electricity generation per year, GWh	SLCC, $/kWh	Total SLCC, $
Coal fuel	13,916.67	4.2706	123,549,452,494.59
wood biomass pellet	13,916.67	0.4159	12,493,981,020.00
Economic benefit of transformation			53,645,153,677.40

Table 4. Economic benefit of transformation based on pellet.

expenditure. This implies that the annual SLCC of coal combustion in Alberta represents 15.82% of its GDP and 343.7% of the total expenditure on health care. Transforming coal plants with pellet can significantly reduce the annual expenditure on health care by 310.2%.

3.4. Transformative potential of carbon price

This study examines the transformative potential of carbon price, which used to be determined by a political will, instead of based on market willingness to pay monetary valuation method. The rate for social cost of environmental damages is usually determined from either epidemiological (or clinical) studies or based on willingness to pay approaches. The Government of Alberta has put a carbon price rate of USD \$11.43 per ton of CO_2 emission. This carbon tax rate was used to estimate the external cost of human health damage per unit of DALY, and the ecosystems damage per unit of PDF.m^2.year. Thus, the economic value per unit of DALY was estimated based on the cost factor for CO_2 equivalent. This study is its first of kind to generate cost rate for DALY and pdf.m2.year based on a specified carbon tax rate.

The *IMPACTWorld + endpoint* LCA method at *characterization level* quantifies the environmental impact per functional unit of 1 kWh electricity generation in units of DALY for short-term and long-term impacts on human health, and PDF.m^2.year for short-term and long-term impacts on ecosystem. Similarly, the *IMPACTWorld + endpoint* method at *damage level* quantifies the environmental damage per functional unit of 1 kWh electricity generation in units of DALY for human health and PDF.m^2.year for ecosystem. On the other hand, the *weighting step* in a LCA method quantifies all environmental impact indicators in the same unit of *Yen2000* (i.e., the value of Yen currency as adjusted to its value in year 2000). All these results can be exported in to an Excel directly from the SimaPro software that was used to model the LCA. The environmental impact results for climate change can be obtained alternatively in units of carbon dioxide equivalent (CO_2 eq), PDF.m^2.year, and DALY from the programing software. Therefore, the unit of CO_2 eq impact for climate change at midpoint can be related to the DALY and PDF.m^2.year environmental damages at endpoint. Thus, the ratio of DALY to PDF.m^2.year was estimated to be 1 DALY for 528870.3 PDF.m^2.year by combining the values for damage assessment and the weighting steps in LCA. These values were further related to the impact values at midpoint to estimate the factors for DALY and PDF.m^2.year, as compared to 1 ton of CO_2 equivalent. Given the rate for carbon price \$11.43 per ton of CO_2 eq, the price rate for human health and ecosystem damages were estimated to be \$2236.8 per DALY and \$0.00423 per pdf.m^2.year, respectively. The monetary valuation given in Section 2.4.1. earlier is 50 times greater than the cost rate per DALY, and 945 times greater than the cost per pdf.m2.year, respectively. This implies that the rate assigned politically for carbon tax underestimates the actual valuation to environmental damage.

4. Conclusion and policy implications

The costs of environmental externalities are not considered during planning nor are they accounted in the retail price of electricity. This research applied a novel societal life cycle costing approach to estimate the economic values of environmental damages to society that result from coal and biomass fired electricity generation. Coal-fired electricity has the highest economic value of environmental externalities, whereas pellet mono-combustion demonstrated the lowest economic value for all environmental damages. On the other hand, the transition scenarios caused higher economic impact, but resulted in lower environmental externality, when compared to coal-fired electricity generation. Although coal fuel is cheaper to produce electricity, yet its societal LCC is significantly higher than bioenergy systems. Subjective choices made related to willingness to pay can influence the study results. A sensitivity analysis demonstrated that a 50% decrease of price rates per DALY and PDF would not change the overall outcome. Therefore, bioenergy can potentially support in decarbonizing the electricity grid toward a more sustainable system. Mainstreaming of environmental externalities creates market advantages for low carbon energy sources. Coal power plants cause Alberta to lose at least $117.8 billion per annum due to externalities. Ending electricity from coal with wood pellet can save 53.7 billion USD per year. The societal life cycle cost per year of coal power plants in Alberta represents 15.8% of the province's GDP and 343.7% of the total expenditure on health. Carbon pricing alone cannot meaningfully support the prospect for energy transformation. Externalities for health and ecosystems should also be priced and included in the electricity market.

Author details

Yemane W. Weldu[1,2]*

*Address all correspondence to: ywweldem@ucalgary.ca

1 Division of Sustainability, College of Science and Engineering, Hamad Bin Khalifa University, Qatar Foundation, Doha, Qatar

2 Faculty of Environmental Design, University of Calgary, Calgary, Alberta, Canada

References

[1] A. Energy, Electricity System Improvements, 2015 (2016). http://www.energy.alberta.ca/index.asp

[2] Weldu YW, Assefa G. Evaluating the environmental sustainability of biomass-based energy strategy: Using an impact matrix framework. Environmental Impact Assessment Review. 2016;**60**:75-82. DOI: 10.1016/j.eiar.2016.05.005

[3] Weldu YW. Life cycle human health and ecosystem quality implication of biomass-based strategies to climate change mitigation. Renewable Energy. 2017;**108**:11-18. DOI: 10.1016/j.renene.2017.02.046

[4] J. Deyette, B. Freese, Burning Coal, Burning Cash: Ranking the States that Import the Most Coal, Union of Concerned Scientists, 2010

[5] Lockwood AH, Welker-Hood K, Rauch M, Gottlieb B. Coal's assault on Human Health. Physicians for Social Responsibility Report; 2009

[6] Weldu YW, Assefa G. Life Cycle Human Toxicity and Ecotoxicity Assessment of Bioenergy Strategy in Decarbonizing Alberta's Grid. In: LCA XV, American Center for Life Cycle Assessment, The University of British Columbia, Vancouver, Canada; 2015

[7] Weldu YW, Assefa G, Jolliet O. Life cycle human health and ecotoxicological impacts assessment of electricity production from wood biomass compared to coal fuel. Applied Energy. 2017;**187**:564-574. DOI: 10.1016/j.apenergy.2016.11.101

[8] Schneider CG, Banks JM, Tatsutani M. The Toll from Coal: An Updated Assessment of Death and Disease from America's Dirtiest Energy Source. Clean Air Task Force. 2010

[9] Krewitt W, Heck T, Trukenmüller A, Friedrich R. Environmental damage costs from fossil electricity generation in Germany and Europe. Energy Policy. 1999;**27**:173-183

[10] Anderson K. A Costly Diagnosis: Subsidizing Coal Power with Albertan's Health. Pembina Institute for Appropriate Development; 2013

[11] Weldu YW. Accounting for Human Health and Ecosystems Quality in Developing Sustainable Energy Products: The Implications of Wood Biomass-based Electricity Strategies to Climate Change Mitigation. Canada: University of Calgary; 2017. DOI: 10.5072/PRISM/24649

[12] E. Canada. National Inventory Report 1990-2012: Greenhouse Gas Sources and Sinks in Canada; 2013. http://www.ec.gc.ca/ges-ghg/

[13] Weldemichael Y, Assefa G. Assessing the energy production and GHG (greenhouse gas) emissions mitigation potential of biomass resources for Alberta. Journal of Cleaner Production. 2016;**112**:4257-4264. DOI: 10.1016/j.jclepro.2015.08.118

[14] Spalding-Fecher R, Matibe DK. Electricity and externalities in South Africa. Energy Policy. 2003;**31**:721-734

[15] Prakash R, Bhat IK. Energy, economics and environmental impacts of renewable energy systems. Renewable and Sustainable Energy Reviews. 2009;**13**:2716-2721

[16] Klaassen G, Riahi K. Internalizing externalities of electricity generation: An analysis with MESSAGE-MACRO. Energy Policy. 2007;**35**:815-827

[17] Machol B, Rizk S. Economic value of US fossil fuel electricity health impacts. Environment International. 2013;**52**:75-80

[18] Markandya A, Wilkinson P. Electricity generation and health. Lancet. 2007;**370**:979-990

[19] Hainoun A, Almoustafa A, Aldin MS. Estimating the health damage costs of Syrian electricity generation system using impact pathway approach. Energy. 2010;**35**:628-638

[20] Owen AD. Renewable energy: Externality costs as market barriers. Energy Policy. 2006; **34**:632-642

[21] Martinez-Sanchez V, Tonini D, Møller F, Astrup TF. Life-cycle costing of food waste management in Denmark: Importance of indirect effects. Environmental Science & Technology. 2016;**50**:4513-4523

[22] Munksgaard J, Ramskov J. Effects of internalising external production costs in a north European power market. Energy Policy. 2002;**30**:501-510

[23] Owen AD. Environmental externalities, market distortions and the economics of renewable energy technologies. The Energy Journal. 2004:127-156

[24] Swarr TE, Hunkeler D, Klöpffer W, Pesonen H-L, Ciroth A, Brent AC, Pagan R. Environmental life-cycle costing: A code of practice. International Journal of Life Cycle Assessment. 2011;**16**:389-391

[25] Hunkeler D, Lichtenvort K, Rebitzer G. Environmental Life Cycle Costing. Pensacola Florida, USA: CRC Press; 2008

[26] Weldu YW, Assefa G. The search for most cost-effective way of achieving environmental sustainability status in electricity generation: Environmental life cycle cost analysis of energy scenarios. Journal of Cleaner Production. 2017;**142**:2296-2304. DOI: 10.1016/j.jclepro.2016.11.047

[27] Weidema BP. Using the budget constraint to monetarise impact assessment results. Ecological Economics. 2009;**68**:1591-1598

[28] Pizzol M, Weidema B, Brandão M, Osset P. Monetary valuation in life cycle assessment: A review. Journal of Cleaner Production. 2015;**86**:170-179. DOI: 10.1016/j.jclepro.2014.08.007

[29] AESO. AESO 2012 Long-term Outlook, 2015; 2012. http://www.aeso.ca/index.html

[30] Sebastián F, Royo J, Serra L, Gómez M. Life cycle assessment of greenhouse gas emissions from biomass electricity generation: Cofiring and biomass monocombustion. In: Proceedings of the 4th Dubrovnik Conf. Sustain. Dev. Energy Water Environ. Syst. Dubrovnik, Croatia. 2007. pp. 4-8

[31] Shao Y, Wang J, Preto F, Zhu J, Xu C. Ash deposition in biomass combustion or co-firing for power/heat generation. Energies. 2012;**5**:5171-5189

[32] Meldrum J, Nettles-Anderson S, Heath G, Macknick J. Life cycle water use for electricity generation: A review and harmonization of literature estimates. Environmental Research Letters. 2013;**8**:15031

[33] C. Power, Capital Power Corporation's Genesee Generating Station, Canada: Capital power; 2015 (2012)

[34] Zhang J, Smith KR, Ma Y, Ye S, Jiang F, Qi W, Liu P, Khalil MAK, Rasmussen RA, Thorneloe SA. Greenhouse gases and other airborne pollutants from household stoves in China: A database for emission factors. Atmospheric Environment. 2000;**34**:4537-4549

[35] Desaigues B, Ami D, Bartczak A, Braun-Kohlová M, Chilton S, Czajkowski M, Farreras V, Hunt A, Hutchison M, Jeanrenaud C, Kaderjak P, MácA V, Markiewicz O, Markowska A, Metcalf H, Navrud S, Nielsen JS, Ortiz R, Pellegrini S, Rabl A, Riera R, Scasny M, Stoeckel ME, Szántó R, Urban J. Economic valuation of air pollution mortality: A 9-country contingent valuation survey of value of a life year (VOLY). Ecological Indicators. 2011;**11**:902-910

[36] AESO. How Have Electricity Prices in Alberta Evolved over Time? 2016. http://www.aeso.ca/index.html

[37] WHO, Health statistics and information systems, 2016 (2015). http://www.who.int/countries/can/en/

[38] S. Canada. Gross domestic product, expenditure-based, by province and territory, CANSIM, Table 384-0038. 2016; 2015. http://cansim2.statcan.gc.ca/

[39] S. Canada. Health and social service institutions revenue and expenditures, by province and territory, CANSIM, Table 385-0008. 2016; 2010. http://cansim2.statcan.gc.ca/

[40] S. Canada. Population by year, by province and territory, CANSIM, Table 051-0001. 2016; 2015. http://cansim2.statcan.gc.ca/

Chapter 8

Greening Municipality Through Carbon Footprint for Selective Municipality

Warangkana Jutidamrongphan,
Luke Makarichi and Samnang Tim

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.78565

Abstract

Evaluation of the organizational greenhouse gas (GHG) emissions from operational activities of selective municipality was investigated in this study. The selected municipality is located in Songkhla Province, the southern part of Thailand, and is divided into seven functional units. The total GHG emissions were estimated at 16,920.29 ton CO_2 eq. in the fiscal year 2016. The carbon footprints under direct, indirect, and optional indirect emissions (scopes 1, 2, and 3, respectively) were found to be 1129.92, 255.24, and 15,535.13 ton CO_2 eq./year, respectively. The highest carbon footprint was from methane emissions related to solid waste decomposition in sanitary landfills (15,524 ton CO_2 eq./year). Therefore, the main GHG mitigation strategy proposed was the installation of waste to energy recovery in order to reduce waste throughput to the landfill. For specific municipal operations, diesel combustion in municipality-owned vehicles had the highest carbon emission followed by fugitive emissions from refrigerants and electricity consumption (746.92, 289.60, and 255.24 ton CO_2 eq./year, respectively). The important constraints in reducing GHG emissions from upstream and downstream of the organizational activities were identified in terms of time, cost, and data accessibility. Further, convergent cooperation and public participation are also significant for effective implementation of global warming mitigation strategies.

Keywords: carbon footprint for organization, GHGs emission, global warming, waste to energy

1. Introduction

1.1. Significance of carbon footprint for organization evaluation

Global warming and climate change have become a serious problem the world is faced with today. Global warming results from the emission of greenhouse gases (GHGs) as a result of anthropogenic activities related to agriculture, transportation, energy production, and use. The production and combustion of carbon-rich fossil fuels, especially coal, oil, natural gas, as well as agricultural activities including deforestation are undoubtedly the chief generators of GHGs. Global warming and climate change are adversely impacting on human and animal life.

The Kyoto Protocol identified the main GHGs accelerating climate change. The Intergovernmental Panel on Climate Change (IPCC) reports has shown that there is a strong correlation between the increasing CO_2 emissions and climate change. Consequently, increasing awareness of the impact of this crisis as well as GHG mitigation is indeed an important achievement, globally. As a result, many countries are making tremendous effort in preparing, coordinating, protecting, and developing strategies aimed at carbon mitigation and effecting changes at both local and national levels.

Carbon footprint (CF) is defined as the measurement of GHG emissions from an individual, product, or organization. According to Wiedmann et al. [1], CF is the measure of CO_2 emissions related either directly or indirectly to an activity during the complete life cycle of a product or a service. However, CF is not only concerned about CO_2 but other GHGs as well. Therefore, in order to simplify CF assessments, GHGs are all expressed in terms of carbon dioxide equivalent (CO_2 eq). This means that an activity is described for a given mixture and quantity of GHGs, in terms of the CO_2 that would have the same global warming potential (GWP), when measured over a specified time scale (normally, 100 years) [2].

Carbon Footprint for Organization (CFO) refers to an approach where the GHGs associated with an organization's activities are evaluated and calculated in terms of CO_2 eq. This is important in order to formulate mitigation strategies for activities where outstanding gains in CO_2 reduction can be achieved. This enables the development of a set of guidelines for the effective reduction of GHG emissions from urban, transportation, industrial, and service sections at both local and national levels. For this reason, CFO evaluations have been conducted worldwide for various organizations including nongovernmental organizations (NGOs), business enterprises, public authorities, and educational institutions at different scales (personal, institutional, city level, regional, national, and international) [3].

However, in Thailand, the evaluation of CFO has progressed at a very slow pace. Only a few large organizations have started to cooperate with the Thailand Greenhouse Gas Management Organization (TGO) in evaluating and verifying GHGs emissions. Most organizations still lack the knowledge, technical expertise, and skills for carbon foot printing. Due to the urgency of this issue, the focus of research in Thailand in relation to climate change is shifting, and already, carbon footprint analysis for local authorities has begun. "Promoting the Carbon Footprint of Local Government Organizations and Reporting Greenhouse Gas Emissions" project was established in order to activate the development of low carbon cities by supporting the implementation and budget of the TGO to report on GHG emissions from various activities and corporate service within the local municipalities. Several municipalities were selected to be part of this project. A GHGs reduction guideline is also in place to support the organization's carbon footprint assessment for Thailand. In order to achieve sustainable low carbon cities, improving the capacity of Thai local government organizations is imperative.

1.2. Carbon footprint for organizations for sustainable municipality

Local governments have a crucial role to play in the management of natural resources and the environment. However, rapid urbanization leading to an increase in both the number and size of cities directly works against their efforts. Consequently, urban areas have the highest GHG emissions due to the high-energy consumption, waste generation, and reduced forest cover. The latter also means reduced natural carbon sinks as forests are able to absorb most of the CO_2 naturally. Local governments should therefore play an instrumental role in global warming mitigation through the effective management of GHGs from their internal activities. Through CFO, they can account for all the GHGs emitted in terms of CO_2 eq, thereby enabling the formulation of management guidelines aimed at reducing GHG emissions.

A number of local authorities also calculated their carbon footprint to achieve various objectives, for example, to integrate sustainability into work performance, to perform a sustainability assessment of their operations, for use as a management tool with staff and customers, as well as for use in policy development. CF analysis can be a strategy through which a municipality can reduce their GHG emissions, promote sustainability, and raise public awareness for the organization as a low carbon city. The current project emphasizes CF performance calculation and mitigation of GHG emission for selected municipalities. Based on the results of the assessment, scenarios for sustainable environmental management were suggested. Mitigation approaches were discussed with operational teams and proposed to the municipality management committee.

In light of this, the Kho-hong Municipality, Hat Yai District, Songkhla Province, Thailand, joined the local GHG emission and reduction program in order to become a carbon neutral city and support the voluntary carbon market in Thailand with TGO. For the purpose of the project, data were collected from municipal activities in one fiscal year. The benefits for municipalities from participating in this program could be divided in terms of output, outcome, and impact. The GHG emission inventory showing the activities of the municipality together with the respective quantities of GHG emissions represents the "Output." In the scope of municipal responsibility and cooperation, there are several strategies for reducing GHG emissions from various activities and operations. Further, the municipal staff and administrators receive knowledge and gain valuable skills and experience in carbon evaluation and mitigation. Previously, lack of these skills and experience hindered efforts to conduct proper carbon foot printing for the municipality. "Outcome" represents the result of the implementation of the GHG emission reduction program in the organization. Consequently, budgetary management for personnel and organizations with improved consciousness of the need to conserve natural resources and the environment is made easier. The "impact" would be the realization of sustainable municipalities. Further, this can be developed as part of the Thailand Voluntary Emission Reduction Program (T-VER) in which case the carbon credits in the voluntary carbon market of Thailand can generate additional revenue for the municipalities [4].

2. Literature review

2.1. Sources of GHG and UNITS OF measurement

2.1.1. GHGs types

The seven GHGs identified in the fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) on Climate Change 2014 [5] are considered in the carbon footprint calculation. These are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3).

2.1.2. Equivalency factors of global warming potential

The global warming potential (GWP) was established for the comparison of environmental impacts of different gases. Generally, the period set for GWPs is 100 years. GHG evaluation is determined in terms of carbon dioxide equivalents (CO_2 eq) in which case the other GHGs are converted to the universal unit based on their respective equivalency factors for GWP over the 100-year period in line with the latest version of the IPCC report. For example, the GWP of CH_4 as compared to CO_2 is 25. This means that 1 kg of CH_4 has an impact on global warming equivalent to 25 kg of CO_2 for 100 years. In other words, the emission of 1 kg CH_4 is 25 kg CO_2 equivalent. **Table 1** shows the GWPs of the various GHGs in terms of IPCC's Fifth Assessment Report (AR5) [6].

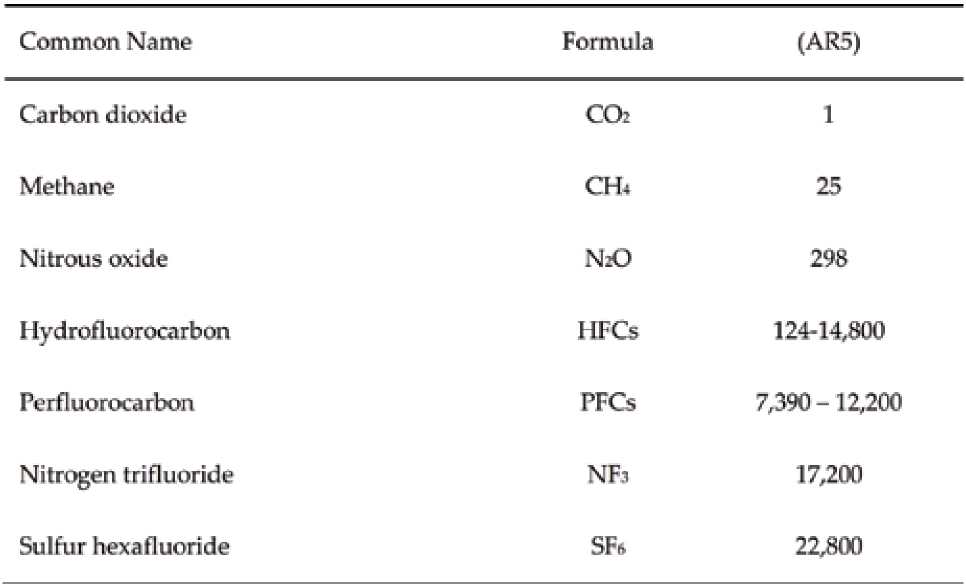
2.1.3. Sources of GHG emissions

These following sources of GHG emissions are taken into account for carbon footprint:

- raw material acquisition
- electricity production and consumption
- combustion processes
- chemical reactions in industry
- processing, manufacturing and operations
- transportation of entire process
- leakage of refrigerants and other fugitive gases
- livestock, agricultural production and waste generation
- waste and waste management
- fossil fuel are included in carbon footprint calculation but CO_2 emissions from biogenic sources are excluded.

2.1.4. Unit of analysis

Unit for GWPs calculation could be obtained from the common unit of measurement which provides a simple guide enabling the policymakers to compare GHGs emission and effectiveness of mitigation measures for various sectors and gases. The unit of analysis can therefore be set as per unit of product such as per kg, per liter, per piece, and so on.



Common Name	Formula	(AR5)
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298
Hydrofluorocarbon	HFCs	124-14,800
Perfluorocarbon	PFCs	7,390 – 12,200
Nitrogen trifluoride	NF_3	17,200
Sulfur hexafluoride	SF_6	22,800

Table 1. GHG and the global warming potential (GWP) [6].

2.2. GHGs protocol emission scopes

Figure 1, adapted from the World Resources Institute (WRI) GHG Protocol, illustrated the three different groups, or "scopes," including direct, indirect, and optional sources of GHG emissions under the GHG Protocol. As the rule of thumb, data for direct emissions, including wastewater treatment, direct energy generation, travel in the company-owned vehicles, landfill gas, and fugitive GHG emissions, should be reported. Further, indirect emissions from subscribed electricity and steam, for example, must be included. Most of the programs do not report GHG emissions from optional source, such as from vehicles that are not owned by the company, outsourced activities, waste disposal, purchased materials, and product use [7].

2.2.1. Principle of GHG protocol

The five principles of the GHG protocol are relevance, completeness, consistency, transparency, and accuracy (**Figure 2**) [8].

2.2.1.1. Relevance

The GHG sources to be selected, the GHG sinks, reservoirs, data, and methodologies for assessment must be appropriate to the specific needs of the intended user.

2.2.1.2. Completeness

It includes all relevant GHG emissions and removals.

All the relevant GHG emissions and removals must be included.

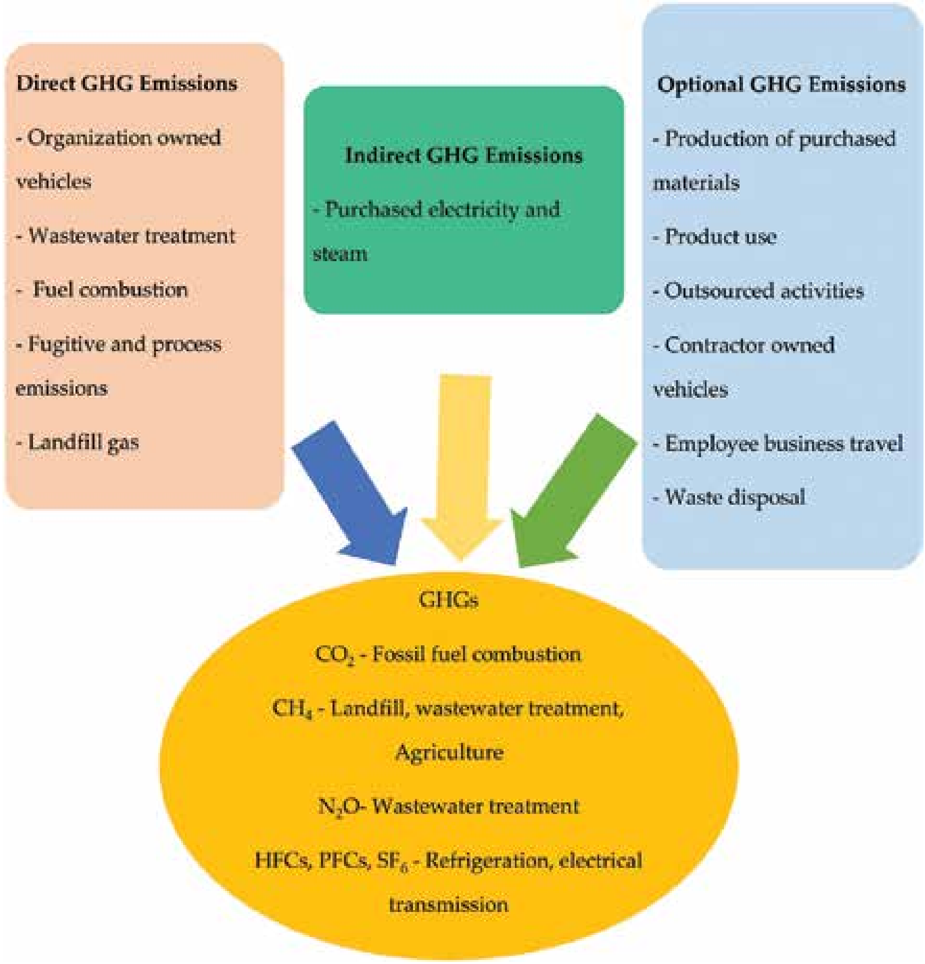


Figure 1. GHGs protocol emissions scopes.

2.2.1.3. *Consistency*

It enables meaningful comparisons in GHG-related information.

2.2.1.4. *Accuracy*

It reduces bias and uncertainties as far as is practical.

Bias and uncertainties must be reduced as far as is practical.

2.2.1.5. *Transparency*

It discloses sufficient and appropriate GHG-related information to allow intended users to make decisions with reasonable confidence.

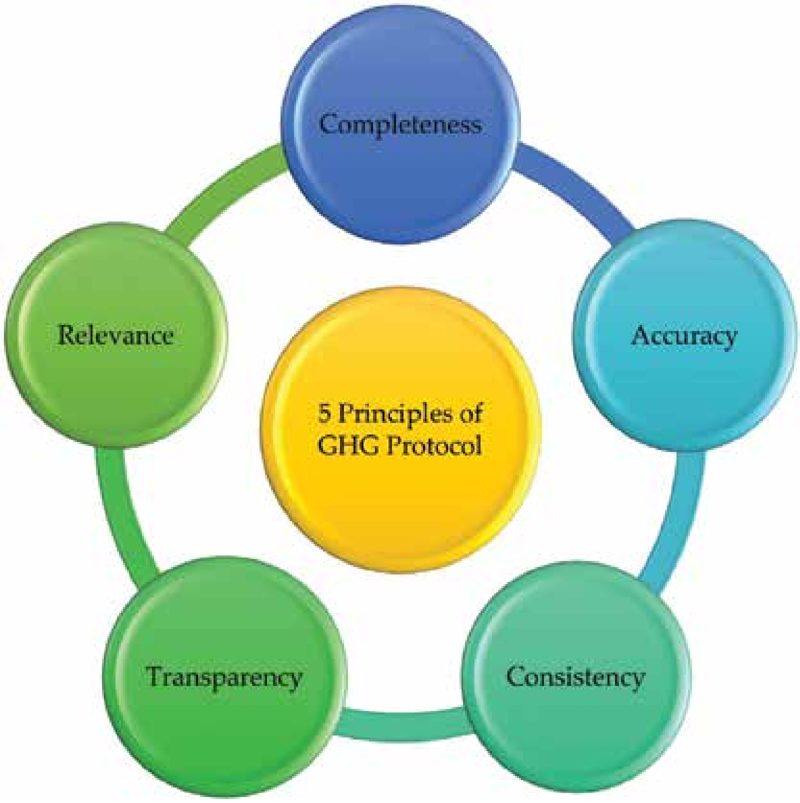


Figure 2. Principles of GHG protocol.

The first principle of relevance is important for providing available information to stakeholders both internal and external to the company. The completeness of the GHG report is measured in terms of how comprehensive and meaningful the compiled information is. Consistency in the organization's reporting of GHG emissions will allow them to track emissions over time to identify trends. Transparency within the GHG report allows for a clear audit trail of the information presented. Accuracy, along with the four other accounting and reporting principles, will ensure that the organization produces a true and fair representation of their GHG emissions [9].

2.3. Scope of the GHG emission source

The GHG emission sources were categorized into three different "scopes." Scope 1 accounts for direct emissions from sources that are controlled or owned by the organization; scope 2 refers to indirect emissions that occur from the generation of subscribed electricity, steam, or heat used by the organization; and scope 3 accounts for all other indirect emissions resulting from the company activities, but emitted from sources not controlled or owned by the company as presented in **Figure 3** [8].

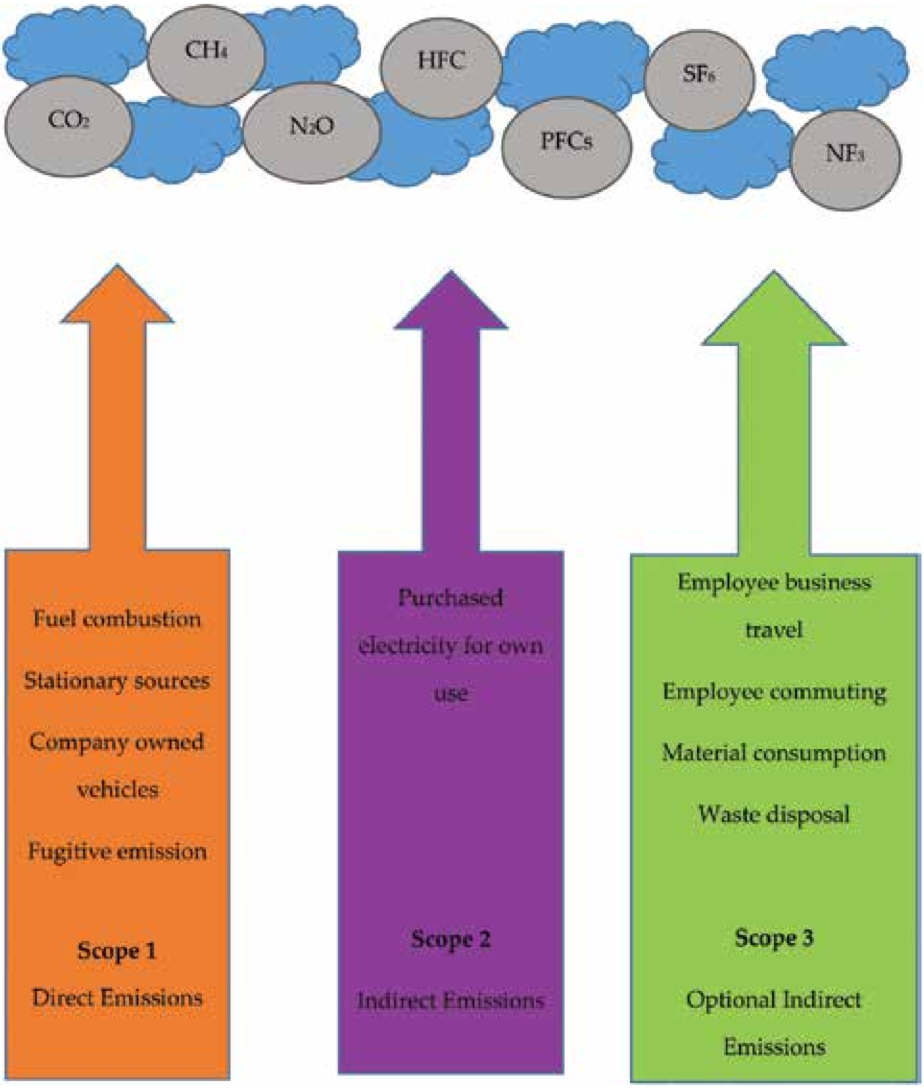


Figure 3. The carbon emission sources in three scopes.

GHG inventories reporting now include all direct and indirect emissions for all activities in the upstream supply chain as well as those emissions resulting from the consumption and disposal of an entity's products. This broadened view highlights the necessity for a consumption-based approach [10]. Consequently, the quantification of scope 3 emissions is a demanding task since a number of sectors have to be analyzed in order to capture changes in the consumption patterns. Downstream purchasing entities often lack access to the detailed information pertaining to the manufacturing of each product they purchase. Further, they lack the resources, and in some cases, the technical capacity to investigate the supply chain for each product. Consequently, the estimation of scope 3 emissions makes use of streamlined methods [11].

The GHG emissions emitted from direct and indirect sources by an entity can be categorized into different scopes:

Scope 1 accounts for direct emissions of GHG emitted from sources, such as fossil fuels burned on site, emissions from entity-leased or entity-owned vehicles, and other direct sources, which are controlled or owned by the entity.

Scope 2 accounts for indirect emissions of GHG emitted from source, such as the electricity generation, the transmission and distribution (T&D) losses associated with some purchased utilities (e.g., chilled water, steam, and high temperature hot water), and heating and cooling, or steam, which are generated off site but purchased by the entity.

Scope 3 accounts for emissions of GHG emitted indirectly from sources, such as T&D losses associated with purchased electricity, employee travel and commuting, contracted solid waste disposal, and contracted wastewater treatment, which are not controlled or

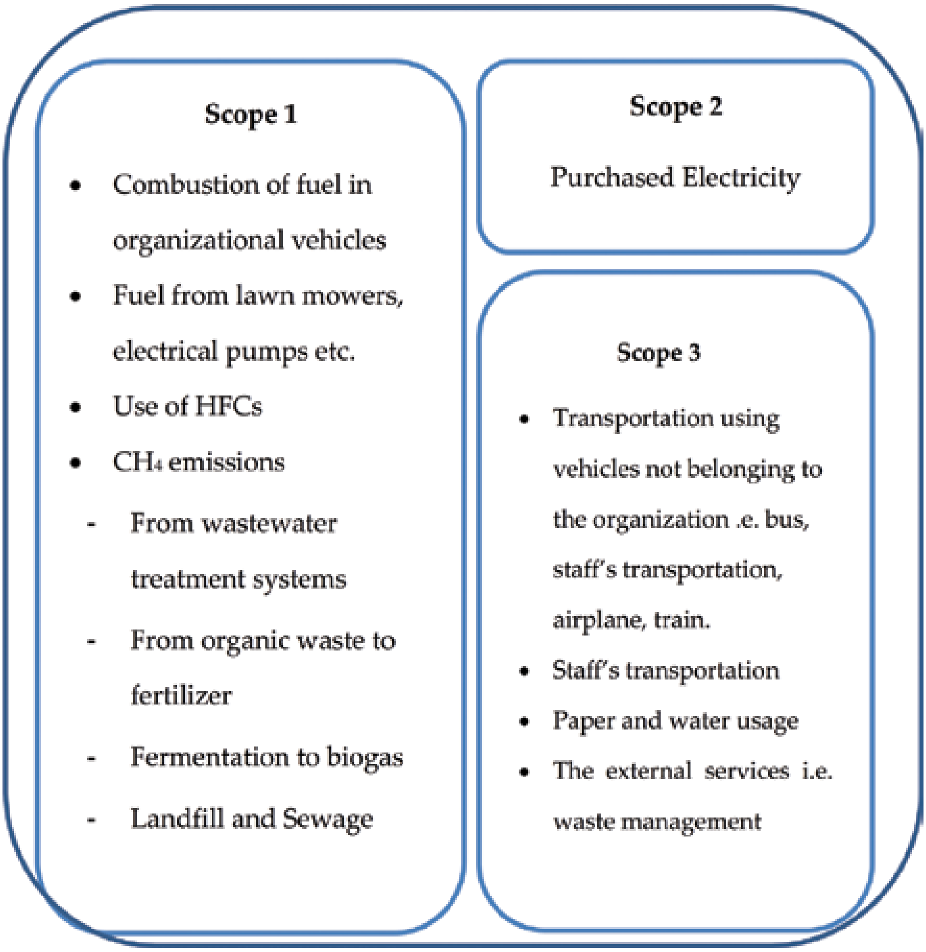


Figure 4. The scope of carbon emission sources in local organization [12].

owned by the entity but associated to the entity's activities. Those GHG emission sources are currently required for federal GHG reporting. Additional sources, such as GHG emissions from leased space, outsourced activities, vendor supply chains, and site remediation activities, are presently optional under federal reporting requirements, but they are substantial.

TGO defined the framework for carbon footprint for organizations in terms of three scopes as illustrated in **Figure 4** [12].

2.4. Step for GHG accounting and reporting

In order to measure the GHG emission and mitigation, the procedure for GHG calculation and reporting is illustrated in **Figure 5** [13].

2.5. Background of Kho-hong municipality

In general, Kho-hong municipality is located on the east of Hatyai municipality as illustrated in **Figure 6**. It is 2.5 km away from Hatyai district office and 30 km away from Songkhla province. The distance from Bangkok is about 1125 km.

The information of Kho-hong municipality could be described as follows:

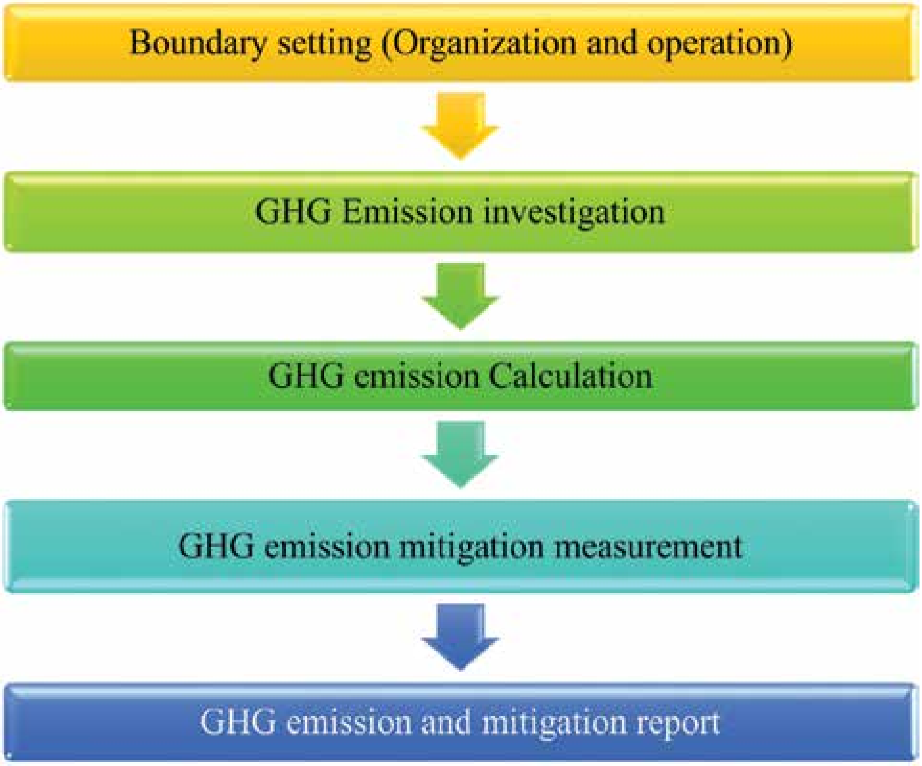


Figure 5. Steps for GHG accounting and reporting (modified from [13]).

2.5.1. Boundary

Kho-hong municipality territorial areas are as follows:

- In the north, the municipality borders with the Klong-hae municipality and Nam-noi sub-district.
- In the south, it borders with the Ban-pru municipality and Ban-rai sub-district.
- In the east, it borders with the Sub-district Administration Organization (hereafter SAO) of Thung-yai and Na mom and.
- On the western side, the municipality borders with Hat-yai and Kuan-lung municipalities.

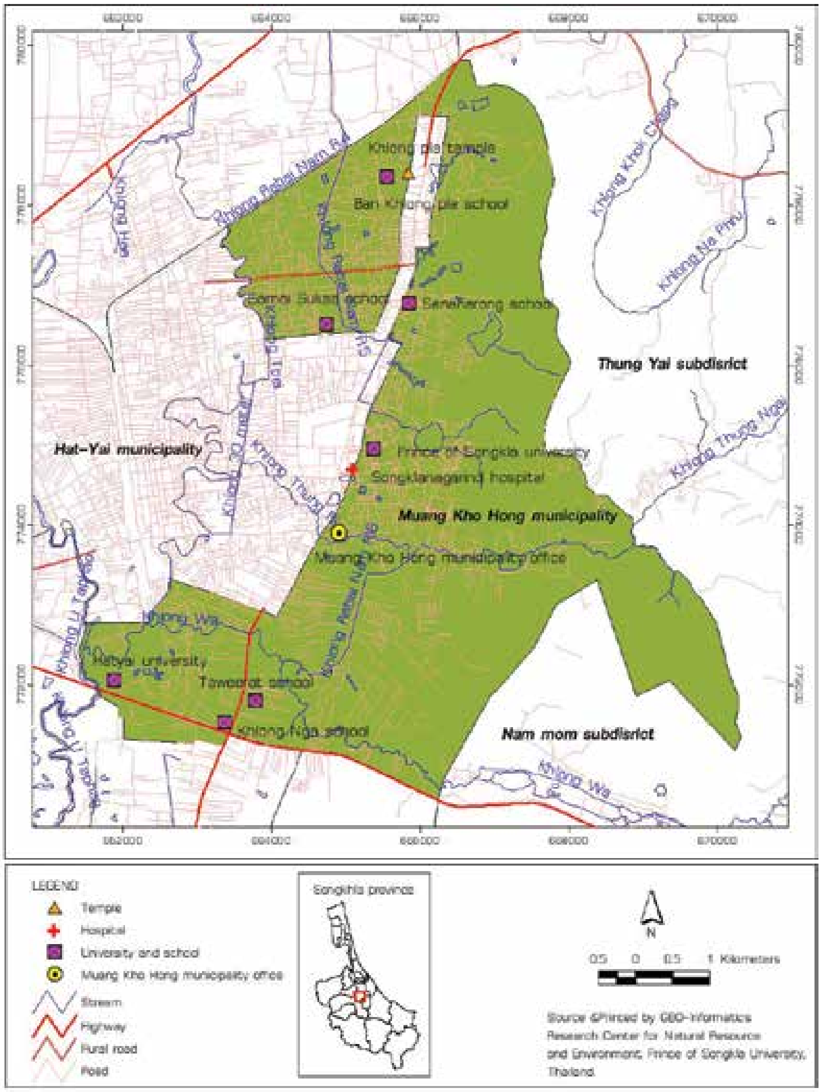


Figure 6. Map of Kho-hong municipality [4].

2.5.2. Population

The current population of Kho-hong municipality is about 45,939 persons which are 22,283 males and 23,656 females (February 2018) [14]. The total household in the municipality is 27,739 households, divided into 30 groups [4].

2.5.3. Geography

The area of Kho-hong municipality is approximately 34.57 km^2 or 8,542.43 acres (**Figure 6**). The area is generally a flat area near Kho-hong hill slope down to the Au-tapao Canal which is the border line of the Kuan-lang and Kho-hong districts. The predominant soil texture is sandy soil and sandy loam, with isolated portions of clay soil [4].

2.5.4. Community settlements

The municipality is located in the area between the floodplain and highland areas in the eastern part of the district. According to data gathered from the Prince of Songkla University (PSU) also located in Kho-hong municipality, the community was not established many years ago, when compared to other municipalities in the Southern provinces of Thailand. The community type is also educational and residential zone. A much older community is located in the northern end of Kho-hong municipality. This area supported the expansion of the city's residential area. However, frequent floods affected the progression of settlements in the municipality.

2.5.5. Climate data

Kho-hong municipality is located in the tropical monsoon zone: the southwest and the northeast monsoon. The northeast monsoon blows from October to mid-January and the southwest

Figure 7. Kho-hong municipality office.

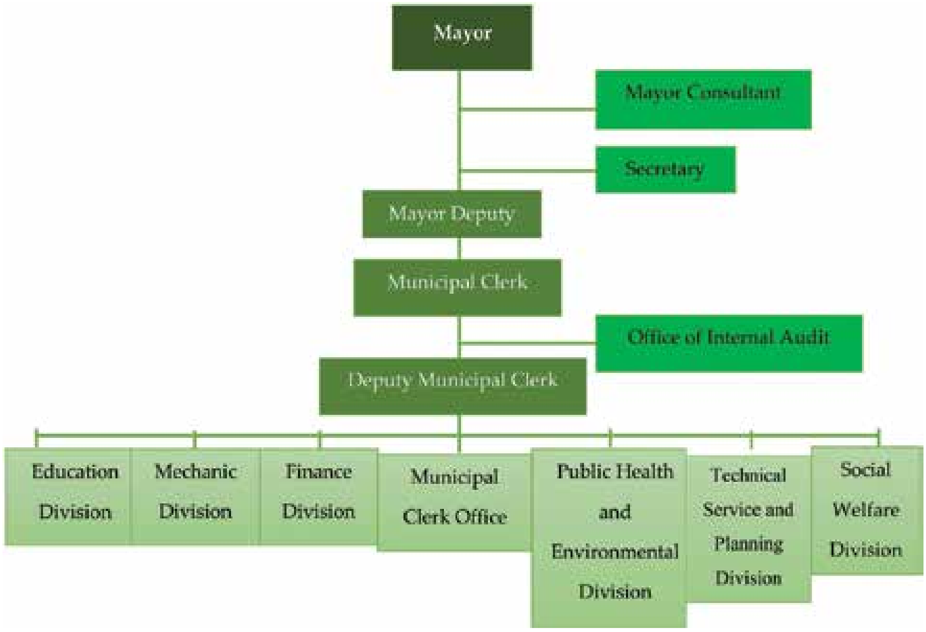


Figure 8. Organization chart for Kho-hong municipality **[5].**

monsoon blows from mid-May to mid-October. Due to the monsoon influence, there are only two seasons: summer which spans from February to July and the rainy season which spans from August to January. The annual rainfall is approximately 1995 mm. The average temperature is 28.1°C. In summer and rainy seasons, the average temperature is about 27.7–29.1°C and the average temperature reduces to 26.7°C in December [15]. The lowest temperature on record was measured at 13.7 on February 4, 2014, at Kho-hong air quality monitoring center. The average minimum and maximum temperatures are 24.8 and 40.3°C, respectively. The relative humidity is 77% [16].

2.5.6. Organization information

Kho-hong municipality office (**Figure 7**) comprises seven divisions based on its function including education service, mechanic, finance, municipal clerk office, public health and environment, technical service and planning, and social welfare. Each division is responsible for municipal council management. According to this classification, **Figure 8** illustrates the organization profiles of Kho-hong municipality which has a service schedule from 8.30 am to 4.30 pm in a full operation mode on weekdays (Monday to Friday). The office closes during weekends and public holidays. The full working time is therefore 8 h a day excluding lunch time break.

3. Materials and methodology

To evaluate CFO, Kho-hong municipality has a committee in order to collect and provide data and relevant information in February 2017. The first step to run the project began with in-house training for staff by consultant from the Faculty of Environmental Management, Prince of Songkla University, Hatyai, Songkhla, Thailand.

3.1. Scope and boundary

Scope and boundary of collecting data were clarified in terms of the following:

3.1.1. Organization boundary

Control approach in terms of operational control which account for the activities owned and run by municipality.

3.1.2. Base year

Single base year approach in fiscal year 2016 started from October 2015 to September 2016.

3.1.3. Geographical operations: Activities

Prior to set the operational boundary, the organization context was defined in terms of

1. layout
2. organization structure
3. the area and amount of staff
4. organization type: management function of Kho-hong municipality.

3.1.4. Operational boundary

In order to obtain an effective data collection, a clear determination of emission sources was necessary. Based on TGO greenhouse gas reporting and literature review, the operational boundary can be classified into three scopes as follows:

Scope 1: All direct GHG emissions, with the exception of direct CO_2 emissions from biogenic sources.

1. GHG emissions from stationary combustion units
    - **1.1.** Electricity production for organization use
    - **1.2.** Fossil fuel combustion from stationary machines which are controlled or owned by organization
2. GHG emissions from mobile combustion
3. Fugitive GHG emissions.

Scope 2: Indirect GHG emissions associated with the consumption of purchased or acquired electricity, heating, cooling, or steam.

Scope 3: All other indirect emissions which are not covered in scope 2 including upstream and downstream emissions, emissions resulting from the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting organization, use of sold products and services, outsourced activities, recycling or used products, waste disposal, and so on [9].

3.1.5. GHG from operational activities

The research is carried out to measure GHG emission from the operation control of Kho-hong municipality for the purposes of consolidating and reporting GHG emissions.

In this study, seven GHGs, which are the target for the first commitment period of the Kyoto Protocol, are included namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbon (HFCS), perfluorocarbon (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3) were investigated.

With the TGO's guidelines, all of human activities are taken into account to GHG emission. So the assumption and estimation of the GHG were analyzed baseline annual calculation on Kho-hong municipality in fiscal year 2016.

3.1.6. Facilities for consideration in GHG emissions calculation

- The facilities include seven divisions of municipality function namely education service, mechanic, finance, municipal clerk office, public health and environment, technical service and planning, and social welfare.
- Excluded facilities:

  1) The outsource performance related to municipality operation and staff own vehicle.

  2) Dry chemical in extinguisher according to its application was not regarded as an impact on GHG emission.

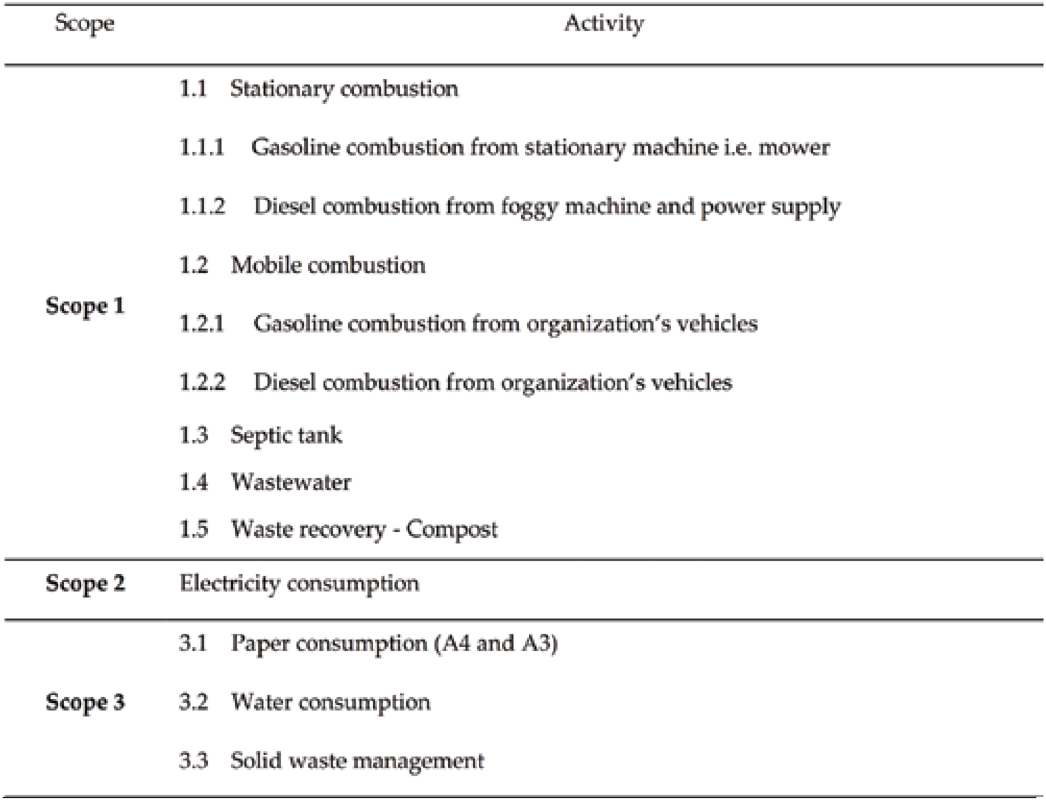
The activity data and source of GHG emission were provided for evaluating carbon performance as presented in **Table 2**.

3.2. Data collection

In order to achieve data evaluation, data collection and report are requisite to confirm that the process is following principle guidelines of the GHG protocol by TGO, which provided a guideline GHG protocol corporate concept and the GHG emissions report. Data flow (**Figure 9**) was analyzed and evaluation criteria were established before primary data were collected by means of measurement, evaluation, and interview. Secondary data could be reached from calculation, statistical data, exploration, literature review, and so on.

3.3. Data calculation

To achieve the first objective, "Identify and quantify carbon mitigation possibility," all data collected from scopes 1–3 were calculated by Eq. (1). An example of these data and the subsequent carbon footprint calculations has been provided in Appendix A



Scope	Activity
Scope 1	1.1 Stationary combustion
	1.1.1 Gasoline combustion from stationary machine i.e. mower
	1.1.2 Diesel combustion from foggy machine and power supply
	1.2 Mobile combustion
	1.2.1 Gasoline combustion from organization's vehicles
	1.2.2 Diesel combustion from organization's vehicles
	1.3 Septic tank
	1.4 Wastewater
	1.5 Waste recovery - Compost
Scope 2	Electricity consumption
Scope 3	3.1 Paper consumption (A4 and A3)
	3.2 Water consumption
	3.3 Solid waste management

Table 2. Activities data.

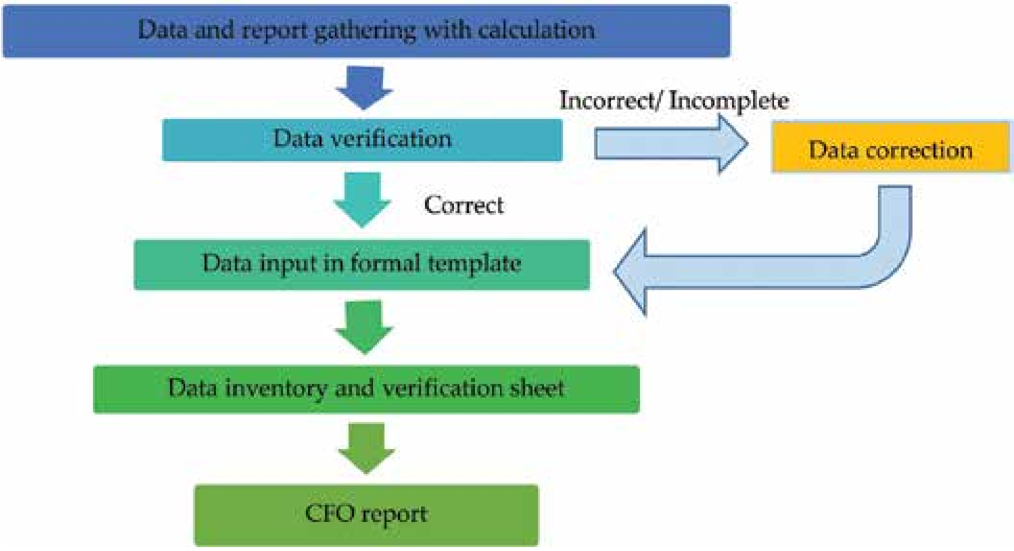


Figure 9. Data flow for carbon footprint evaluation.

$$CO_2\ Emission\ =\ Activity\ Data\ x\ Emission\ Factor \tag{1}$$

3.3.1. Activities data

Activity data and source of GHG emissions were gathered from each division and summarized following the scope as summarized in **Table 3**.

Resource	GHG	Pollution Source	Emission Factor (kg GHG/unit)	Emission Factor Source
Scope 1				
Stationary combustion	CO_2	Gasoline Combustion	2.1816	IPCC Vol. 2 table 2.2 DEDE
	CH_4		0.0001	
	N_2O		0.0000	
Mobile combustion	CO_2	Gasoline Combustion	2.1816	IPCC Vol.2 table 3.2.1, 3.2.2, DEDE
	CH_4		0.0010	
	N_2O		0.0001	
	CO_2	Diesel Combustion	2.6987	IPCC Vol.2 table 3.2.1, 3.2.2, DEDE
	CH_4		0.0001	
	N_2O		0.0001	
Septic tank	CH_4	Wastewater from septic tank	25.00	IPCC 4th Assessment Report, Climate Change 2007
Wastewater w/o treatment	CH_4	Domestic wastewater	25.00	IPCC 4th Assessment Report, Climate Change 2007
Compost	CH_4	Compost waste	25.00	IPCC 4th Assessment Report, Climate Change 2007
R-22 refrigerant	CO_2	Fugitive emission from refrigerant R-22	1,810	R-22 (HCFC-22), World Meteorological Org, 2006, Carbon Footprint for Organization (TGO, 2017)
Scope 2				
Electricity	GHG	Electricity appliances	0.5821	Thailand Grid Mix Electricity LCI Database 2014, Carbon Footprint for Organization (TGO, 2017)
Scope 3				
Paper consumption	GHG	Working documents, meeting documents	2.0859	Thai National LCI Database/MTEC, Carbon Footprint for Product (TGO, 2016)
Water consumption	GHG	Faucets, sanitary wares	0.7043	Thai National LCI Database/MTEC, Carbon Footprint for Product (TGO, 2016)
Sanitary landfill	CH_4	Anaerobic Digestion from Sanitary Landfill	25.00	IPCC 4th Assessment Report, Climate Change 2007

Table 3. Emission source and emission factor.

Figure 10. Verification process in Kho-hong municipality office.

3.3.2. Emission factors

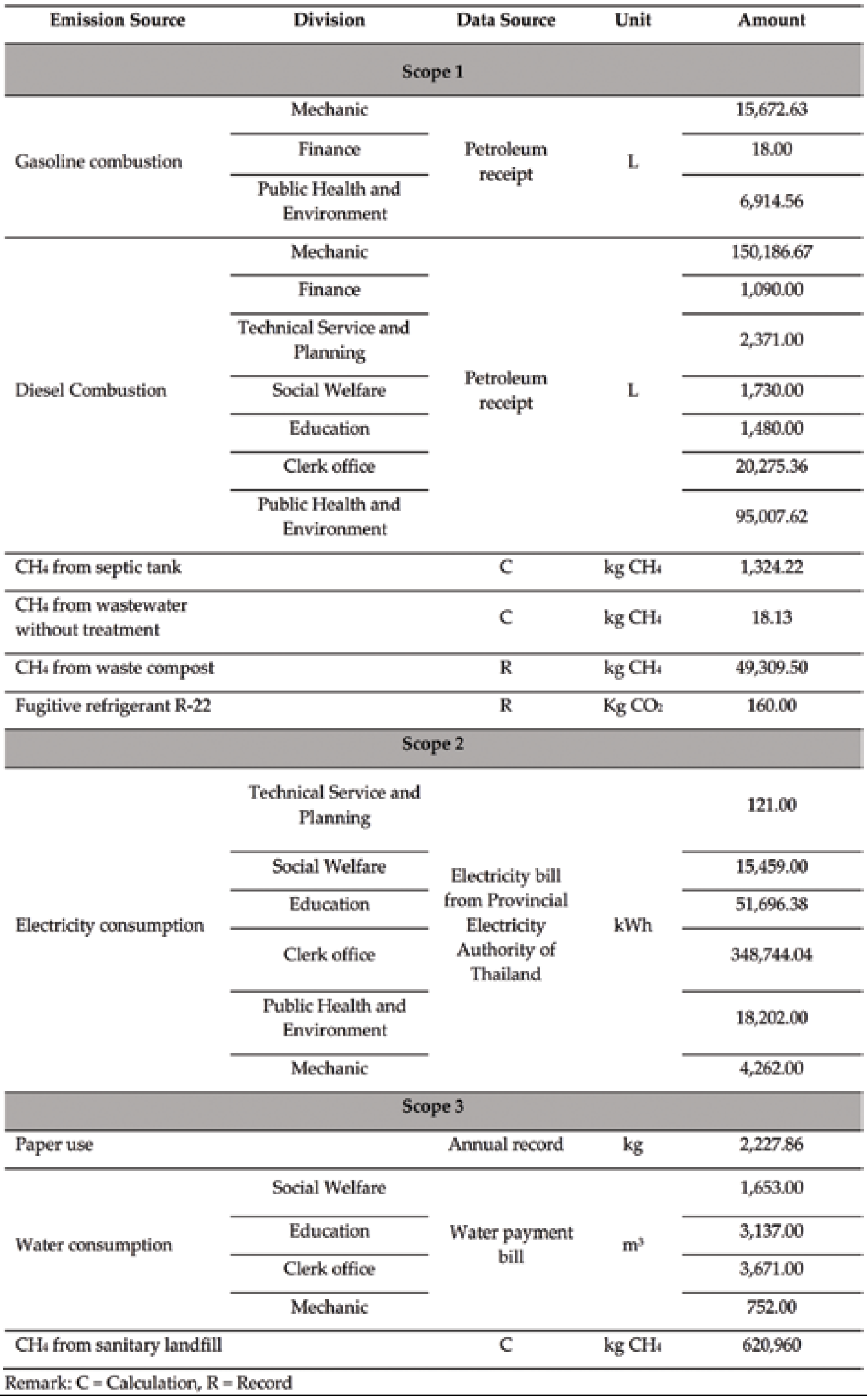
The emission factors were chosen from reliable data sources, that is, IPCC, Thai LCI Database, DEDE, and TGO as presented in **Table 3**.

3.4. Data verification

After the inventory data were compiled by municipality, the verification process began. The collected and analyzed data were verified by a consultancy team from Thaksin University in terms of collection method, data acquisition and accessibility, data correctness, including emission factors and calculations. The meeting was hosted by Kho-hong municipality (**Figure 10**).

4. Results and discussion

The GHG emission sources were summarized by scope. The primary data of each emission source were obtained for calculation in different conversion units. The GHG emission sources were presented for each division document and evidence as presented in **Table 4**. GHG emissions were calculated in terms of ton CO_2 eq. Total direct GHG emissions from stationary and mobile combustion including fugitive emissions were calculated to be 1129.92 ton CO_2 eq. The diesel combustion from mobile source occupies the biggest portion of scope 1 emissions of about 746.92 ton CO_2 eq/year. Meanwhile, CH_4 emissions generated from waste in sanitary landfill was the major source of alternative indirect emission for scope 3 equal to 15,524 ton CO_2 eq./year or 91.75% of total emissions with regard to municipality responsible for Kho-hong waste management. The least proportion emission was from consumed electricity for the municipality (255.24 ton CO_2 eq./year). Therefore,



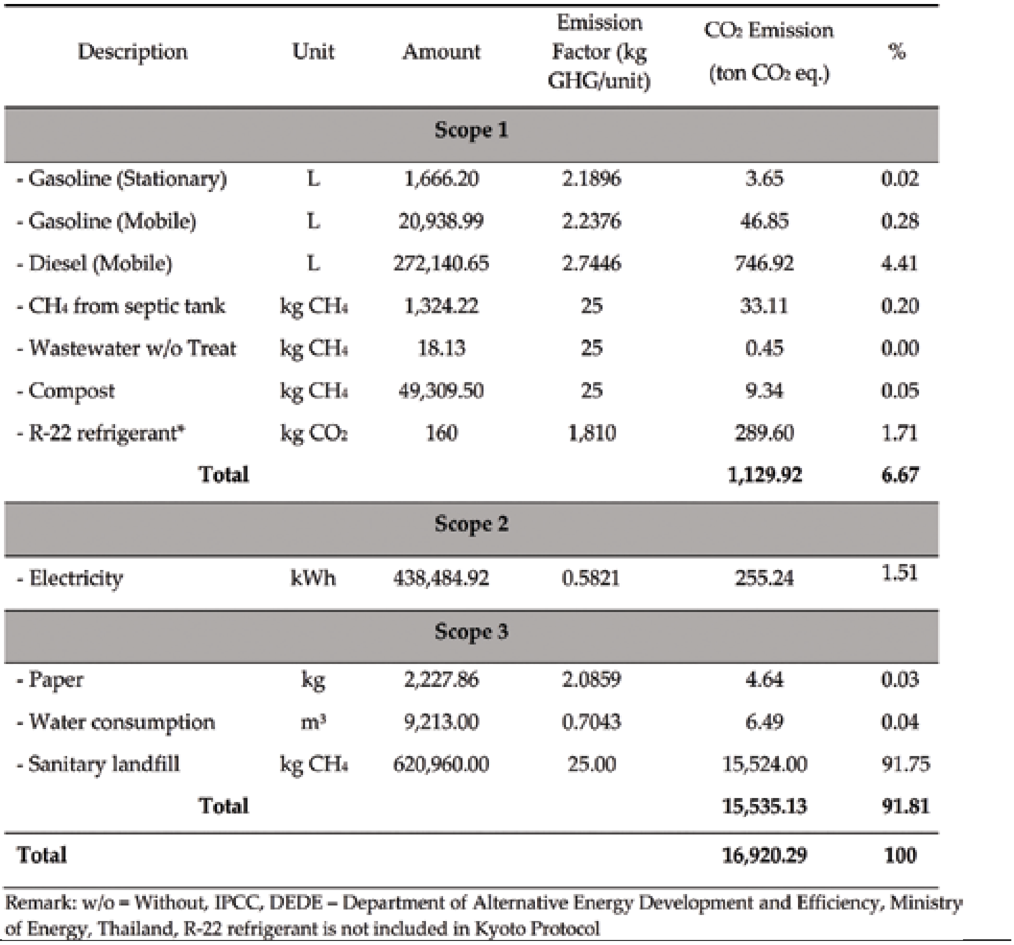
Emission Source	Division	Data Source	Unit	Amount
Scope 1				
Gasoline combustion	Mechanic	Petroleum receipt	L	15,672.63
	Finance			18.00
	Public Health and Environment			6,914.56
Diesel Combustion	Mechanic	Petroleum receipt	L	150,186.67
	Finance			1,090.00
	Technical Service and Planning			2,371.00
	Social Welfare			1,730.00
	Education			1,480.00
	Clerk office			20,275.36
	Public Health and Environment			95,007.62
CH_4 from septic tank		C	kg CH_4	1,324.22
CH_4 from wastewater without treatment		C	kg CH_4	18.13
CH_4 from waste compost		R	kg CH_4	49,309.50
Fugitive refrigerant R-22		R	Kg CO_2	160.00
Scope 2				
Electricity consumption	Technical Service and Planning	Electricity bill from Provincial Electricity Authority of Thailand	kWh	121.00
	Social Welfare			15,459.00
	Education			51,696.38
	Clerk office			348,744.04
	Public Health and Environment			18,202.00
	Mechanic			4,262.00
Scope 3				
Paper use		Annual record	kg	2,227.86
Water consumption	Social Welfare	Water payment bill	m^3	1,653.00
	Education			3,137.00
	Clerk office			3,671.00
	Mechanic			752.00
CH_4 from sanitary landfill		C	kg CH_4	620,960

Remark: C = Calculation, R = Record

Table 4. Summary of carbon emissions for Kho-hong municipality under three scopes.

total emissions from Kho-hong municipality operations were evaluated to be 16,920.29 ton CO_2 eq. The carbon footprints under scopes 1, 2, and 3 are 6.67, 1.51, and 91.81% of the total emission, respectively, as presented in **Table 5**. In comparison, scope 3 revealed the highest carbon footprint in this study. Correspondingly, it was found that 75% of an industry sector's carbon footprint is attributed to scope 3 emissions [17]. The emissions for scope 3 increased due to the increasing population and complex nature of activities performed by different kinds of organizations and the varying scales in which they function [18]. Although scope 3 emissions represent the largest proportion of the organizational carbon footprint, they represent the priority in carbon balance strategies [19].

In order to reduce GHGs emission, several strategies were proposed. 3Rs (Reduce, Reuse, and Recycle) are approaches which would effectively reduce waste at source and transfer stations. Waste to energy is another alternative to waste recovery prior to disposal in landfill. However, the cooperation and participation of municipal staff impacts negatively on GHG mitigation efforts through electricity consumption reduction including energy savings through responsible



Description	Unit	Amount	Emission Factor (kg GHG/unit)	CO_2 Emission (ton CO_2 eq.)	%
Scope 1					
- Gasoline (Stationary)	L	1,666.20	2.1896	3.65	0.02
- Gasoline (Mobile)	L	20,938.99	2.2376	46.85	0.28
- Diesel (Mobile)	L	272,140.65	2.7446	746.92	4.41
- CH_4 from septic tank	kg CH_4	1,324.22	25	33.11	0.20
- Wastewater w/o Treat	kg CH_4	18.13	25	0.45	0.00
- Compost	kg CH_4	49,309.50	25	9.34	0.05
- R-22 refrigerant*	kg CO_2	160	1,810	289.60	1.71
Total				**1,129.92**	**6.67**
Scope 2					
- Electricity	kWh	438,484.92	0.5821	255.24	1.51
Scope 3					
- Paper	kg	2,227.86	2.0859	4.64	0.03
- Water consumption	m^3	9,213.00	0.7043	6.49	0.04
- Sanitary landfill	kg CH_4	620,960.00	25.00	15,524.00	91.75
Total				**15,535.13**	**91.81**
Total				**16,920.29**	**100**

Remark: w/o = Without, IPCC, DEDE – Department of Alternative Energy Development and Efficiency, Ministry of Energy, Thailand, R-22 refrigerant is not included in Kyoto Protocol

Table 5. Carbon footprint evaluation from Kho-hong municipality in 2016.

vehicle usage. Incentives for GHG emission mitigation would be optional for increasing motivation for carbon footprint balance [20]. The three most influential constraints to collect data and GHG emissions reduction from upstream and downstream of the organizational activities would be identified in terms of time, cost, and data accessibility. Many organizations have a poor understanding of GHG emissions directly and indirectly associated with their activities. Consequently, this limited reduction for GHGs mitigation in the local municipality is a subject requiring further exploration. The carbon footprint should also be continually evaluated to monitor the GHG reduction and energy conservation measures [21]. The convergent approaches are practically involved in global warming mitigation thoroughly as well.

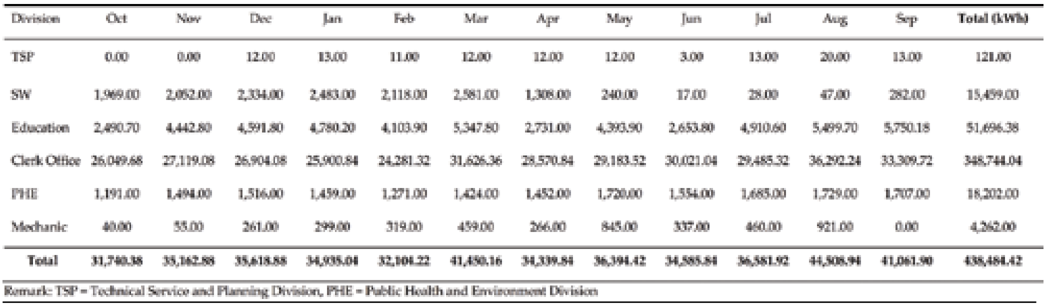
5. Conclusion

A general methodology, which provides a practical, reliable, and transparent inventory for practitioners in assessing the carbon footprint for local organizations, was followed. The total carbon footprint for Kho-hong municipality is 16,920.29 ton CO_2eq/year. Carbon footprints under scopes 1, 2, and 3 are 1129.92, 255.24, and 15,535.13 ton CO_2eq/year, respectively. The highest carbon footprint was represented by waste to sanitary landfill (15,524 ton CO_2eq/year) while the highest emission from activities in municipality was due to diesel combustion from municipality-owned vehicles (746.92 ton CO_2eq/year) followed by fugitive emissions from refrigerant (289.60 ton CO_2eq/year), and third emissions were electricity consumption (255.24 ton CO_2 eq/year). The lowest emissions were due to emissions from wastewater without treatment (0.45 ton CO_2 eq/year). Though indirect emissions (scope 3) represent the largest proportion of the organization's carbon footprint, these are seldom the priority in carbon management policies in municipalities. In order to reduce GHGs emission, several strategies were proposed. 3Rs (Reduce, Reuse, and Recycle) are adaptive approaches which would effectively reduce waste at source and transfer stations. Waste to energy is another alternative to waste recovery prior to disposal in landfill. However, the cooperation and participation of municipal staff impacts negatively on GHG mitigation efforts through electricity consumption reduction including energy savings through responsible vehicle usage. Incentives for GHG emission mitigation would be optional for increasing motivation for carbon footprint balance. The carbon mitigation with cost reduction should not only be one's task responsibility but public participation is also required to provide sustainable workplace [22]. Convergent approaches would be a good alternative for GHGs mitigation for local organizations. However, limitations in time, cost, and human behavior (negatively impacting on public cooperation) were some of the most important barriers identified.

Acknowledgements

The provision of funding from Thailand Greenhouse Gas Management Organization (Public Organization) (TGO) on "Promoting the Carbon Footprint of Local Government Organizations and Reporting Greenhouse Gas Emissions" Project with Research Unit for Energy Economic and Ecological Management, Science and Technology Research Institute, Chiang Mai University, Thailand, is gratefully acknowledged. The financial contribution from the Center of Excellence on Hazardous Substance Management (HSM), Bangkok, Thailand, provided partial support for this research. The authors are also thankful to staff in the Kho-hong municipality for their support and cooperation during the carbon footprint evaluation program.

Appendix.A. Example of scope 2 carbon emission from electricity consumption



Division	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total (kWh)
TSP	0.00	0.00	12.00	13.00	11.00	12.00	12.00	12.00	3.00	13.00	20.00	13.00	121.00
SW	1,969.00	2,052.00	2,334.00	2,483.00	2,118.00	2,581.00	1,308.00	240.00	17.00	28.00	47.00	282.00	15,459.00
Education	2,490.70	4,442.80	4,591.80	4,780.20	4,103.90	5,347.80	2,731.00	4,393.90	2,653.80	4,910.60	5,499.70	5,750.18	51,696.38
Clerk Office	26,049.68	27,119.08	26,904.08	25,900.84	24,281.32	31,626.36	28,570.84	29,183.52	30,021.04	29,485.32	36,292.24	33,309.72	348,744.04
PHE	1,191.00	1,494.00	1,516.00	1,459.00	1,271.00	1,424.00	1,452.00	1,720.00	1,554.00	1,685.00	1,729.00	1,707.00	18,202.00
Mechanic	40.00	55.00	261.00	299.00	319.00	459.00	266.00	845.00	337.00	460.00	921.00	0.00	4,262.00
Total	**31,740.38**	**35,162.88**	**35,618.88**	**34,935.04**	**32,104.22**	**41,450.16**	**34,339.84**	**36,394.42**	**34,585.84**	**36,581.92**	**44,508.94**	**41,061.90**	**438,484.42**

Remark: TSP = Technical Service and Planning Division, PHE = Public Health and Environment Division

Calculation steps

$$GHG\ emissions\ electricity(kg\ CO\ 2\ eq.yr\ {-1})\ =\ E\ x\ EF\ e \tag{A1}$$

where E = Electricity consumption (kWh/year).

EFe = CO_2 emission factor for electricity consumption which, is 0.5821 kg CO_2/kWh (Thailand Grid Mix Electricity LCI Database 2014_Update 1 Jan 2017, **Table 3**).

From the data above, the total electricity consumption = 438,484.42 kWh

$GHG\ emissions_{\text{electricity}}$ = 438,484.42 × 0.582

= 255,241.78 kg CO_2 eq/year

= 255.24 ton CO_2 eq/year

Table A1. Electricity consumption of Kho-hong municipality in 2016 [4].

Author details

Warangkana Jutidamrongphan[1,2], Luke Makarichi[1,3]* and Samnang Tim[1]

*Address all correspondence to: makarichiluke@gmail.com

1 Faculty of Environmental Management, Prince of Songkla University, Hatyai, Songkhla, Thailand

2 Research Program: Municipal Solid Waste and Hazardous Waste Management, Center of Excellence on Hazardous Substance Management (HSM), Bangkok, Thailand

3 Environmental Protection Department, Environmental Management Agency, Harare, Zimbabwe

References

[1] Wiedmann T, Minx J. A definition of "carbon footprint". Pertsova CC, editor. Ecological Economics Research Trends: Chapter 1. Hauppauge NY, USA: Nova Science Publishers; 2008. pp. 1-11

[2] Tjandra TB, Yeo RNZ, Song B. 2016. Framework and methods to quantify carbon footprint based on an office environment in Singapore. Journal of Cleaner Production 2016;**112**(5):4183-4195

[3] Waas T, Hugé J, Ceulemans K, Lambrechts W, Vandenabeele J, Lozano R, Wright T. Sustainable Higher Education. Understanding and Moving Forward Flemish Government – Environment. Nature and Energy Department, Brussels; 2012

[4] Faculty of Environmental Management, Prince of Songkla University. Final report of Carbon Footprint for Kho-hong Municipality on "Promoting the Carbon Footprint of Local Government Organizations and Reporting Greenhouse Gas Emissions" Project. Prince of Songkla University; 2017. pp. 1-44

[5] IPCC. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri RK, Meyer LA, editors]. Geneva, Switzerland: IPCC;2014. pp. 151

[6] The Intergovernmental Panel on Climate Change (IPCC). Chapter 4 Sustainable Development and Equity. 2013. Available from: http://report.mitigation2014.org/drafts/final-draft-postplenary/ipcc_wg3_ar5_final-draft_postplenary_chapter4.pdf. [Accessed: April 03, 2016]

[7] Ravin A, Raine T. Best Practices for Including Carbon Sinks in Greenhouse Gas Inventories. 2007. Available from: http://www.epa.gov/ttnchie1/ conference /ei16/ session3/ravin.pdf. [Accessed: July 10, 2016]

[8] Thailand Greenhouse Gas Management Organization (TGO). 2016. Carbon Footprint for Organization Evaluation. 3rd ed. Bangkok, Thailand: Thailand Greenhouse Gas Management Organization; Available from: http://thaicarbonlabel.tgo.or.th/admin/uploadfiles/download/ts_7be0b6757c.pdf [Accessed: November 22, 2017]

[9] Thailand Greenhouse Gas Management Organization (TGO). Reporting Protocol: Revised CFO Program (Version2). 2015. Available from: http://thaicarbonlabel.tgo.or.th/admin/uploadfiles/emission/ts_11335ee08a.pdf. [Accessed: February 14, 2017]

[10] Larsen HN, Hertwich EG. The case for consumption-based accounting of greenhouse gas emissions to promote local climate action. Environmental Science & Policy. 2009;**12**(2009):791-798

[11] Thurston M, Eckelman MJ. Assessing greenhouse gas emissions from university purchases. International Journal of Sustainability in Higher Education. 2011;**12**(2011):225-235

[12] Thailand Greenhouse Gas Management Organization (TGO). Global Warming Reduction @ Local Administrative Organization. 2012. Available from: http://www.conference.tgo.or.th/download/tgo_main/publication/CF/CF_Guidline_for_localgov_reviseI.pdf. [Accessed: August 08, 2016]

[13] Charmorndusit K. Overview of GHG Accounting and Corporate Carbon Footprint Analysis. Mahidol University. 2007. Available from: http://www.en.mahidol.ac.th/EI/CFO/Download/Overview%20of%20GHG%20Accounting%20and%20CFO%20Analysis.pdf. [Accessed: July 15, 2017]

[14] Kho-hong Municipality. Polulation of Kho-Hong Municipality. 2013. Available from: http://www.khohongcity.go.th/content/people. [Accessed: March 17, 2018]

[15] Thailand Meteorological Department (TMD). Agricultural Meteorology to know for Songkhla. 2013. Available from: http://www.arcims.tmd.go.th/DailyDATA/Agromettoknow/SS/อุตุนิยมวิทยาน่ารู้เพื่อการเกษตรจังหวัดสงขลา.pdf. [Accessed: March 18, 2018]

[16] Thailand Meteorological Department (TMD). Songkhla Climate Pattern. 2017. Available from: http://climate.tmd.go.th/data/province/ใต้ฝั่งตะวันออก/ภูมิอากาศสงขลา.pdf. [Accessed: March 19, 2018]

[17] Huang YA, Weber CL, Matthews HS. Categorization of scope 3 emissions for streamlined enterprise carbon footprinting. Environmental Science & Technology. American Chemical Society. 2009;**43**(22):8509-8515

[18] Williams I, Coello J, Kemp S, McMurtry E, Turner D, Wright L. The role of business and industry in climate management after Durban. Carbon Management. 2012;**3**(5):431-433

[19] Ozawa-Meida L, Brockway P, Letten K, Davies J, Fleming P. Measuring carbon performance in a UK University through a consumption-based carbon footprint: de Montfort University case study. Journal of Cleaner Production. 2011;**56**(1):185-198

[20] Tim S, Jutidamrongphan W. Life cycle cost analysis and energy performance of President's office, Prince of Songkla University, Thailand. Songklanakarin Journal of Science and Technology. Mar-Apr 2018;**40**(4):439-447

[21] Tim S. Evaluation and Mitigation of GHG Emission from President's Office, Prince of Songkla University, Thailand [thesis]. Prince of Songkla University, Thailand. 2017

[22] Tim S, Jutidamrongphan W. Energy efficiency and green building: A case of Prince of Songkla University, Thailand. In: Proceedings of the 53rd International Conference on Civil and Architectural Engineering (ICCAE); 13 July 2016; Phnom Penh, Cambodia; 2016. pp. 1-6

Edited by Valter Silva,
Matthew Hall and Inês Azevedo

Most leaders of developed nations recognize the importance of following policies and strategies to achieve a low-carbon economy based on new and innovative technologies that are able to reduce greenhouse gas emissions and create new employment and growth. In the broad spectrum of the feasible decarbonisation pathways, the challenge for political and economic decision-makers is to weigh uncertain impact from different technologies and to build a comprehensive evidence-based framework for research, business, investment and policy decision-making. This book aims to provide the reader with a comprehensive overview of the current state-of-the-art technology in the Low Carbon Technology and Economy field, discussing a set of new technology approaches and environmental and economic implications.

Published in London, UK

IntechOpen

ISBN 978-1-83881-506-6