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Energy Management for Sustainable Development

Edited by Soner Gokten and Guray Kucukkocaoglu

ENERGY MANAGEMENT FOR SUSTAINABLE DEVELOPMENT

Edited by **Soner Gokten**
and **Guray Kucukkocaoglu**

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Notice

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Meet the editors

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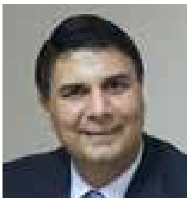

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Preface

Sustainable development is the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs—Brundtland Report (1987)

We are more aware of the need to achieve sustainable development than ever before. It is fair to say that two of the most important factors affecting sustainability are the ways of both producing and using energy. In this sense, this book provides a forum to articulate and discuss energy management issues in the frame of achieving sustainable development. And undoubtedly, we are also deeply concerned about these issues in the recent times.

This volume contains 6 chapters and is organized into two sections: "Policies and Strategies," and "Technologies and Industries."

The first section "Policies and Strategies" includes four chapters. In the first chapter, Ying Li and Ke Chen review the development of air pollution control policies in China nearly 70 years of history and discuss some political and institutional factors that have resulted in the ineffectiveness of policy implementation. They examine the pollution charge system, a key policy measure used in air pollution regulation between the 1980s and 2000s, and highlight some major changes in control policies since 2000. They also present a comparison of pollution control policies between China and the United States. In Chapter 2, Norbert Edomah presents the key historical drivers of energy infrastructure change in Nigeria by discussing the roles of politics, technologies, resources, and geographies on how energy system must also change. Shadreck Mubiana Situmbeko summarizes the energy problems in sub-Saharan Africa and discusses the future of that region in Chapter 3. The last chapter in this section by Li-Min Cheng analyzes the promotion methods in the electric vehicle industry in Taiwan and suggests that nations should actively and effectively develop an electric vehicle industry to reduce carbon dioxide emissions and energy consumption.

The second section "Technologies and Industries" includes two chapters. In Chapter 5, Ali Samadiafshar and Atiyye Ghorbani discuss dedicated technological solutions to the growing global needs for sustainable development in the frame of clean energy management. The last chapter by Ambar Pertiwiningrum, Cahyono Agus, and Margaretha Arnita Wuri discusses the biogas purification and reveals the advantages of using adsorption technology in the purification.

We would like to express our sincere gratitude to all the authors for their high-quality contributions. The successful completion of this book has been the result of the cooperation of many people. In the end, we would like to thank Mr. Julian Virag, Publishing Process Manager, for his support during the publishing process as well as Ms. Ana Pantar, Commissioning Editor, for inviting us to be the editors of this book.

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Section 1

Policies and Strategies

Chapter 1

A Review of Air Pollution Control Policy Development and Effectiveness in China

Ying Li and Ke Chen

Additional information is available at the end of the chapter

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Abstract

Upon economic booming and rapid urbanization, China has been suffering from severe air pollution problem. While the Chinese government strives to reduce emissions through numerous laws, standards and policy measures, rapid economic and social changes challenge policy design and implementation. Over time, control policies have been largely ineffective and air quality in the majority of the nation has not been significantly improved and even worsened in many urban areas. This chapter reviews the development of the air pollution control policies in China's nearly 70 years' history and discusses some political and institutional factors that have resulted in the ineffectiveness of policy implementation. We examined the pollution charge system, a key policy measure used in air pollution regulation between 1980s and 2000s, and highlighted some major changes in control policies since 2000s. A comparison of pollution control policies between China and the United States is also presented. The purpose of this chapter is to inform decision makers, particularly in the developing world, with some insights of improving policy designs and environmental governance in the control of air pollution.

Keywords: air pollution, control policy, effectiveness, China

1. Introduction

Upon economic booming and rapid urbanization, China has been suffering from severe air pollution problem. A recent study based on satellite observations reported China as one of the regions with the highest long-term concentrations of fine particulate matter ($PM_{2.5}$, particulates with an aerodynamic diameter of less than or equal to 2.5 μm) [1]. The population-weighted average $PM_{2.5}$ concentration reached 59 μg/m^3 in 2010, with more than 80% people living in areas where air quality did not meet China's annual average $PM_{2.5}$ standard of 35 μg/m^3 [2].[1] Air pollution has caused serious public health and environmental damages in China, resulting in enormous economic loss. For instance, a recent evaluation estimated that the health-related economic loss in China's 74 cities caused by PM_{10} and sulfur dioxide (SO_2) ranged from 1.63 and 2.32% of the GDP [3].

While China is confronted with one of the highest levels of air pollution in the world, rapid economic and social changes challenge policy design and implementation for the endeavors to reduce pollution. The problem of regulating air pollution is complex, not only because it involves many different pollutant emitters, but also because regulations involve many institutions that cut across domains of environment, energy, natural resource, public health, and economic policy [4]. Policies that work well in western developed countries can fail in a less developed country for any economic, social, and institutional reasons [4]. In China, the central government has been addressing this issue since late 1970s and has promulgated a series of laws, regulations as well as programs to mitigate pollution. However, although China has worked diligently for more than three decades to address its air pollution issue, the current pollution levels are still severe across the country. This has raised the questions that how successful the air quality policies have been in terms of policy design, enforcement and effectiveness. This chapter reviews the development of the air pollution control policies in China's nearly 70 years' history, focusing on its basic structure and distinct features, addressing some political and institutional factors that have resulted in the ineffectiveness of policy implementation. A comparison of control policies between China and the USA is conducted to highlight their similarities and differences, followed by a few conclusion remarks for future air pollution designs and implementations in China. The purpose of this chapter is to inform decision makers, particularly in the developing world, with some insights of improving policy designs and environmental governance in the control of air pollution.

2. China's air pollution control policy development and effectiveness

2.1. Environmental policies before China's 1979 economic reform a brief history[2]

For many years before China's reform of the economic system in 1979, pollution was a so-called nonissue in China [5]. For example, only a few regulatory standards (largely oriented to occupational health) based on Soviet practice were promulgated in 1956 and revised in 1962 but were almost ineffective [6]. For almost two decades (1950s and 1960s), China's economic sector paid very little attention to pollution control because it was neither included in enterprise norms and received state investment funds, nor did it receive public concerns [5].

[1]The World Health Organization (WHO) recommended annual PM2.5 level is 10 μg/m^3.
[2]Historical issues in this section were heavily informed by [5].

China's lack of pollution control, both ideologically and practically, both by governmental actions and by general public demand, was because of several reasons: first, during that period China placed the policy priority exclusively on economic development, particularly the development of heavy industries, so as to fulfill rapid industrialization in this country; second, China's political isolation from the western world made this nation slow in understanding and participating in the world's increasing concerns about pollution in 1960s, which was even aggravated by the anti-intellectual ferment of the Cultural Revolution from 1966 through 1976 [5]; third, because of the poor income levels and living conditions in general, Chinese people were the most concerned with basic life demands such as food and clothes, and therefore little heed had been taken of environmental issues. However, the development of heavy industries in this period and the ubiquitous use of "dirt" technologies as well as abuse of natural resources, along with the expansion of population had gradually caused severe threats to China's environment as well as natural resources.

The United Nations Conference on the Human Environment, held in Stockholm, Swedish in 1972 motivated China to address the increasingly serious environmental problems in this country, and significantly improved China's understanding of this issue. A conference on stack dust removal was held in Shanghai in 1972 that led to a pilot emission control project in Shenyang, one of China's most air-polluted cities located in Eastern-north part [5]. Perhaps this was China's first formal air pollution control project.

In 1973, the State Planning Commission convened a national conference on environmental protection. The conference led to China's first State Council Directive on environmental protection, named "Some Regulations on Protecting and Improving the Environment," which signified the beginning of official environmental protection work in China, and included some industrial emissions standards for air pollutants such as particles. It covered only power plants, boilers, steel-smelting furnaces, and cement plants, which were arguably the most significant point sources in urban areas [4]. When China first began to develop regulations for air pollution control in late 1970s, China did not adopt the technology-standard approach that was then popular in the USA and some other OECD countries [4]. The main guideline of the Directive was to incorporate environmental considerations into planning while not retarding economic development [5]. The idea of pollution control, however, was not clearly indicated in the document. Following the conference, China began to establish a bureaucratic structure to deal with environmental problems: in October 1974, a leading group for environmental protection under the State Council was set up with a small staff of 20, and following that, similar units were also formed at the provincial level in many parts of China.

McElroy argued that the US air pollution legislation had a problem-trailing character because it addressed only problems that were already apparent, many of them unanticipated when the responsible technologies were first introduced [7]. In this regard, China was without exception, or even in a worse situation than the USA. Over the history, China's environmental decision-making seemed to mainly pay attention to environmental damages when the problems were already fairly obvious, risking serious long-term environmental and resource destruction, which can be very expensive to cure later.

2.2. China's major air quality regulations during 1980s and 1990s

As discussed in previous section, before the 1978 political and economic reform, China's environmental governance had been relatively inert, and compared with the western countries such as the USA, who began to nationalize pollution control soon after the publication of Rachel Carson's influential book *Silent Spring*, the government responded to accumulating environmental issues more than one decades behind. Once the Chinese government began to respond, how effective it has been to improve environmental quality and protect natural resource? It seems that it had not been fairly effective during the decades of 1980s and 1990s, at least in terms of stopping the deterioration of environmental quality. With regard to air quality, no significant improvement was observed in major air-polluted cities. For instance, the annual mean concentrations of TSP and SO_2 for five large Chinese cities (Beijing, Shenyang, Xi'an, Shanghai, and Guanzhou) during 11 years (1981–1991) did not change apparently and continuously violated the WHO recommending limit to a large extent [8]. Deng Xiaoping's political and economic reform in 1979 is a turning point for China's environmental protection. As China was infused with the idea of sustainable development, and more importantly, as the government became increasingly concerned with and better understanding the environmental destruction resulting from economic development during 1970s, they started issuing measures of pollution control and natural resources protection.

A salient characteristic of China's air pollution issue is that, like many developing countries, the early stages of industrial growth were pursued without much investment in environmental protection, leading to heavy air pollution in urban areas [4]. Brandon and Ramankutty called it "grow first, clean up later" environmental strategies and argued that they had resulted in serious environmental problems such as exceedingly polluted air [9]. The essential problem is, arguably, that a fairly significant gap has existed between the goals embodied in China's environmental laws and regulations and actual levels of environmental quality [10].

2.2.1. China's air pollution regulation: an overview

Since the government began responding to environmental issues at the national level in late 1970s, they became increasingly active in promulgating environmental laws and issuing legally binding administrative regulations, as well as organizing regulatory agencies at different levels of governments. Two types of environmental statutes exist in China: a "basic law," namely, *People's Republic of China National Environmental Law*, and specific environmental laws to direct particular issues such as air pollution, water pollution, natural resources and ecosystem protection, and so forth [10]. With regard to air pollution, the special environmental law is *People's Republic of China Air Pollution Prevention and Control Law*, which was first enacted in 1987, and then was subsequently revised twice in 1995 and 2000, respectively, and most recently in 2015 in response to the urgent air pollution in China.[3] Besides laws, regulations on air pollution include the National Ambient Air Quality Standards (NAAQSs) and various

[3]Source: The website of the National People's Congress of the People's Republic of China, http://www.npc.gov.cn/npc/xinwen/2015-08/31/content_1945589.htm. Accessed December 1, 2017.

emission standards targeting industrial facilities (particularly coal-fired power plants) and motor vehicles (refer to **Table A1** in the Appendix).

Despite of about 30 environmental laws and hundreds of regulations, standards and programs and agencies that provide a foundation for curtailing further degradation, it seems that China's environmental quality has not been considerably improved for decades. Scholars have argued that a significant gap exists between the goals embodied in China's environmental laws and regulations and their actual effects [10, 11]. In the succeeding section, this problem will be discussed by investigating the design, implementation and effectiveness of China's pollution levy system, one of the major national programs targeting industrial emissions.

2.2.2. China's pollution levy system

First promulgated in 1979, China's Environmental Protection Law established national and local Environmental Protection Bureaus (EPB),[4] required polluters to comply with waste discharge standards, and directed enterprises to assess environmental impacts of proposed projects and ensured that new projects satisfied applicable environmental standards [10]. For the first time, it formally stipulated the polluter pays principle and based upon this, authorized the creation of a pollution levy system to assess fees on all enterprises for pollution emissions that exceed standards, and it also required that new facilities demonstrate design compliance with emissions standards as a condition of obtaining a construction permit [12].

2.2.2.1. The development of the pollution levy system[5] and monitoring network

Preliminary discussion of a possible pollution charge system (pollutant discharge fees) began in China after the Stockholm Human Environment Conference in 1972. The idea was formally adopted by the central government in 1978, when the Leaders Group for Environmental Protection in the State Council provided a work report to the Central Committee of the Chinese Communist Party. The report stated "Pollution source control should be an important component of environmental management; fees should be charged against pollution discharge; and environmental protection authorities, in cooperation with other departments, should set up a detailed levy schedule." Several local governments immediately began experimenting with charges, and by the end of 1981, 27 of China's 29 provinces, autonomous regions and municipalities had established programs of some type. After studying these local experiences, the central government issued an "Interim Procedure on Pollution Charges" in February, 1982. The procedure defined the system's objectives, principles, levy standards, levy collection methods, and principles for fund use. Under the pollution levy system, enterprises must pay fees for releases on air-borne and water-borne pollutants that violate standards on emissions and effluents, and typically, fees are based on the pollution indicator that exceeds the discharge standard by the greatest amount [10].

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[4]Environmental Protection Bureaus (EPB) is China's main government agency created under China's basic environmental law in charge of environmental protection tasks. All levels of governments (e.g. central, provincial, municipal, and county) have their own EPB as one of the government agencies.

[5]Unless noted, information on China's pollution levy system development in the succeeding paragraph was cited from [13].

Monitoring compliance is a key step of implementing pollution levy system. To what extent industrial firms obey the rules heavily depends on their beliefs in how likely their emission activities would be monitored and discovered. Article 23 of People's Republic of China Air Pollution Prevention and Control Law authorizes the state and local environmental agencies to design standard monitoring methods and direct to set up environmental monitoring networks and release the information on air quality to the public.[6] Based on this, the EPBs at all levels organize their affiliates of local environmental monitoring stations. Monitoring stations are responsible for checking up on polluters' activities, and EPBs are authorized to penalize enterprises that fail to meet emission standards [10]. To determine the actual pollution levels, on the one hand, enterprises are often required to monitor their waste releases (a process called "self-monitoring"), and to report results to environmental agencies ("self-reporting"), and on the other hand, state and local EPBs conduct periodic facility inspections to gauge the reliability of self-reported data [10]. Specifically, staffs of the environmental monitoring station regularly collect samples outside a facility, analyzes the samples, and submits results to the environmental inspection station, which are another affiliate of a local EPB [10]. The inspection station then determines the total pollution charges and report to their affiliated local EPBs. Ma and Ortolano argued that the Chinese system for self-monitoring differs from the one in the USA in that US permit holders that falsify data are subject to severe penalties under both civil and criminal law [10]. However in China, there were many cases that the self-reported data were not reliable. Therefore, regulators often rely on their own monitoring information to determine the levies.

After a few years' discussion, preparation, and experimenting, nationwide implementation of the pollution levy system rapidly followed in 1982, which has turned out to be one of the Chinese government's major responses to the deteriorating environmental problems since 1980s. During the 1980s and 1990s, almost all of China's counties and cities have implemented the levy system. As a national environmental regulatory program, the pollution levy system was originally created both to penalize industrial polluters who exceed emission standards and to fund local environment bureaus [4].

China's environmental regulation in the 1980s and 1990s was largely a "direct regulation" or "command-and-control" system: the required behavior of enterprises was spelled out and sanctions were imposed if requirements were violated [4]. Although the pollution levy system can be considered as a market-like policy instrument, it still heavily relied on government regulations [14]. The levy system is based on a discharge standard system, and only discharges exceeding the standards are subject to a fee. However, management options look good on paper may fail in reality. In China's pollution control practice, regulatory behaviors were confronted with resource obstacles, institutional conflicts as well as budget limits, which were not anticipated while designing policies. In the next section, some specific issues in the implementation of China's pollution levy system will be reviewed and critically analyzed.

[6]Source: The website of the National People's Congress of the People's Republic of China, http://www.npc.gov.cn/npc/xinwen/2015-08/31/content_1945589.htm. Accessed December 1, 2017.

2.2.2.2. Conflicts between economic and environmental goals

Andrews argued that the creation of environmental policy often involves conflicts among exclusive preferences, and "such conflicts are far less amenable to political compromise or compensation than other policy issues" [15]. As China is in the stage of rapid industrialization, the conflicts between economic development and environmental protection often become salient, whereas it seems that environmental policy design has not adequately considered these inherent conflicts. Case studies in [10] indicated that typically the Mayor's Offices in China try to balance their obligations for both economic development and environmental protection, and they usually favors industrial growth over pollution abatement when both goals conflict, although China's fundamental environmental protection law explicitly stipulates that governments at all levels (national, provincial, municipal, county, etc.) are responsible for environmental protection within their jurisdictions. Their case studies found that work can be intervened by upper level government or other government agencies. For instance, mayor's offices asked local EPBs to approve a new project even though it failed to satisfy environmental regulations, or forced EPBs not to enforce any penalties when environmental regulations were violated. An example that higher level governments were involved in the enforcement of pollution levy is: the mayor's office forced the local EPB to return the pollutant discharge fees that they had collected from a noncompliant plant because the office argued that the facility had financial problems and the penalty fees had made its economic position even worse. Eventually the local EPB had to return the fees. As a result, the polluting facility was implicitly allowed to continue with their emissions that violated the standard. In some other cases, for the purpose of their own prestige, the government leaders just offset the EPB's penalty on an industrial enterprise by giving the enterprise a tax break proportioned to the size of the fee. Ma and Ortolano concluded from their extensive case studies in China that "the instances in which a mayor's office interfered with an EPB's work are common" [10]. This kind of "government failure" phenomena happened for two main reasons: first, China's post-1978 decentralization policies gave local officials strong financial incentives to expand their economies—as a consequence of decentralization, much municipal government revenue comes from enterprises in the form of taxes, and thus often favor industrial development over pollution control [10]; second, apart from producing revenue, for a long time in China, creation of jobs (lower unemployment rate), income of residents as well as other economic indexes have been the indicators of government accomplishment. Consequently, government leaders have strong incentives to improve these evidence in order to have more reputation, perhaps seeking for promotions. To tackle this problem, Jahiel argued that China would have to "significantly weaken the regional economic interests that make environmental inter-jurisdictional co-ordination so complex and contentious" [16]; third, China's environmental protection apparatus (such as EPBs) had suffered from insufficient authority and lack of co-ordination between institutional actors [16]. In the government administrative hierarchy, EPBs stay at the same level as other agencies such as economic commission, planning commission, industrial bureaus, etc., but they are all at a lower level than central leaders such as Mayor's Office of a city. In most cases, local EPBs (at provincial, city, or county levels) do not have sufficient authority or independent roles for environmental regulation; fourth, because China's environmental laws are general and often intentionally ambiguous, they allow the State Council, national agencies, and local governments to add details that influence implementation [10]. Most day-to-day implementation of a national environmental law occurs at the local level [10]. Typically, local governments respond to national edicts by producing their own versions of national regulations, notices, etc.; and due to the ambiguity of the national laws, local government has a big opportunity to design local environmental regulations to their own interests whereas not visibly inconsistent with national legal enactments [10]. All these lingering problems seem to facilitate government's self-interests against environmental goals, particularly at local levels. As the highest administrative government official has enormous incentives to promote local economic development, and they have more powerful jurisdiction than environmental protection apparatus, it is very likely that they would intervene local EPBs' work when preference conflicts are involved in decision-making process [10]. Andrews discussed this kind of "intrinsic hazards of governance processes" as "government decisions are routinely designed to promote the short-term self-interests of public officials, perhaps at the price of long-run environmental damage," and "governments tend to externalize the environmental costs of their decisions" [15]. Not surprisingly, these shortcomings of government behaviors are responsible for China's environmental deterioration in the past despite of the extensive efforts to address the issues.

2.2.2.3. Revenue-driven environmental regulators

Not only the governmental agencies other than environmental regulators can unfavorably affect the implementation of policies targeting pollution control, but also the environmental regulators (in most cases local EPBs) themselves would favor some other preferences over environmental goals. In practice, this damages the effectiveness of environmental policies. EPBs may act as self-interested politicians whose decisions can lead to environmental costs to the society. With regard to China's national pollution levy program, examples include that the regulators simply collect fees to maximize their own revenues, irrespective of the ultimate purpose of pollution abatement; they may act inconsistently with the laws, or strategically to their own preferences. Public choice theory argues that politicians, just like people who act in the free market, are motivated by self-interest. Using public choice theory, Schneider and Volkert argued that an incentive-oriented environmental policy has hardly any chance of being implemented, and pure environmental interest groups are difficult to organize [17].

Under China's pollution levy system, local EPBs are supposed to respond to violations of environmental rules through several enforcement options including issuing warnings, imposing fees, revoking emission permits (which are issued to each industrial facilities under the pollution levy system), and gaining court assistance to collect fees, in the order from the least to the most severe degrees in terms of EPBs' enforcement actions [10]. Although as mentioned before, the primary purpose of pollution levy is to provide incentives to industrial pollutants to mitigate their emissions, and a supplementary intension is to fund local environment bureaus. However, in many cases, the latter has become regulators' essential goal. Ma and Ortolano, through their case studies in six large industrial cities, concluded that what EPB actually did were often different from what they were authorized to do [10]. For instance, in some cases they imposed heavy penalties, and in others they helped enterprises resolve their noncompliance problems and imposed no sanctions at all, and usually the decisions were made for their own benefits. Examples include calculating the pollution discharge fees not based on what is set by laws, but on the criteria to maximize their own revenues. Not surprisingly, due to regulators' rent-seeking behaviors, the pollution levy system works less effective than expected in terms of emission control.

The transit from planned to market economy had substantial influence on China's air quality, and policy designs and implementation to control air pollution as well. One issue of concern has been the impacts of China's state-owned enterprise (SOEs) on the environment upon their changes resulting from China's economic reform. For instance, upon the reform, SOEs had become increasingly depended on bank loans and retained profits to finance investment other than on government funds as previous [10]. It resulted in disincentives for SOEs to invest on environmental projects, since these projects had to compete for capital against factory renovation and expansion projects [10]. Furthermore, since late 1980s, the fraction of SOEs incurring net losses had increased rapidly: For example, the percentages of industrial SOEs losing money rose from 13% in 1986 to 44% in 1995 [18]. Money-losing SOEs pose serious environmental concerns. Local EPBs tended to avoid requiring these enterprises to satisfy environmental requirements because the money to pay for environmental facilities would generally have to come from the state. Moreover, local government leaders would be unlikely to support an EPB that imposed demand on a money-losing SOE supporting large numbers of workers or retirees [10].

However, on the other hand, China's rapid economic growth, particularly since 1990s, also has positive impacts on air quality. Although economic growth has increased the variety and magnitude of emission-generating activities, which result in more emissions, it also generates the wealth needed to build a stronger infrastructure for environmental management of industry [4]. Likewise, in the household sector, economic growth has helped households move up the energy ladder, replacing dirty fuels with cleaner ones [4]. With respect to SOEs, the bankruptcies and mergers resulting from the on-going program of SOE reform since 1990s have shut down many old industrial facilities that were large, inefficient consumers of energy (mainly coal, China's most important fuel) [19], which implies a significant contribution to the decrease of emissions from these sections [4].

In the preceding discussion, several factors were examined that have resulted in significant gap between the goals and effects of China's pollution levy system. While they are still far away from indicating all the reasons attributable to ineffectiveness of the system, they do shed light on some government failure problems and institutional barriers common in China's environmental regulation during the decades of 1980s and 1990s. Jin et al. summarized four major limitations of air pollution control policies during that early time period as follows: (1) the general absence of environmental rights and interests; (2) lack of regional co-ordination in air quality management; (3) lack of monitoring capacity; and (4) weak laws and regulations [11].

2.3. New air pollution concerns and some major changes in control policies since 2000s

2.3.1. A brief overview of the air quality trend in China's major cities over the past two decades

Since the 1990s, China has seen some improvement in ambient air quality in major cities, particularly the levels of SO_2. **Figure 1**, adopted from [11], summarizes the annual average levels of SO_2, PM_{10}, and NO_2 in China's seven megacities between 1996 and 2014. Although the levels of SO_2 have been improved, the concentrations of two air pollutants of the greatest health impacts, that is, $PM_{2.5}$ [20] and ground-level ozone [21], have been worsened in recent years.

2.3.2. Some major changes in control policies since 2000s[7]

This section briefly summarizes some major changes in China's air pollution control policies since the beginning of the twenty-first century.

1. Air pollution regulation executed more stringent emission standards for coal-fired boilers and power plants, and motor vehicles, and the NAAQSs (**Table A1** in the Appendix). The emission and air quality standards in China were initially established early between 1980s and 1990s, and since then has been significantly revised several times and tightened over time, particularly after the "$PM_{2.5}$ crisis" that happened between 2012 and 2013 [11]. These standards are generally in line with international ones, and some of them (for instance, emission standards for power plants) are even more stringent than those used by western developed countries such as the USA [11]. Example of specific policy measures include use of low-sulfur and low-ash coal or more advanced pollution control equipment, installation of central heating to replace individual coal boilers, banning the use of coal stoves for cooking in urban areas, shutdown or relocation of coal-fired power plants in urban areas, restricting vehicle purchase and use, enhancing public transportation system, and regulating dust from construction sites.

2. Mass-based emission control took the place of concentration-based control. Concentration-based emissions standards have the disadvantage that emission standards can be met by diluting the waste gas stream with air, rather than by reducing the mass of pollutant discharged [4]. During 2006–2012, China implemented the "total emission control on SO_2" and an "energy saving" policy: A 10% reduction in SO_2 and a 20% reduction in energy consumption per unit of GDP from the 2005 levels were set as the national targets [11]. These targets were decomposed among provinces and local governments were required to fulfill the "assigned" target. The 10% SO_2 reduction goal was achieved [11].

3. Stronger political will to prevent pollution, instead of generating pollution and then treating it. Based upon previous experiences and research, the central government has realized that the costs to the entire society could be much higher to use the so-called end-of-pipe strategy than to prevent emissions. The 2014 government work report stated that "China shall punch hard to strengthen the prevention and control of pollution, and resolutely declare war against pollution" [11].

4. Market-based instruments started to be utilized in air pollution control. Market-based environmental policies are generally considered by economists to have the advantages over traditional command-and-control approaches in terms of cost-effectiveness and dynamic incentives for technology innovation and diffusion [22]. In early 2000s, China learned market-based tools for air quality regulation from western developed countries, and began to

[7]This section was heavily informed by [11].

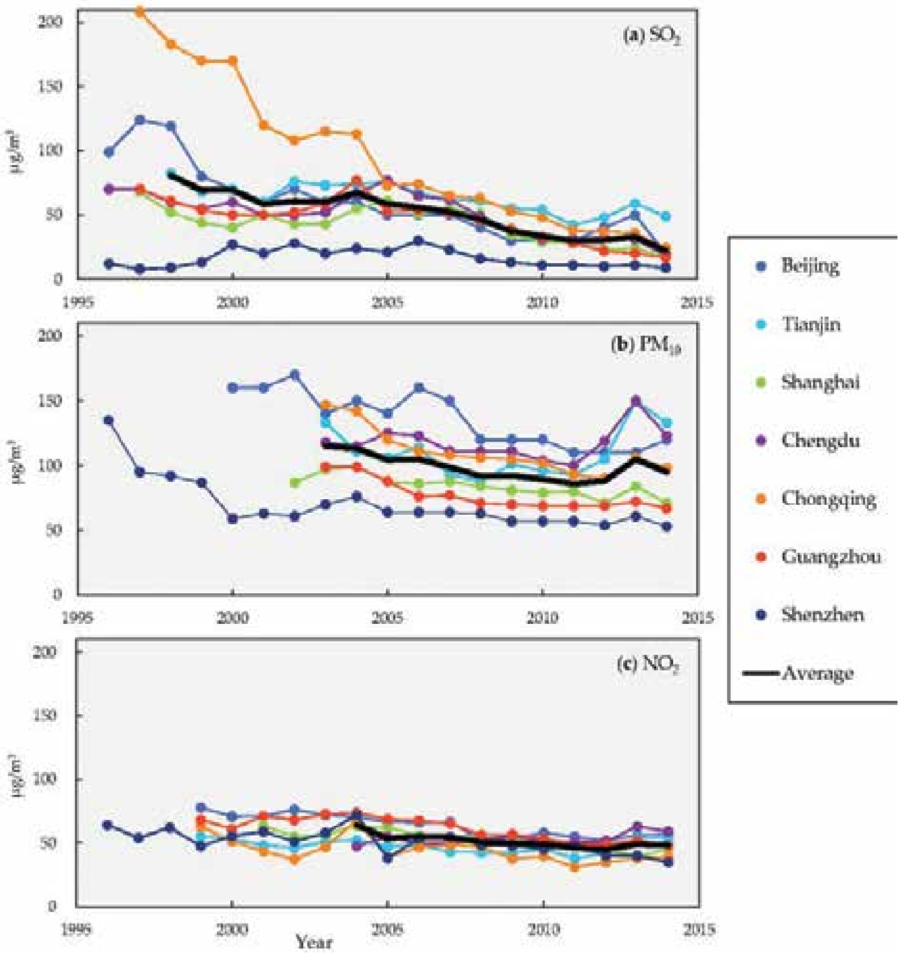

Figure 1. Trends of SO_2 (a); PM_{10} (b), and NO_2 (c) annual concentrations of seven China megacities in 1996–2014 (adopted from [11]).

experiment and demonstrate these policy tools through pilot projects. Examples include tradable pollutant permits that are currently being tested in pilot provinces and cities [11]. Florig et al. argued that some of China's emission standards do not consider source-to-source variations in the unit costs of emission abatement, and thus impose higher compliance costs on some polluters than others for the same amount of abatement [4]. Therefore, emission trading program seems to be promising in terms of reducing abatement costs. Experiences in the USA illustrate that the emissions trading program, which created a nationwide market for emissions reductions, has resulted in greater reductions in SO_2 emissions at much lower cost than would have been required under the technology-based approach of the past [23]. However, due to China's distinct political and institutional system, and immature development of market economy, as well as a strong tradition of command-and-control environmental regulation, the success of emissions trading system requires new administrative departments to be set up and the actual effect is still rather uncertain [11]. Beside the trading program, a carbon tax policy is under consideration by the government.

5. Increasing public participation and civil society's role in combating air pollution. Chinese citizens, particularly urban residence demand better air quality as the income increase and living standard improvement [11]. Real-time air quality monitoring data have become more available to the general public, particularly in the most polluted megacities. Some data on emission sources and penalties on polluters have also been disclosed to the public [11].

Despite of the major reforms of regulations, air quality improvements remain insignificant in most cases. Jin et al. discussed some reasons for policy ineffectiveness: emission data reported by local government were unreliable; failure of inter-regional cooperation in abatement efforts (regional transboundary pollution issue); "campaign style" regulations that temporarily occur during some major international events such as the 2008 Olympics in Beijing—the effects of those temporary regulations diminished after the event; lastly, some argued that the current total control measures should be completely revoked [11].

2.3.3. Changes in energy system in response to air pollution

Coal is the primary energy source in China due to it abundance and has been the largest contributor to air pollution in China's history. Over the past three decades, coal has been accounted for approximately two-thirds of China's primary energy consumption [24]. In contrast, in the US coal accounts for less than 20% of the nation's energy production[8]. Despite the decrease in the percentage share of coal in China's total energy consumption since the 1950s, the total consumption of coal has been rising dramatically due to the soaring demands [25]. For instance, the total consumption was 1.5 billion tons in 2000 and rose to 3.8 billion tons in 2011[9]. Natural gas consumption generates much less pollution than coal and thus it is often regarded as a cleaner energy [24]. Natural gas currently accounts for about 6% of China's primary energy supply, which is considerably lower than the global average of 24% [24]. In response to the severe ambient air pollution problem, the Chinese government has listed the switch from coal to gas as a key part of China's sustainable energy system transformation strategy [24]. The switch from coal to natural gas in power plants, particularly over winter as part of the efforts to cut concentrations of $PM_{2.5}$ that causes smog, was first implemented in the capital city Beijing, and quickly adopted by other provinces [11]. However, many provinces suspected or canceled the "coal to gas" initiative soon mainly due to natural gas shortages and soaring heating cost in China [11]. For instance, in early December 2017, the Beijing city government ordered an immediate restart to coal-fueled generators to ease the shortage of natural gas in northern China, which had caused numerous freezing homes and schools[10]. Despite the challenges facing China, it is

[8]Data in 2016. Sources: U.S. Energy Information Administration, https://www.eia.gov/energyexplained/?page=us_energy_home. Accessed January 23, 2018.
[9]Data source: U.S. Energy Information Administration, https://www.eia.gov/todayinenergy/detail.php?id=9751. Accessed January 23, 2018.
[10]Source: China Daily Online, http://en.people.cn/n3/2017/1211/c90000-9302785.html. Accessed January 23, 2018.

expected that China's move away from coal to cleaner energy sources will happen quickly in the near future. In December 2017, China released the nation's five-year plan (2017–2021) to convert northern Chinese cities to clean heating during the winter [26]. The plan sets the goal of converting half of northern China to clean heating (mainly natural gas and electricity heating) and reducing coal burning by 74 million tons by 2019 [26]. By the end of the five-year period in 2021, the goal is to achieve 70% cleaning heating and reduce coal burning by 150 million tons [26]. Overall, as part of China's national strategies to control the impacts of energy system on air quality, a national campaign to replace traditional, dirty coal with cleaner energy sources is under way, but it is likely to encounter many challenges. The government needs to develop strategies to ensure energy supply without boosting prices and hurting the economy.

3. Comparing air pollution control policies in China and in the USA[11]

China, in particular in the past two decades, learned a lot of policy tools from western industrialized countries such as the USA, which are considered to be more advanced in policy designs and implementations, and which in general has a much better air quality thus implying more successful in curbing air pollution. However, as mentioned before, policies work well in developed countries may fail in a developing country such as China, due to the differences of political and institutional systems, situations of economic development as well as many other social and cultural factors. Compared to the USA, China has a much more concentrated population, resulting in a much greater demand for energy consumption to survive its residents, which perhaps makes the air quality regulation issue even more complicated.

3.1. Centralization and decentralization of air pollution regulation

Regarding the historical path, China responded to air pollution almost a decade behind the USA. For instance, as mentioned in the previous section, China's first formal air pollution control project was initiated after a conference on stack dust removal held in 1972, whereas the very first air pollution statutes in the USA, designed to control smoke and soot from furnaces and locomotives, were passed by the cities of Chicago and Cincinnati in 1881 [23]. This is not surprising due to China's slowness in industrialization (started in 1950s but only began to develop rapidly after the 1979's economic reform) compared to the USA's early industrial revolution. One significant difference between China and the USA with regard to the features of the evolution of environmental governance particularly the air and water pollution issues perhaps is, that they followed an opposite path on the centralization and decentralization of pollution control. In the USA, the states, cities, and countries' governments first reacted to pollution problems by enacting their own ordinances targeting pollution control. Examples include the first air pollution statutes by Chicago

[11]The information about the US draws heavily on [23].

and Cincinnati governments and increasingly air pollution laws by other states, cities, and counties. By 1980, there were already 50 state, 81 municipal, and 142 county air pollution control jurisdictions with statutes in the USA [23]. The US federal government entered the control efforts for the first time with the passage of the Air Pollution Control Act in 1955 [23]. Until the 1970, the federal role in environmental protection had been greatly enlarged, indicated by federal minimum standards and regulations as primary policy tools [15]. In China, on the contrary, the central government first responded to the issue by promulgating national level environmental laws, regulations, and programs, and then instructing the local government (province, municipal, county, etc.) to be responsible for the implementation of them, or to outline their own measures in response to the regulations. This difference between China and the USA is heavily rooted in the USA's federalism political system and China's traditional centralized governmental system. While the decentralized regulations may involve problems such as conflicts, debates, negotiations between federal and local government, China's major problem in the past seemed to be the compliance by local regulators to the national statutes. In very recent years, following China's political reform, which is characterized by the trend of governance system decentralization in particular regarding economic development issue, the environmental governance has also indicated some evidence of decentralized regulations. This trend is expected to gradually become more apparent, but the change may be slow.

3.2. Some features of the basic air pollution control law

Regarding the national air pollution control law (For China, Air Pollution Prevention and Control Law and for the USA, the Clean Air Act first passed in 1963 and followed by the 1970 amendments), there are a couple of similarities. For example, both laws provides support from central government for air pollution research, and for the development of local pollution control agencies; both laws' initial focus was industrial and residential sources of air pollution, and later the regulation of emissions from mobile sources was added together with vehicle emissions standards, when the problem became more apparent (an exception in the USA was the state of California, who took on the air quality problems associated with motor vehicle exhausts when it first passed its air pollution ordinances [23]). Technological innovations and the adoption of "best available technology" are strongly encouraged in under both laws. Both countries' laws execute so-called new source performance standards, that is, newly constructed (or substantially modified) plants are subject to stricter emissions standards than currently existing factories. In the USA, "federal controls on new sources, but state controls on existing sources" [23]. On the other hand, Florig et al. argued that China's grandfather rules (similar to the USA policy toward existing factories) may have the unintended consequence of extending the time that older facilities are kept in service, to avoid having to incur the additional operating costs or pollution levy fees associated with a new replacement facility with more stringent emissions requirements, and the more stringent emissions requirements for use of more advanced pollution control technologies provides a disincentive to adopt these measures [4]. One distinct feature of the US law that is not seen in China's law is that the US Clean Air Act addressed the federal government's assistance to the states when cross-boundary air pollution problems arose [23]. Although China's national control law is silent about cross-boundary air pollution issue, this problem might still rise in practice, because despite of China's strong tradition of "centralized regulation," the actual day-to-day implementations of laws are authorized to local governments.

3.3. National ambient air quality standards and emission performance standards

Both China and the USA have national level ambient air quality standards. **Tables A1** and **A2** in the Appendix list both countries' NAAQSs. **Tables A1** and **A2** illustrate that both countries focus on the six common (or criteria) air pollutants in regulation. While the USA has been using primary standards for human health and secondary standards for the environment (primary and secondary standards are the same in most cases except for SO_2 and the annual standard for $PM_{2.5}$), historically China had been using three categories of standards that applied to different types of land. The latest one (GB3095–2012, see **Table A1**) revoked the Grade III standard. Although the complexity of China's NAAQSs allowed more flexibility in regulation based on the demand for air quality or variations of costs to control at different types of regions, it may involve more debates, dispute, negotiations, or even conflicts in determining which standard to apply, resulting in more difficulties in regulations. Comparably, the US 1977 amendments also established three classes of "already clean" areas: in Class I areas (which include national parks, forests, and wilderness areas, and other areas that states elect to include), very little additional deterioration in air quality is permitted, even if current concentrations are far below the NAAQSs; somewhat more pollution is permitted in Class II areas (which make up most of the remaining clean air regions); in Class III areas, air quality is permitted to deteriorate up to but not beyond the level of the NAAQSs [23]. Generally, China's Grade II standards (which applies to regular living areas) is comparable to the USA's primary standards. Taking $PM_{2.5}$ as an example, China recently started the nation's $PM_{2.5}$ standard in 2016. China's Grade II $PM_{2.5}$ annual average standard is 35 $\mu g/m^3$, which is less stringent than the USA primary standard of 15 $\mu g/m^3$. At present, it may not be economically and politically feasible for China to adopt the standards as stringent as those used in the USA, due to the possible high costs resulting from emission reduction. Nevertheless, a ubiquitous problem in China is nonattainment. For example, a review of $PM_{2.5}$ concentration in major Chinese cities during 2005–2016 reported that nearly 90% of the pollution levels exceeded the annual limit of 35 $\mu g/m^3$ [20].

4. Conclusion remarks

Due to the severity of China's air pollution issue, the nation's economic growth may have been offset by the economic loss due to adverse health impacts and environment damages attributable to air pollution. As stated in Rock "the human health costs of environmental degradation and growing spontaneous public pressure have made it increasingly difficult for all levels of Chinese government to ignore the environmental degradation attending high-speed urban-industrial growth" [24]. The government is currently confronted with an onerous challenge to better design and implement policies to clean the ambient environment.

This chapter reviews the development of air quality policies since 1950s in China's political and economic development context, focusing on the period since China's reform of the economic system in 1979. Over time, environmental policy designs and implementations were rooted in China's broad institutional development, agenda settings and policy processes, and today's policies have been strongly shaped or influenced by past policies. It was found that both China's central government and the local EPBs had a strong will to clean the environment and had been seriously addressing this issue since the initiation of China's national environmental regulation in late 1970s. However, they had experienced great difficulty in enforcing emissions standards not only on individual pollutants, but also on the industrial bureaus that control them, and the economic commissions and mayors that depend on them to deliver income and employment [27]. As the daunting result, there had been a huge gap between the set goals and the actual outcomes. With regard to environmental governance, Rock argued "the focus in China is how a nascent environmental agency learned how to take advantage of the rules of economic governance to influence powerful economic actors" [24]. As for policy design and implementation, China has to significantly strengthen government's interests at all levels in environmental objectives.

Since China still needs to substantially balance the costs of pollution reduction, market-based policies seem to be very promising as China's market economy becomes more mature. While market-based policy instruments such as the cap-and-trade system have been arguably successful in the USA in term of emission reduction and cost-effectiveness, their actual effects in China are still uncertain. China should definitely learn the experience established in developed nations, but may not simply follow their practice. The uniqueness and distinctiveness of China's political and institutional characteristics requires it to be very prudent when referring to policies developed in other countries.

A common problem in China's past environmental policy designs is, arguably, policy and regulations may be not politically or economically feasible or enforceable, and the goals are sometimes unrealistic. China's future environmental policy designs should systematically and thoroughly evaluate the feasibility through comprehensive policy analyses, and address the effectiveness issue, and dynamically adjust policies based on evaluation of past effects and problems.

By and large, China, in the stage of rapid industrialization and urbanization, is now facing an arduous challenge to tackle its air pollution problem: For instance, requiring the use of "clean" energy would result in a fundamental change in China's energy consumption structure, whereas China's energy shortage problem, particularly shortages of cleaner fuels such as natural gas, is still a substantial issue; emission control of transportation system may dauntingly conflict with the rapidly increasing demand for automobiles; and changes in urban infrastructure for better emission control would impose an enormous costs on cities. However, huge health and environmental damage attributable to air pollution has made regulation targeting pollution abatement imperative. Therefore, China has to seriously balance its interests on economic growth with the risk of inexorable increase in the damage to human health and environment in the development of future economic and energy policies. Revolutionary change is very likely and air quality management based on health risk is primary direction [11]. In this regard, the government is incumbent on developing a wiser course that protects the environment in order to improve the welfare of its citizens and ensure a sustainable development.

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A. Appendix

See **Tables A1** and **A2.**

Year	**No. of standard**	**Grade**[2]	**SO_2**	**TSP**	**NO_2**	**CO**[3]	**O_3**[4]	**PM_{10}**	**$PM_{2.5}$**[5]
1982	GB3095–82	I	50	150	50	100	120	50	—
		II	150	300	100	100	160	150	—
		III	250	500	150	200	200	250	—
1996	GB3095–1996	I	20	80	40	100	120	40	—
		II	60	200	40	100	160	100	—
		III	100	300	80	200	200	150	—
2000	Amended GB3095–1996	I	20	80	40	100	160	40	—
		II	60	200	80	100	200	100	—
		III	100	300	80	200	200	150	—
2016	GB3095–2012	I	20	80	40	100	160	40	15
		II	60	200	40	100	200	70	35

[1]Unless specified, all standards are in the unit of $\mu g/m^3$, 24-h average.
[2]Grade I standard applies to places like national park or forests, where stricter requirements for air quality are needed; Grade II applies to usual urban industrial, residential and commercial areas and rural areas; Grade III applies to heavy or special industrial areas.
[3]CO: mg/m^3, 1 h average.
[4]O_3: $\mu g/m^3$, 1 h average.
[5]$PM_{2.5}$: $\mu g/m^3$, annual average.

Table A1. National Ambient Air Quality Standards[1] (NAAQSs) table, China (adopted from Jin et al. [11]).

Pollutant	Primary standards	Averaging times	Secondary standards
Carbon monoxide (CO)	9 ppm	8 h	None
	35 ppm	1 h	None
Lead (Pb)	0.15 μg/m^3	Rolling 3 month average	Same as primary
Nitrogen dioxide (NO_2)	100 ppb	1 h	None
	53 ppb	1 year	Same as Primary
Ozone (O_3)	0.070 ppm	8 h	Same as Primary
Particulate matter ($PM_{2.5}$)	12.0 μg/m^3	1 year	15.0 μg/m^3
	35 μg/m^3	24 h	Same as primary
Particulate matter (PM_{10})	150 μg/m^3	24-h	Same as primary
Sulfur dioxide (SO_2)	75 ppb	1 h	
		3 h	0.5 ppm

*Source: the USEPA official website: https://www.epa.gov/criteria-air-pollutants/naaqs-table, [Accessed December 8, 2017].
Note: *Primary standards* set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. *Secondary standards* set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings.

Table A2. National Ambient Air Quality Standards (NAAQSs) table, United States*.

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Chapter 2

Historical Drivers of Energy Infrastructure Change in Nigeria (1800–2015)

Norbert Edomah

Additional information is available at the end of the chapter

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Abstract

This chapter, building on a previously published paper, presents the key historical drivers of energy infrastructure change in Nigeria. The study revealed five main drivers that impacted on the Nigerian energy transitions which are: (a) Policy and institutional interventions on energy; (b) Technological interventions and energy technology pathways; (c) Social (societal) practices and public values for energy; (d) Available energy resource options; and (e) Economic considerations. Based on these drivers, four important influences that impacted on energy systems choices and the kind of energy infrastructure Nigeria ended up with were also discussed. These influences are: (a) Politics and energy governance structures; (b) Technological changes; (c) Energy resources (and the quantity of available reserves); (d) The geographies of energy. It concludes by highlighting some of the implications of these influences on the future of energy in Nigeria.

Keywords: energy transitions, energy future, energy sector, energy governance, electricity regulation

1. Introduction

Energy transitions entail a shift, or movement, in decreasing the use of fossil fuel in our energy supply systems [1]. Across the world, fossil fuels, such as coal, crude oil and natural gas, accounts for a large percentage of our energy supplies. There has been growing interest in energy transitions because beyond the fact that most fossil fuel resources are reserve based, which means that are limited, the major driver of energy transitions is the threat posed by burning the available large quantities of fossil fuels and their corresponding impact on the environment [2]. To generate this transition, the role of policy cannot be overemphasized. The clean energy transition is somewhat unique because it has to be driven by policy. Markets cannot provide the platform to reduce greenhouse gas emissions, since markets naturally tend towards more consumption of fossil fuels. As such, it is important to understand the role of policy, policy levers and policy decisions, in effecting energy transitions [3].

In developing economies, energy supply shortages, poor or non-existent infrastructure and subsidized end-user prices are some key direct challenges which tend to slow-down the implementation of structural changes in energy systems. In industrialized countries, the main challenges are: rapid speed of change and imbalance in the development path of energy systems [4]. Understanding how policy decisions are taken, how current policies are interpreted and how energy infrastructure is shaped, is dependent on the understanding of the actors and stakeholders, their socio-psychological biases, the internal workings of the institutions within which they act, and their organization's wider interests. On this basis, the broader drivers, influences and consequences of the policy decision process and energy governance need to be considered.

According to the International Energy Agency (IEA), to facilitate energy transition, there is need for concerted, early and consistent policy action [5]. The IEA argues that well designed policies that aid decarbonisation through cutting down on household energy expenses related to fossil fuel and improving air quality can aid the transition to a low carbon economy. The International Renewable Energy Agency (IRENA) further argues that transiting to a low carbon economy will require a drastic deployment of renewable energy solutions and energy efficiency measures [5–7].

This paper serves as an extension of a previously published work titled "*Energy transitions in Nigeria: The evolution of energy infrastructure provisions (1800–2015)*". In that work, the Nigerian energy transition was presented with emphasis on the key practices, interventions and events that led to changes in energy infrastructure supply and use within each energy era [8]. The Nigerian energy transitions, covering a period of 1800–2015 were divided into five major energy eras which are:

- *Pre-industrial (agricultural) era*—up to mid-1800s.
- *Early industrial (advanced metallurgy) era*—late 1800s.
- *Industrial (steam engines) era*—early to mid-1900s.
- *Late industrial (dynamo, internal combustion engines) era*—mid to late 1900s.
- *Information (microprocessor) era*—early 2000s onwards.

The previous work emphasized the connection between event, practices and changes in energy supply infrastructure without much attention to the drivers and how they influenced the transition in energy use. This paper looks at the key drivers within each energy era and how they influenced the Nigerian energy transitions.

In this chapter, some methodological considerations used in this research are presented in Section 2. In Section 3, the drivers and influences of Nigeria's energy supply infrastructure changes are presented. Section 4 discusses these influences further and what they mean for the future of energy in Nigeria. The concluding thoughts are presented in Section 5.

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2. Materials and methods

Data from documentary archives and other published sources that links to the Nigerian historical energy infrastructure provisions were used for analysis in order to have a better understanding of the Nigerian energy (infrastructure) history. Diaries, letters, memos and policy documents from the archives of the Nigerian Railway Corporation were used and analyses.

The detailed account of the history of the Nigerian Railways by Francis Jackel (1997) covered in three volumes was also useful sources of data.

It is noteworthy that in many existing transition studies, one can easily notice the extensive use of quantitative (and qualitative) data from published literatures, and particularly archives of some agencies, used in collecting data and making meaningful analyses which serves as pointers, suggesting various constitutive elements of the energy history under study.

2.1. Why choose these documents?

These set of documents were selected for analyses for the following reasons:

1. The Nigerian Railway Corporation is the oldest institution in Nigeria which has existed since colonial times (in late 1800s). They hold some of Nigeria's oldest archives.

2. The archives of the Nigerian Railway Corporation (NRC) contain records of associated events that led to decisions on the provision of several rail infrastructure. Some of these documents contained the reasoning (and contexts) behind those decisions and the future benefits the government aimed at achieving. An example is the case of providing rail infrastructure linking Kano to Lagos to aid the easy movement of agricultural produce from the hinterland (in the north of Nigeria) to the ports (in the south of Nigeria) for export [9]. Some, trade and policy contexts on infrastructure decisions taken.

2.2. How were the documentary/archival records analysed?

Documentary and archival records were analysed and used to prepare a historical narrative on the various factors that influenced the evolution of energy infrastructure provisions in Nigeria [8]. The following steps were followed in analysing archival documents/records [10, 11].

1. *Meeting the documents*: this process involves checking to ascertain if there are any special markings or figures on the documents which could tell us something in connection with the subject under study.

2. *Observing the parts*: this entails finding out who wrote the documents and for what purpose. When was the record produced? Are those dates useful in analysing times of energy transition and how society develops over time?

3. *Trying to make sense of the documents*: this stage entails trying to obtain the main ideas of the documents. Why was the document written? Are there useful aspects that support my research and can be used as evidence?

4. *Use the documents as historical evidence*: this stage helps in asking questions that can help provide answers to validate the use of those documents as evidence. For example, where can I find more information about a particular event referenced in the document? Where can I find more information about the person who wrote the document? Are there empirical evidences that are aftermaths of the things observed in the documents?

3. Energy supply infrastructure changes in Nigeria: drivers and influences

A panoramic view of the energy eras and the different features that characterized the Nigerian energy transitions within each energy era is presented in **Figure 1**. The study and analysis of these eras were centred on four important characteristic features that served as points of departure for understanding the influences that have impacted on changes in energy infrastructure supply and use in Nigeria. These central features are:

1. *Energy (re)sources* used in satisfying demand for energy.
2. *Technological interventions* that served as enablers in production and consumption of energy.
3. *Commercial and end-use practices* that shaped and influenced demand for energy
4. *Institutions responsible* for energy (and electricity) infrastructure governance and provision

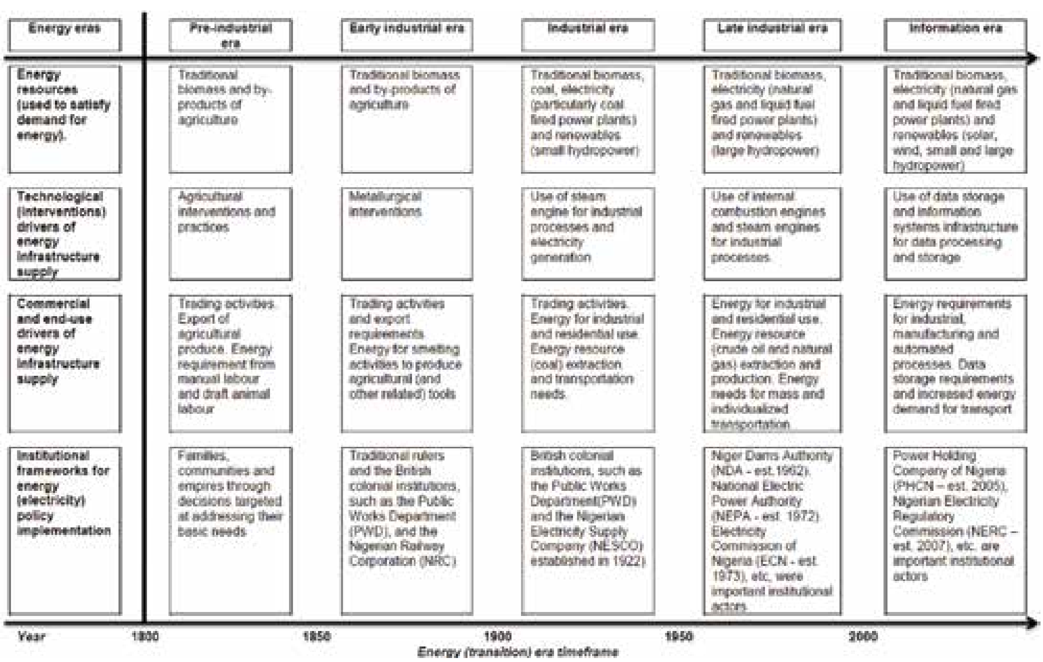

Figure 1. A panoramic view of the energy eras and the key features of the Nigerian energy transitions (1800–2015).

This research revealed that changes in Nigeria's energy supply infrastructure have been driven and influenced within the following contexts:

1. Policy and institutional interventions on energy
2. Technological interventions and energy technology pathways
3. Social (societal) practices and public values for energy
4. Available energy resource options
5. Economic considerations

Policy and institutional interventions have been one of the greatest contributors to changes and transformation in energy supply infrastructure systems. These policy interventions have come about as a result of the increasing need to address issues, such as energy access, energy security, decarbonizing future energy, and combating the effects of anthropogenic climate change and its consequences.

Technological interventions and different technological pathways have also contributed to changes in energy infrastructure systems in Nigeria over time. This started with the use of steam engines (up to early 1900s), coal fired power plants (up to mid-1900s) and thermal power plants (since the 1980s). The development of renewables (hydroelectric power) started in the mid-1900s. This development is deemed to continue due to national and international pressures to cause a shift to the use of renewables (including the use of solar photovoltaic cells, wind power and nuclear energies where applicable).

Public values for energy was driven more by the perceived (and actual) merit that provision of energy infrastructure conferred. Indeed, there were changes in societal and social practices brought about by the provision of electricity supply infrastructure. Some of these practices, such as commuting, trading and entertainment became more energy intensive. The provision of electricity infrastructure did not only help guaranty the continuation of these practices, but also aided its sophistication.

The availability of natural resources, particularly primary energy resources such as coal, crude oil and natural gas aided the increased use and consumption of those resources. Resource availability served as a primary driver of energy consumption. Rising demand for energy served as a secondary reason. Indeed, the effect of rising demand and resource availability led to transitions in energy use as shown in **Figure 1**. This same transition was also supported by, and influenced the creation of, several decision-making institutions within each era, as well as the policy direction of the government (see **Figure 1**).

Economic considerations impacted on historical energy infrastructure investments. Future energy infrastructure supply will require further leadership and sustained investments by public and private entities in providing energy infrastructure that addresses the changing (current and future) needs of people in society. Governments, through public institutions, will have to provide economic incentives to increase energy infrastructure provision through promulgation of policies to aid private investment going into the future.

The following sub-sections now delve into the details of the various influences/drivers of energy systems change within each energy era.

3.1. Pre-industrial (agricultural) era—up to mid-1800s

This era, which was characterized more by agricultural practices and interventions, saw the extensive use of traditional biomass (mostly by-products of agriculture, such as wood) as the major source of energy. The following were key drivers of energy infrastructure supply in this era:

1. Institutional interventions
2. Economic considerations
3. Energy resource options
4. Social practices and public values

3.1.1. Institutional interventions

There were two pre-dominant decision-making institutions during this era:

1. Families
2. Traditional institutions (rulers)

Decisions at the level of families were made based on their available resources and needs. By-products from agriculture such as oils were used for addressing lighting needs using oil lamps [12]. A source of food for most families was through peasant farming. Decisions on domestic energy needs impacted on increased energy demand in the forms of food calories and other agricultural by-products required for various domestic needs such as wood for cooking. Indeed, the aggregate value of the combined energy needs of several families resulted in thinking about new innovative ways of addressing and satisfying the rising energy demand.

Rulers of traditional communities played a pivotal role with respect to trade activities. For most communities, traditional rulers, together with the traditional council (also known as 'council of chiefs' in some cultures in Nigeria) encouraged people within their communities to embark on activities that can potentially increase trade activities with other communities and foreign envoys [12]. There are several evidence of this in Badagry area of Lagos and the great Benin kingdom. Trade, which encouraged the exchange of practices and ideas led people in several communities to adopt practices that were energy intensive [13]. Increased trade activities during this era led to the cultivation of more crops for domestic consumption and export [14].

Families and rulers of traditional communities (together with traditional councils—the equivalent of congress at community levels) were the main institutional drivers of energy infrastructure changes and use during this era.

3.1.2. Economic considerations

During this era, increased agricultural output was considered synonymous to economic prosperity. Growth in agricultural productivity meant increased potential for more trade leading to increased income. Since agriculture was the mainstay of the economy during this era,

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increased productivity helped in sustaining families, maintaining communities and supporting traditional festivals, such as: the harvest festivals.

3.1.3. Energy resource options

During this era, the available energy resource was from food calories. Decisions on energy resource use depended on families and local communities. The availability of food calories meant that most practices performed were based on manual labour and draft animal labour. This was very demanding as there was need other energy resource options that could help reduce the use of manual labour in achieving different practices.

3.1.4. Social practices and public values

During this era, energy from food calories was perceived as a common (societal) good. The availability of this energy source provided the basis for several practices to be implemented in different sort of ways, such as commuting and trade. Trade was a very important practice that led to more demand for energy. Trade activities improved and many Nigerian locals saw the need to increase their export produce that would be sold to their trade partners. It is the perceived value (a means of livelihood) and the trade practices that led to demand for new forms of energy to help increase production output of food produce, arts and crafts for export.

3.2. Early industrial (metallurgical) era—mid to late 1800s

This era saw the extensive use of metallurgical interventions in energy use. The key drivers of energy infrastructure supply during this era were:

1. Institutional interventions
2. Technological interventions
3. Economic considerations

3.2.1. Institutional interventions

The institutional decision-making platforms that were vital in shaping this stage of the Nigerian energy transition were:

- Colonial institutions
- Traditional institutions (traditional rulers)

The British colonial government was the key decision maker during this era. Since Nigeria was divided into regions, there were regional governors for the northern, western and eastern regions. Decision making on new infrastructural development was effected through some institutions established during this era. The two pivotal institutions set up during this era were:

1. The Public Works Department (PWD)
2. The Nigerian Railway Corporation (NRC)

The PWD was established to plan and develop several infrastructural facilities in Nigeria (roads, electricity, ports and harbours, etc.). The PWD intervened in the establishment of the first electrical power plant in Lagos, which served lighting purposes. This intervention led to increased demand for electricity since this provision led to increased perceived public value for electricity.

The NRC intervened in the planning, surveys and provision of rail transport infrastructure. The NRC was established to plan, implement and maintain rail infrastructure in order to open up the hinterlands of the country and aid the easy transportation of agricultural produce to coastal cities and ports for export. This led to the provision of the first rail line in Nigeria in 1896, linking Lagos and Ibadan, two cities in South-West Nigeria.

Traditional rulers still remained relevant in the scheme of things at the community level [15]. However, colonial rule and institutions were having greater impact in changing the infrastructure and governance landscape [14]. In order to gain acceptance at local community levels, the colonial institutions worked closely with community leaders to ensure decisions made were accepted and implemented at community level.

3.2.2. Technological interventions

Changes in energy systems during this era were also influenced by technological interventions. Two forms of technological interventions were evident during this era:

1. Metallurgical technology

2. Electrical technology

The extensive use of metallurgy during this era aided the planning and development of several infrastructure. Metallurgical interventions aided the production of farm tools to aid agricultural practices and increase crop production. The provision of the first railway line in Nigeria was also aided by the extensive deployment of metallurgical interventions during this era. These interventions aided the provision of mass transportation infrastructure (such as the railway line).

Electrical technology interventions aided the provision of the first electrical power plant in Nigeria which was used mainly for lighting applications. However, this initial provision paved the way for future electrical technology interventions to cater for future electrical energy needs due to increased demand for other applications, such as, electricity needs for the workshops of the Nigeria Railway Corporation.

3.2.3. Economic consideration

During this era, economic considerations were centred on increased trade volume, growth in income and productivity. Policies of the colonial administration at the time were centred on providing infrastructure aimed at economic development that supports trade. These were part of the considerations for the planning and eventual provision of the first railway line and electricity infrastructure in Nigeria.

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3.3. Industrial (steam engine) era—early to mid-1900s

During the industrial era, there were five vital drivers of energy infrastructure supply. These were:

1. Technological interventions
2. Changes in social practices
3. Policy and institutional interventions
4. Economic considerations
5. Energy resource options

3.3.1. Technological interventions

During this era, the use of metallurgical and electrical technology interventions in infrastructural provisions became further widespread. New railway infrastructure opened up the hinterlands and connected more towns which aided mass transportation of people and goods. The use of steam engines for transport and manufacturing applications were also evident in this era.

New electricity supply infrastructure was provided to cater for increased electricity demand. The existing steam plants were expanded in response to increased demand. This era also saw the introduction of new technology pathways for electrical energy generation. The discovery of coal in 1909 paved the way for the introduction of coal fired electrical power plants in (Lagos and Enugu) Nigeria. There were also plans during this era which paved the way for future hydroelectric power plants.

3.3.2. Changes in social practices

The introduction of various technological interventions during this era led to changes in social practices of Nigerians which became dependent on more dense energy sources. Indeed, some of these practices became more energy intensive. The provision of more road and rail infrastructure led to a change in commuting patterns from walking to the use of mass transportation models, such as railway lines. This period also saw a gradual change from mass transportation (in the beginning of the era) to individualized transportation (towards the end of the era). The change in commuting patterns led to increased demand for more transport infrastructure which also had some effects on increased demand for energy infrastructure supply.

3.3.3. Policy and institutional interventions

This era saw the introduction of several policies, implemented within institutional frameworks, which aided the eventual provision of targeted infrastructure (including energy). This era was dominated by colonial institutions, established to achieve specific infrastructural and policy targets [16]. Two institutions were pivotal in the provision of electricity infrastructure during this era:

1. Nigerian Electricity Supply Company (NESCO)
2. Nigerian Government Electricity Undertaking (NGEU)

Established in 1922, the Nigerian Electricity Supply Company (NESCO) was tasked with the responsibility of developing electrical energy supply (generation) infrastructure. NESCO was involved in generation and bulk trading of electricity to different towns and cities such as Bukuru (1936) and Vom (1944), covering a total of 600 square-miles (including the mines). The peak load rose to 12 MW with an annual load factor of 60%. As of 1922, the Enugu building of NESCO was already in place, just off the railway workshops. Engines, dynamos, boilers and a riveted steel chimney were in position at an audited cost of over £103k, which is worth around £4.6m in current estimates. This power plant supplied electrical power to the mines from 1924.

The Nigerian Government Electricity Undertaking (NGEU) was established in 1946 to plan and implement the provision of electricity infrastructure by at least 200%. The aim was to ensure the provision of electricity to support industrialization. The implementation of this policy led to industrialization in the 1950s in Nigeria. Many manufacturing plants based their future growth projections on the electrical infrastructure expansion plans.

3.3.4. Economic considerations

Trade activities continued to grow during this era. This was evident by the complex movements of goods over time as highlighted in **Table 1**. The growth in trade was supported by increased agricultural productivity and the presence of small cottage industries. **Table 1** shows the goods tonnage and passenger journeys (1913–1976). Between 1925 and 1930, the movement of coal led to increased trade and commercial activities.

The introduction of the new energy policy for the provision of more energy supply infrastructure was based purely on economic considerations, to support industrialization. The Nigerian Government Electricity Undertaking (NGEU) had the responsibility of planning and implementing this policy. Indeed, economic considerations from individuals and government and impacted on more demand for energy which then influenced more electricity infrastructure supply.

3.3.5. Energy resource options

During this era, there was a deliberate attempt by the Nigerian government (still under colonial rule) to conduct surveys aimed at exploring and searching for possible mineral reserves. This led to the discovery of coal in 1909.

The discovery of coal changed the electricity and transportation landscape. There was a shift to the use of coal fired power plants for electricity generation due to the availability of coal. The use of coal in cottage industries also increased. The transportation landscape was also affected by the discovery of coal as more locomotives depended on coal as the fuel source.

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Year	Paying tonnage ('000)	Non-paying tonnage ('000)	Total tonnage ('000)	Passenger journeys ('000)
1913	–	–	–	1160
1917	152	60	212	1094
1920	–	–	527	2211
1924/25	541	113	645	1023
1928/29	–	–	–	3162
1932/33	646	180	826	2378
1935/36	709	238	947	7941
1936/37	892	270	1162	8426
1941/42	1042	266	1308	4810
1943/44	1239	397	1636	5245
1944/45	1339	371	1710	5342
1952/53	1543	543	2086	5516
1953/54	1714	584	2298	5454
1954/55	1983	619	2602	5451
1955/56	2000	653	2653	6310
1958/59	2353	743	3096	7015
1960/61	2054	668	2722	9822
1961/62	2381	622	3003	11,061
1962/63	2209	551	2760	12,006
1963/64	2534	436	2960	11,288
1970/71	1493	111	1604	8942
1975/76	1521	126	1647	6755

Table 1. Goods tonnage and passenger journeys in Nigeria (Source: Archives of the Nigerian Railway Cooperation).

3.4. Late industrial (dynamo/internal combustion engine) era—mid to late 1900s

This era saw some drastic changes in energy infrastructure supply. These were influenced by the following:

1. Energy resource options
2. Technological interventions
3. Policy/institutional interventions
4. Societal practices and public values
5. Economic considerations

3.4.1. Energy resource options

The discovery of crude oil in commercial quantities in Nigeria in 1958 changed the entire energy landscape during this era. After the Nigerian independence and the civil war, there was a shift in the use of fuel from the use of coal to a greater dependence on natural gas and crude oil (and its by-products) for electricity generation and other industrial uses. Indeed, there were more options to choose from between coal, natural gas and crude oil. This era also saw the development of dams for hydroelectric power generation.

3.4.2. Technological interventions

During this era, dynamos and internal combustion engines played a key role as the major technology driver of changes in energy infrastructure supply. The extensive use of internal combustion engines for vehicles and road transportation impacted on fuel sources. This also led to extensive investment in road infrastructure and a gradual decline in the use of rail transport infrastructure.

During this era, new technological pathways were adopted for electrical energy generation. Extensive development of hydroelectric and thermal power plants was evidenced in this era. This era also saw a swift decline in the use of coal for electrical power generation and the retiring of several coal-fired power plants.

3.4.3. Policy/institutional interventions

This era saw the extensive use of policy and institutional frameworks as intervention tools in addressing issues of energy infrastructure supply. The rising energy demand after the Second World War led to increased electrical infrastructure supply constraints. As such, the government intervened by carving out a new unit off the Public Works Department called the Nigerian Government Electricity Undertaking (NGEU). The NGEU was established in 1946 as an entity that will metamorphose into a future corporation with the aim of preparing and implementing a plan that can aid the provision of more electricity infrastructure to aid industrialization. Indeed, the NGEU prepared a 10-year plan covering the period 1946–1956 with the aim of increasing electricity infrastructure provision by at least 200% to support industrialization.

Another important institution is the Electricity Corporation of Nigeria (ECN). The ECN was established on 6th July 1950 and was charged with the task of developing Nigeria's electricity potential in a manner as to provide cheap and affordable sources of energy in a consistent and sustainable way.

The beginning of this era saw the gradual handover of institutions under colonial control as the country prepared for independence (which took place on 1st October 1960) [17]. Series of military coups and counter coups experienced a few years after the independence led to instructional instability, highly militarized decision making structure, and less attention and adherence to laid down policy plans and processes [18, 19].

The Niger Dams Authority (NDA) was established in 1962 to develop Nigeria's hydropower potential. This paved the way for the development of hydroelectric power infrastructure in Nigeria with the building of several dams for irrigation, water supply and electricity generation.

The National Electric Power Authority (NEPA) was established in 1st April 1972 which is a product of the merger of the Niger Dams Authority (NDA) and the Electricity Corporation of Nigeria (ECN). The merger actually took effect from 6th January 1973. The NEPA was a public company, owned and managed by the Nigerian government. All through this era, NEPA had responsibility for the provision, operation and maintenance of electricity infrastructure in Nigeria.

The Nigerian National Petroleum Corporation (NNPC) established on 1st April 1977 to participate and regulate Nigeria's petroleum industry. The role of the NNPC in regulating activities of players in the oil and gas sector had direct impact on electricity infrastructure provision since fuels required to power the electrical power plants depended on the dynamics of the downstream oil and gas sector.

In 1979, an act of government (which was later amended in 1988 and 1989) established the Energy Commission of Nigeria (ECN). The ECN was charged with the responsibility of coordinating and strategically planning the national energy policies. The ECN have focused on developing actions plans that aids in addressing the Nigeria's energy challenges through establishing and implementing policies. Indeed, since its establishment, the ECN still has a huge gap to fill.

3.4.4. Societal practices and public values

In this era, there were swift changes with regards to social practices which impacted on energy demand and consumption. The public value for energy services was on the rise and energy was highly perceived as a public good. Education played a vital role in the changes in social practices and perceived public values for energy. There was an increase in the number of educational institutions at primary, secondary and tertiary levels. Educational institutions also needed energy for teaching and research.

With regards to commuting, there was a change in commuting patterns from mass transportation to individualized transportation. More people had their private vehicles for personal and business purposes. Aside the reasons of comfort and convenience, a major driver of change from mass transportation to individualized transportation were increased concern for security and safety. There were also changes in lifestyles and leisure that impacted on the energy consumption and use that leads to increased need demand for energy supply infrastructure.

Rapid population growth, migration and urbanization also impacted on changes in practices. Some towns and cities ended up becoming more cosmopolitan (such as Lagos). Multiplicity of diverse practices within cities, aided by migration and population growth, impacted on changes and provision of infrastructure for commuting (transport), leisure (recreation), learning (education), trading (commerce), etc. These practices impacted on energy use and increased demand for energy infrastructure supply.

3.4.5. Economic considerations

This period saw changes in trade and investment dynamics. The discovery of more natural resources paved the way for further trade activities and other economic considerations investments. Crude oil export started in the 1970s. Export of agricultural produce continued but at a reduced rate due to a shift in attention from agriculture to crude oil as the major income earner for the country. The produce that was now exported (crude oil) required a lot of energy for its exploration and production.

There was an increase in manufacturing activities during this era. Increased electricity requirements for industries posed a greater challenge with regards to electricity supply infrastructure. Inadequate supply during the latter part of this era impacted on many manufacturing and cottage industries. Industrial growth was pegged as a result of inadequate electricity supply infrastructure. Most industries opted for self-generation of electricity for their industrial needs. Indeed, this infrastructure deficit resulted in the need for planning and future provision of more electricity supply infrastructure.

3.5. Information (micro-processor) era—early 2000s

During this era, four major drivers of energy systems change were noticeable:

1. Technological interventions
2. Policy and institutional interventions
3. Societal practices and public values
4. Economic considerations

3.5.1. Technological considerations

During this era, the use of microprocessor technology was on the rise which impacted on automation of processes in different sectors. In manufacturing, microprocessor technology aided the automation of many industrial processes. The use of Programmable Logic Controllers (PLCs), industrial sensors and other related technologies in manufacturing depended on microprocessor technology. The automation of several industrial processes aided increased production of goods. Even though there was more attention on energy efficiency and energy conservation measures, the introduction of these new technologies in manufacturing also impacted on electricity demand as more industries opted for automation to improve productivity.

3.5.2. Policy and institutional interventions

This era is characterized by democratic and civil institutions involved in the decision-making and policy process [17]. At the start of this era, two institutions emerged:

- Power Holding Company of Nigeria (PHCN).
- Nigerian Electricity Regulatory Commission (NERC)

Owing to inefficiencies in the Nigerian electricity sector, the Nigerian government started a process of unbundling the National Electric Power Authority (NEPA) in order to reduce government bureaucratic process in electricity supply infrastructure provision, operation and maintenance. The PHCN was established on 5th May 2005 as a holding company, owning the various divisions responsible for generation, transmission and distribution of electrical energy. This paved the way for the future privatization of the PHCN, with transfer and controls of some national electrical power assets by private companies. The privatization process also brought about some changes in models of electricity financing, operation and maintenance.

The NERC was established on 31st October 2007 as a regulatory body for the Nigerian power industry. The NERC has the responsibility for issuance of licenses and permits to market participants in the Nigerian electricity sector. They also ensure compliance to rules and regulatory guidelines in the Nigerian electricity sector.

3.5.3. Societal practices and public values

This era saw lots of private investments in the provision of infrastructure to satisfy the increased demand for convenience and comfort. This was evidenced in the emergence of shopping malls, cinemas, nature reserves and parks. The emergence of these infrastructure posed more pressure on demand for energy. This era continued to experience increased migration and urbanization which posed some infrastructure challenges (including energy). Indeed, in this era, the public value for energy services had increased and people had more dependence on energy to fulfill and accomplish several social practices.

3.5.4. Economic considerations

In this era, the need for increased productivity led to the embrace of automation in the industrial and manufacturing sector. Economic consideration during this era was characterized by the need to address both internal (local) and external (export) demand for certain products. Indeed, this led to more manufacturing activities. Most industrial players had to invest in electrical generation plants to satisfy their electricity needs. Self-generation of electricity also impacted on cost of finished goods as some companies could not measure up to the economies of scale for increased production output.

4. Important learnings from the Nigerian energy transitions

In Nigeria, a very important aspect of the governance of energy and electricity infrastructure provision is the individual interest of policy actors, the individualistic nature of which further emphasizes the need to incorporate economic and social psychological thinking. Some underlying questions they ask themselves before deciding on what type of energy infrastructure to provide include:

- How much does this infrastructure cost? Can our current budget accommodate it?

- How long will it take to deploy this infrastructure? Is it something that I can commission before leaving office?
- What social and political benefits will the provision of this infrastructure confer (on me and the populace)? Will the provision of this infrastructure offer me the possibility of acceptance and possible re-election by the populace?

Indeed, these aforementioned questions are crucial for individual actors within policy frameworks in taking decisions [20]. These also impacts on the governance of energy. This is in contrast with one of the arguments of Kuzemko et al. [21] who asserts that in governing sustainable energy systems change, innovation is important in sustainable energy transitions. In Nigeria, political actor interests are a major driver of energy transitions. The practice of policy making, intertwined with the interests of the political actors, is the principal driver of energy transitions. This is supported by the argument that linking governance with practices and outcomes, and defining energy and climate actor groups are very important in governing changes in energy supply infrastructure in a sustainable way [21, 22].

In Nigeria, institutional (government) interventions, changes in policy direction and new technology pathways constituted major drivers of changes in Nigeria's electricity systems. There are similar trajectories between the energy transitions dynamics of the Nigerian and the Dutch system. In considering the dynamics of the energy transitions in the Dutch electricity systems (1960–2004), Verbong argues that: changing perceptions and goals (1960–1973); direct government interventions (1973–1989); and major changes in rules, network and technology (1989–2004) characterized the Dutch electricity sector [23]. The Dutch system compares with that of Nigeria because electricity infrastructure provisions were influenced by: changing perceptions and goals prior to Nigeria's independence in 1960 (1890–1960) with evidence in changing technology and fuel sources for electricity generation during that period; direct government interventions (1940–1970), an example was the intervention by the then Nigerian Government Electricity Undertaking (NGEU) in 1946 to provide new electricity infrastructure by 200% in a space of 10-years [24]; and major changes in rules (2005–2015), characterized by the new electrical power sector reforms roadmap [25].

The following sub-sections discuss further four important influences of politics, technology, energy sources and geographies of energy on energy systems change in Nigeria.

4.1. Role of politics in energy systems change

Politics play a major role in effecting changes in energy supply infrastructure. For instance, the politics around crude oil and natural gas production and trade is vital for guaranteeing continuity of supply of electrical energy since most electrical power plants depends on the oil and gas sector for fuel to fire the power plants. This means fuel supply (in the forms of liquid fuel and natural gas) for most electrical power plants are highly dependent on the production, market, economics and political dynamics around crude oil and natural gas supply [26].

Arguably, the gas market is a lot more rigid than the oil market. This is because it requires large and expensive investments to ensure the easy transportation of gas around the world. Investing resources in a lot of long term infrastructure for this sort of business requires that there is a good (long term) political relationship with the trade partners, wherever they may be. Indeed, it is easier to get entangled in the global prospect for natural gas, which can lead to a lot of energy security issues, both domestically and internationally.

Looking into the future, the major factor that could either make or break (clean) energy production is policy. This is the topmost variable because: policy plays a major role with respect to investment direction for most investors; it impacts on changes on the supply side of energy systems and infrastructure through definition of standards; and it imposes considerable changes in energy demand patterns and behaviours.

Within the Nigerian context, a major factor that led to the displacement of coal with liquid fuel and natural gas for electricity generation was simply the economics of natural gas over coal. Coal production and use for electricity generation in Nigeria is more expensive than the use of liquid fuels and natural gas. This transition started happening in the 1950s, but became more entrenched from the 1970s. All the coal fired power plants in Nigeria built from the 1920s to the 1950s have all been retired. Indeed, natural gas will gain a lot more grounds in Nigeria in the coming years due to its availability and the policy direction of the government encouraging the use of natural gas for electricity production.

4.2. The role of technology in energy systems change

In Nigeria, there have been lots of changes in energy technology and use over time. This will continue going into the future. Historically, Nigeria has transited from the use of steam engines, to coal-fired technology, thermal power plants and renewables. Going into the future, there will be more changes which will be shaped by the changing nature and politics of electricity infrastructure provision.

In recent times, there has been a rise in the deployment of decentralized off-grid solar solutions in Nigeria. The rapid rise of renewables will continue and solar power will become a regular feature on the energy landscape. New technologies will support global deployment of wind farms and solar solutions. The rise in renewable solutions needed for a clean energy future will be driven more by the increase in energy demand for electricity. Incorporating these renewable technologies will also have impact on the traditional electricity grid as new hybrid grids (transmitting electricity over long distance) and micro grids (playing strategic role in electricity distribution and providing flexibility) will be the mainstream technologies in the future.

As is now being experienced in major urban centres in Nigeria, buildings are now producing electricity through roof top solar solutions. In the future, more buildings will produce energy rather than consume energy. Buildings will also function as energy hubs in the future, offering the entire energy system more flexibility and also ensuring stability of the electricity grid. The use of smart meters, greater energy storage capacity and low cost solar cells will be important technology catalysts of a cleaner electricity future.

4.3. The role of energy (re)sources in energy systems change

Energy sources play a vital role in energy systems change. In Nigeria, it all started with the use of steam engines for electricity generation. The discovery of coal as an energy source (in 1909) changed the energy infrastructure landscape, leading to a switch from the use of steam engines to the adoption of coal-fired power plants. The need to diversify the electricity infrastructure mix led to the development of hydropower plants in Nigeria (with the formation of the Niger Dams Authority). The discovery of crude-oil in commercial quantities (in 1956) had a considerable impact on the electricity infrastructure landscape in Nigeria. The overriding economics of crude oil and natural gas over coal led to a shift to the use of (oil and gas-fired) thermal power plants. Increased demand and consumption of energy in Nigeria have been partly influenced by the availability of energy resources. **Figure 2** shows the Nigerian energy flow linking primary energy resources to end-use sectors.

Energy flow in society starts with the natural energy sources (such as coal and crude oil) which are then converted into different usable forms that society consumes. These usable forms of energy materializes through the services they render society (as evident in **Figure 2**). This is evident through the greater use of energy resources, driven by the need for comfort and more productivity. In Nigeria, the increased societal use of energy resources is impacted by three main sectors: building; manufacturing; and transportation sectors.

4.4. The role of 'geographies of energy' in energy systems change

Aside technological interventions, politics and energy resources, a major driver of energy systems change in Nigeria are the 'geographies of energy' which encapsulates the social, cultural and political dimensions of energy production and consumption. The geographies of

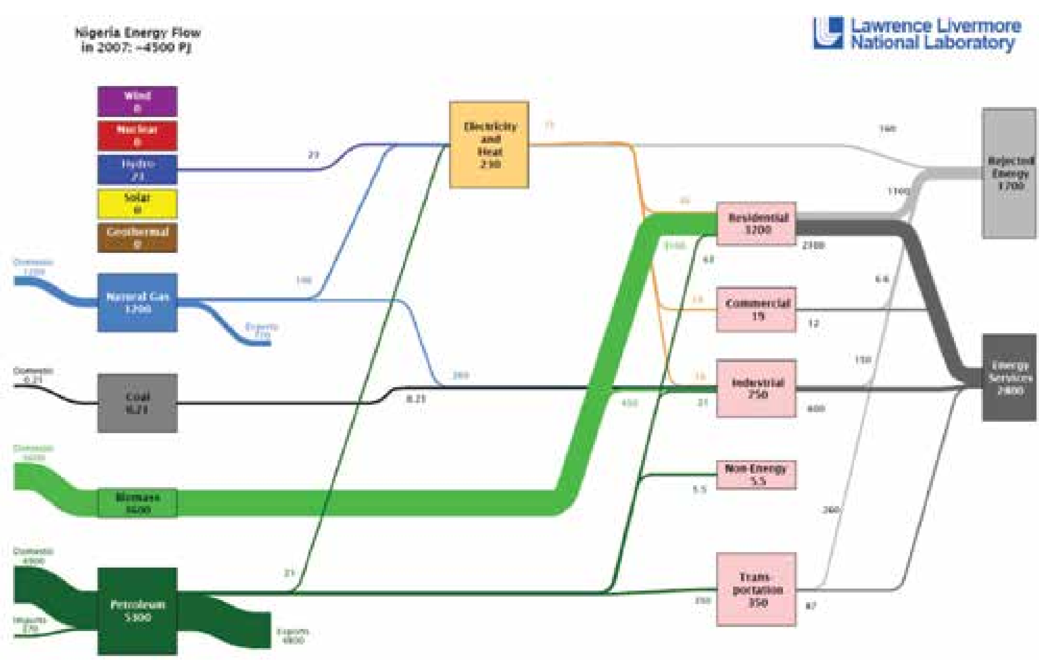

Figure 2. The Nigerian energy flow ([27], p. 90).

energy also considers how territorial, locational and spatial landscape impacts on (and co-constitutes) energy processes.

The geographies of energy played a very important role in Nigeria's energy transitions and infrastructure provision. Prior to Nigeria's independence in 1960, developmental infrastructure projects and provision were centred on regions. Starting with steam powered generation plants in the late 1800s, the discovery of coal in 1909 paved the way for many coal-fired electricity generation plants (mostly around the regions where coal reserves were available). Lagos was the only exception. This was largely because there was already rail infrastructure connecting some parts of eastern Nigeria (Enugu) to Lagos where coal could be easily transported via rail to the power plant in Lagos. **Figure 3** shows a map of the geopolitical zones in Nigeria.

Most crude oil and natural gas resources are concentrated around the South-South and South-East zones of Nigeria. These zones also have a higher concentration of: electricity power plants; natural gas refineries and export terminals; and crude oil refineries and export terminals. Indeed, these zones have the highest concentration of energy production and electricity generation infrastructure in Nigeria. However, for political reasons, government infrastructure decisions have also favoured setting up crude oil refineries outside the zones where the resources are. An example is the crude oil refinery located in Kaduna, North-Central Nigeria. The natural crude had to be transported to the refineries via pipelines. Indeed, political decisions of this sort has created historical tensions among socio-political groups in the geographies where the natural resources are domicile (and beyond), leading to cases of pipeline vandalism, political actions and other forms of externalities which impacts on the energy infrastructure landscape and energy security.

Figure 3. Map of the geo-political zones in Nigeria (Source: http://www.nigerianmuse.com).

5. Conclusion

The Nigerian historical energy transition with respect to the evolution of energy infrastructure provisions was investigated. The dominant drivers of electricity infrastructure supply within each energy era in Nigeria were also investigated. These drivers, which comprises technological interventions and pathways, institutional interventions, social practices and public values, energy resources and other economic considerations, played an important role in the governance and provision of historical electricity supply infrastructure in Nigeria.

A complex connection between resources, trade, institutions and political structures existed. These complexities were further aggravated by the creation of several decision making institutions within each energy era, as well as the policy direction of the government. Decisions by these (public) institutions led to serial changes, and eventual transition, in the use of different primary energy resources (coal, crude oil, natural gas) to satisfy the growing demand for energy. It also reveals that the increased use of primary energy resources were primarily influenced by the availability of those resources, while the growing demand served as a secondary reason.

This chapter presents the need for a greater understanding of the motives and objectives of energy systems supply. What exactly motivates the changes in the energy sector in a given country as against the background of the overall energy demand and supply situation? Possible motives, such as competitiveness, public acceptance, energy security and environmental concerns—within institutional contexts and policy frameworks—needs to be investigated at country levels, for a better understanding of the key drivers of energy transitions within countries.

There is a need to understand the drivers and governance of changes in the respective energy sectors. How are changes promoted in the energy sector? Some possible drivers, such as: technological innovation, government policies, etc., needs to be investigated at country level to ascertain their impact on the institutional structures and frameworks of energy policy governance.

The study of Nigeria's energy transitions presents some policy implications. Since energy infrastructure choices contribute to environmental problems, and changing these energy infrastructure choices requires adequate knowledge of their effects and consequences, there is need for a wide range of changes in energy policies and energy systems to help address these problems. Energy users, including policy makers, generally prefer energy policies that is perceived to have more benefits and less cost. However, since energy infrastructure provision is primarily a political choice, the acceptance of different energy policies (and changes in energy supply systems) is influenced by institutional actors within institutions through institutional values, workings and frameworks responsible for energy infrastructure decisions and choices.

Energy production, distribution and supply are very complex matters. This complexity is evident when viewed with respect to the role of technology, energy resources and geographies of energy in effecting changes in energy supply systems. This implies reliance on parties, such as: energy companies, scientists, non-governmental organizations and policy makers. How much people trust these parties will influence the acceptability of energy policies. Knowledge and understanding of Nigeria's energy past can surely shape current and future decisions. Short term energy decisions have to be put in perspective with the longer term visions in order to limit the effects of unintended consequences.

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Towards a Sustainable Energy Future for Sub-Saharan Africa

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Additional information is available at the end of the chapter

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Abstract

Current global population is estimated at 7.5 billion with 1.25 billion living in developed countries and 6.25 billion in less developed countries. Africa's population is approximated at 1.25 billion with 1.02 billion in sub-Saharan Africa. Globally, an estimated 1.4 billion people lack access to electricity and 3 billion rely on solid fuels for cooking and space heating. Two thirds of those lacking access to electricity live in sub-Saharan Africa, whereas only about 16% of those in sub-Saharan Africa use modern energy forms as the primary cooking fuel. Lack of access to electricity has adverse socio-economic effects, while heavy reliance on solid fuels has negative socio-economic, health, and environmental impacts. Several initiatives are being undertaken to mitigate the situation; notable are future aspirations for universal access to clean and modern energy expressed in the 2030 sustainable development goals (goal number 7), 2063 African Union Commission Agenda, Paris Agreement, and the United Nations Sustainable Energy for All (SE4A). This chapter discusses the past and present energy situation and presents possible scenarios for a sustainable energy future in sub-Saharan Africa, with a particular emphasis on Southern Africa.

Keywords: sub-Saharan Africa, access to electricity, solid fuels, modern energy forms, sustainable energy future

1. Introduction

It is now, generally, agreed that access to advanced forms of energy is associated with improved and sustainable lifestyles; this has reinforced aspirations for universal access to clean and modern energy for all. Energy access is understood to mean the user's ability to access and utilise both electricity and clean cooking technologies. Achieving this universal access in the developing world especially in sub-Saharan Africa has, however, faced several challenges. Sub-Saharan Africa (SSA) refers to the area lying south of the Sahara desert; it consists of all countries that are fully or partially located south of the Sahara and mainly excludes all countries in North Africa and all countries that may lie in sub-Saharan Africa but belonging to the Arab states. It is highly contended that SSA remains the most energy (modern~) impoverished region of the world. For instance, the International Energy Agency (IEA) says that more than 600 million people do not have access to electricity, and close to 800 million people rely on traditional biomass fuels and unimproved cookstoves in sub-Saharan Africa [1]. In the year 2000, only 22.6% of the population in sub-Saharan Africa had access to electricity, compared with 40.8% in Asia, 86.6% in Latin America and 91.1% in the Middle East [2]. Although it can be argued that this situation has some historical connotations, it is also quite true that it has persisted this long due to variations in national developmental priorities, as well as inefficient governance and sub-optimal resources utilisation. Historically, electricity development in sub-Saharan Africa came about for three major reasons: as an amenity or symbol of modernity for non-African settlers, a source of power for mines and industry, or as a stimulus for industrial development [3]. During the colonial era, African residential areas were systematically and deliberately excluded from connection to grids, since Africans were not considered to have any need for electricity.

Nonetheless, the need to resolve the problem of low or lack of access to clean and modern energy services has been reaffirmed nationally and internationally as expressed by the Sustainable Energy for All initiative [4], the Paris Agreement [5], the 2030 Agenda for Sustainable Development [6] and the Agenda 2063 [7]. In the pursuit for solutions, it is worth noting the consensus, however, that this should be done in a sustainable and environmentally benign manner.

This chapter presents a situational review of the energy sector in SSA and examines possible complementary strategies that could strengthen efforts to attaining universal access to clean and modern energy. Section 2 examines electricity supply; Section 3 explores clean fuels and technologies for cooking, while Section 4 presents a review on biofuels for transportation; and finally Section 5 windups the chapter with conclusion and a way forward.

2. Electricity

Currently, on a global level, more than 1 billion people live without access to electricity, with more than half of them found in sub-Saharan Africa (SSA). Electricity is a clean and efficient source of energy; access to affordable, reliable and sustainable electricity supplies is important for the delivery of clean water, sanitation and healthcare services, as well as for providing reliable and efficient lighting, heating, cooking, mechanical power, and transport and telecommunications services. Lack or limited access to electricity, therefore, has negative socio-economic implications [8].

Electricity supply technologies refer to combinations of primary energy resources, electricity generating equipment and distribution infrastructure; the energy resources maybe fossil (coal, oil, gas) or nuclear (uranium, plutonium) or renewables (solar PV, wind, small and large hydro, biomass and waste, biofuels, geothermal), or any mixes thereof. The distribution infrastructure maybe grid-connected and would include transmission and distribution networks, or maybe based on distributed energy technologies. Distributed energy resources encompass mini-grids, micro-grids, stand-alone systems (such as solar home systems, solar lanterns), energy efficiency and storage technologies.

The first electricity supply power plant in Africa was established in the British southern African settler Cape Colony in the 1880s; in the early twentieth century, electricity generation gradually spreads across the continent. In the decades following the end of World War II, electricity systems evolved into large centralised plants, especially hydroelectric plants, mainly to serve mining interests particularly for refining aluminium [3].

The long-lasting effects of this historical exclusion of indigenous populations continue to be evident to date despite post-independence efforts at national and regional grid roll out and rural electrification. The 2012 World Bank reports show the extent of electricity access in sub-Saharan Africa as indicated in **Table 1**.

Traditionally, the electricity supply systems developed into bulk, centralised coal-fired, gas and nuclear-powered plants, hydroelectric dams and large-scale solar power stations and required electricity to be transmitted over long distances to load centres through high voltage (400, 275 and 132 kV) transmission and medium voltage (33 kV, 11 kV, 3.3 kV and 440 V) distribution three-phase systems [9].

In the quest to find solutions to the electricity access problems, several options have been considered including: opening up the energy market to private participation and developing necessary market and regulatory policy framework; streamlining the performance and operation of state owned electricity enterprises; diversifying the energy mix thereby also

% of National population having access to electricity	Number of countries	% of Countries
100	2	4.26
>75	4	8.51
>50	14	29.79
>25	28	59.57
<25	19	40.43
<10	3	6.38

Table 1. Access to electricity in sub-Saharan Africa [3].

integrating distributed energy resources and renewables; promoting sub-continental regional relations and trade in electricity; and developing effective and innovative electricity sector investment financing, and revenue payment and collection systems. The overriding principle behind this paradigm shift is to have efficient, secure and cost-effective electricity services within a framework of market opportunities for competitive business without negating the obligations of national governments to improving access to electricity by unaffording, low income, and quite often rural-based households. Some of these efforts are examined in detail in the following sub-sections:

2.1. Opening up the energy market to private participation

Unbundling of state owned electricity systems can be effected **'vertically'** (e.g. for electricity supply, separating generation, transmission, distribution, metering and supply) and/or **'horizontally'** (separating companies of the same type so there is market competition wherever possible). **Table 2** shows some of the common structures for unbundling of the otherwise vertically integrated and state owned electricity supply system:

2.2. Developing necessary market and regulatory policy framework

Market and regulatory policy frameworks include need for fair and effective sharing and generation of relevant market information and data between stakeholders; addressing difficulties in sourcing investment capital for relatively newer investment markets; the need to develop procedures for resolution of investment, maintenance and operational costs and financial compensation resulting from changes to the power system commercial mechanisms; and provision of long-term market assurances to promote investment and long-term planning.

To this end, most countries have passed legislation establishing national regulation boards with varying mandates to oversee the liberalisation schemes; **Table 3** shows some of the countries that have passed such legislation. **Table 4** shows renewable energy feed-in-tariffs, auctions, net metering and investment incentives adopted by some countries in sub-Saharan Africa.

2.3. Streamlining the performance and operation of state-owned electricity enterprises

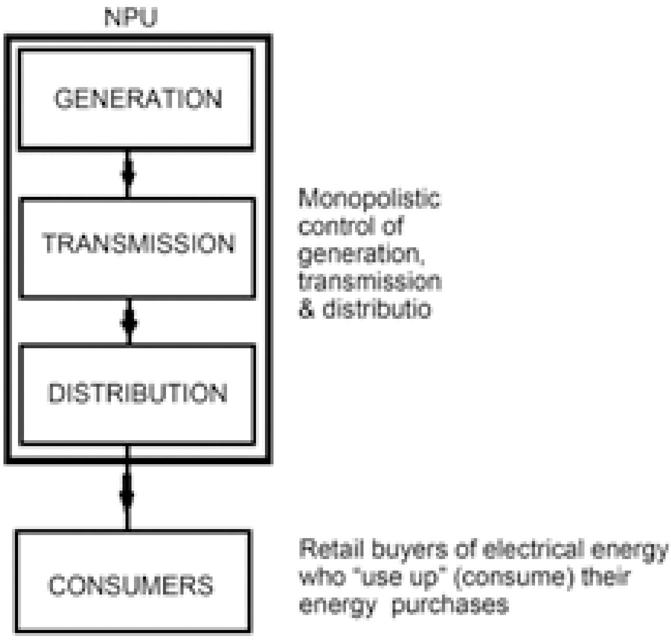
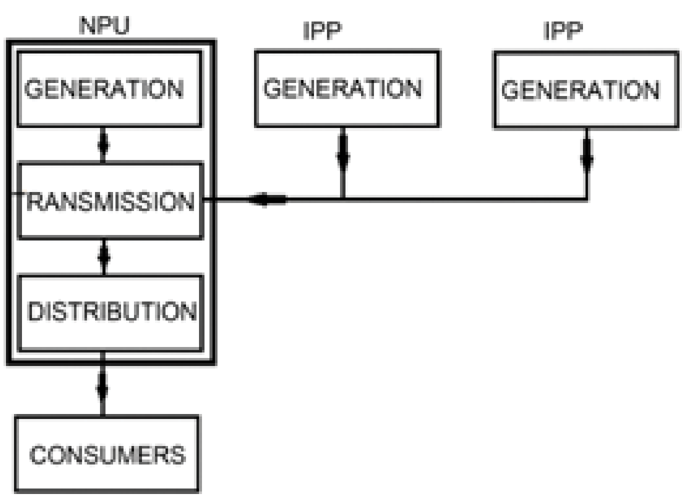
This focuses mainly on the following three aspects:

1. **Lack of system capacity:** in terms of both generation, and transmission and distribution infrastructure; this has adversely affected economic and industrial development resulting in inadequate ability for the sector to reinvest for sustainable and expanding power supply.
2. **Poor sector management:** power sector has consistently failed to reach sustainable operational efficiency for recovery of both recurrent and capital costs.

3. **High system losses:** both technical losses from the ailing transmission and distribution networks, and commercial losses from poor tariffs collection

2.4. Diversifying the energy mix

The majority of households in many sub-Saharan countries lack grid connection due to the poor state and low coverage of the electricity transmission and distribution networks.

Name	Schematic representation
Traditional vertically-integrated power utility; *(NPU = National power utility)*	
Generation competition only. *(IPP = Independent Power producer)*	

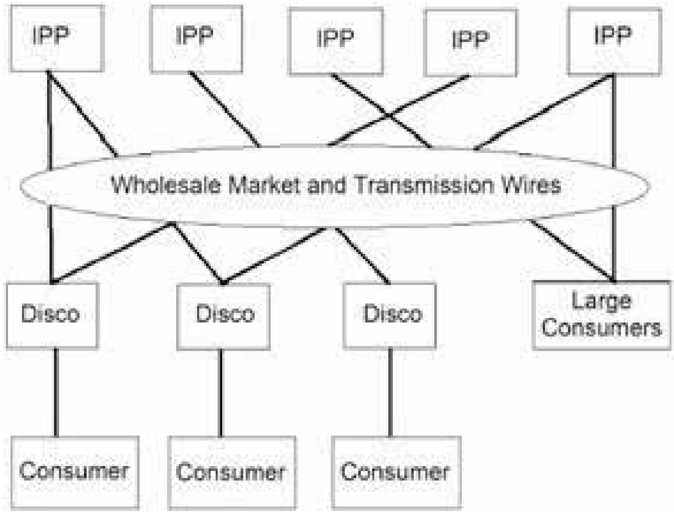
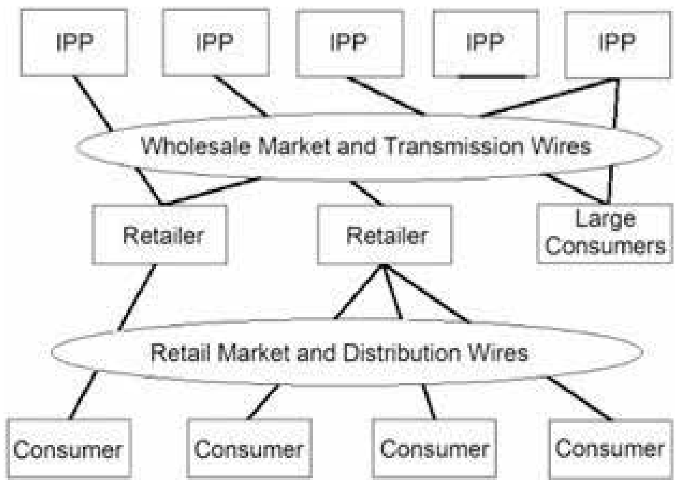
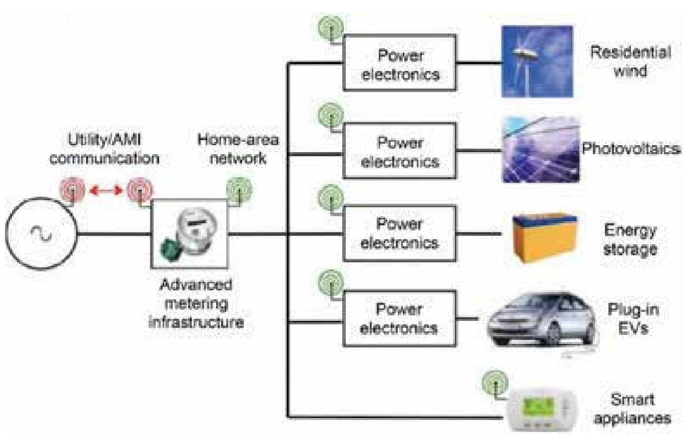
<table>
<tr><th>Name</th><th>Schematic representation</th></tr>
<tr><td>Wholesale competition only (DisCo = Distribution Company)</td><td>
</td></tr>
<tr><td>Both wholesale and retail competition</td><td>
</td></tr>
<tr><td>Consumer-owned distributed energy resource possibilities</td><td>
</td></tr>
</table>

Table 2. Electricity supply liberalisation models [10, 11].

Country	Legislation
Kenya	Kenya Energy Act 2006: converted an advisory regulator into a decision making regulator, the Energy Regulation Commission. It also makes the new commission the sole authority over imports and exports of electricity
Mozambique	Mozambique Minister of Energy's directive July 2006 creates a 'strong' advisory regulator, emphasises the need for transparency and public hearings by the advisory regulator. It also entrusts the regulator with the responsibility of monitoring the performance contract between the government and Electricidade de Moçambique (EdM), the state owned power utility
Namibia	The electricity acts of 2000 and 2007 which established the Electricity Control Board that regulates the issuance of licences for electricity generation and related matters
South Africa	The National Energy Regulator (NERSA) established through the 2006 legislation gives the regulator powers to oversee the registration and issuance of licences for the generation, transmission, distribution, as well as the local and international trade of electricity
Tanzania	The Tanzania Electricity Act 2008 provides for the facilitation and regulation of generation, transmission, transformation, distribution, supply and use of electricity; it also makes provisions for regional trade in electricity as well as for the planning and regulation of rural electrification The section on regulation of rural electrification authorises EWURA, the national electricity regulator to: • vary the nature of its regulation depending on the characteristics of the entity performing the electrification; • delegate regulatory responsibilities to other entities.
Uganda	The electricity act of 1999 provided for the creation of regulatory authority to oversee the licencing and regulation of electricity generation, transmission, distribution, sale and use. It also enforces matters pertaining to plant and equipment and safety. It was also entrusted with the responsibility of liberalisation and introduction of competition in the electricity sector
Zambia	The Energy Regulatory Board, established through a legislative act of 1995, gives the board the responsibility of issuing licences for the production and handling of energy and petroleum products

Table 3. National energy (electricity) legislations [12].

Country	Wind	Solar PV	Concentrating solar power	Small hydro	Biomass	Geothermal
Kenya	√	√	√	√	√	√
Uganda	√	Auction		√	√	√
Namibia	√	√	√		√	
Zambia (Draft Sep 15)	√	√	√	√	√	√
Source: www.bluehorizon.energy [13]						

Table 4. Existing renewable energy feed-in-tariff programs (website: www.bluehorizon.energy [13]).

Diversification of the energy system is one way of resolving this problem. Some factors to consider are as follows:

1. **Dependence on large dams:** the seasonal variability of hydropower output and the impact of prolonged droughts in the region create fragile power systems and increase the financial and climate risks; secondly owing to very high upfront costs, long-term financial viability is not assured.

2. **Dependence on fossil fuels:** the challenges include local air pollution and public health concerns, as well as susceptibility to global fluctuations in fossil fuels prices.

3. **Distributed energy resources (DERs):** the modular nature of renewables such as solar and small-scale hydropower and the improved knowledge and management of energy distribution systems have made DERs an attractive option especially for off-grid applications. Product systems include solar lanterns, solar home systems and solar micro-grids.

4. **Renewables:** offer opportunities for improving and developing energy access as they can be deployed at different levels from small to large systems.

5. **Micro-grids:** a micro-grid is a lower level electricity supply generation and distribution system that delivers electricity to several structures in a village. Micro-grids can supply power to even remote locations because advances in ICTs facilitate demand projecting and pay-as-you-go services. Also, micro-grids do not need huge investments and lengthy construction times—notwithstanding that capital costs are still prohibitive for small- and medium-sized businesses. Initial micro-grids were based on fossil fuels such as diesel; their performance was highly dependent on reliability of fuels supplies as well as fuel prices. However, advancement in renewables has made micro-grids more appealing. An example of a micro-grid is that at a village called Motshegaletau in central Botswana, the village had a population of about 700 as at 1997 projections; the micro-grid consisted of a PV array with an output of 5.7 kW, 48 V dc from 20 x 285 W panels arranged in five parallel rows; two sine wave inverters convert 48 V DC to 230 V AC. Forty-eight batteries rated 2 V DC, 1200 Ah connected in two parallel strings form the battery storage bank rated 48 V DC nominal and 2400 Ah. The grid supplied nine residential houses, a bar, a clinic and a school.

6. **Energy efficiency:** supply side and demand side inefficiencies certainly implicate negatively on improving access to electricity supplies; cogeneration and trigeneration technologies can enhance supply side electricity efficiencies. A successful case of biofuel-based cogeneration has been demonstrated in the sugar industry where the bagasse by-product is used to fire steam generators for heat and electricity production. For instance, Mauritius has been able to meet about half of her electricity needs from bagasse cogeneration plants following reforms aimed at making the sugar industry more attractive for investment. A number of countries in East Africa and Southern Africa have large sugar industrial sectors.

2.5. Promoting sub-continental regional relations and trade in electricity

Regional power pools:

Currently, the sub-continent has four regional power pools; intra- and inter-regional power pools collaborations could help improve performance of the power sector through economies of scale, security of supply from a rich energy mix, and cost efficiency through shared energy storage and improved demand side response management.

2.6. Developing effective and innovative revenue payment and collection systems such as flexible payment schemes

i. **Pay-As-You-Go (PAYG) business model:** Under this model, consumers can finance off-grid renewable electricity systems such as solar lanterns, solar home systems and solar micro-grids either by paying the full cost upfront or by paying in instalments over time using mobile money mechanisms such as M-PESA and Airtel MTN. Two companies, M-Kopa and Mobisol, have adopted this model and are using it in East Africa where off-grid low-income and rising middle-class customers who are unable to pay a once off full purchase price for solar home systems, have been enabled to access electricity services. The M-Kopa systems consist of 8 W solar panels, LED lights, a rechargeable radio, and a cell-phone charger. As of 2016, M-Kopa had connected more than 300,000 homes to solar power (website: www.pwc.co.uk [14]; website: m-kopa.com [15]) while Mobisol, has to date installed more than 3 MW of solar home system capacity in Rwanda and Tanzania (website: [16] energy-access.gnesd.org) (**Figure 1**).

ii. **Fee-for-Use (F4U) business model**: Under this model, the customer does not buy the stand-alone system, but only pays rent to use it. A solar company retains ownership, ensures that the system is operating properly and is responsible for maintenance. The customer makes a one-time installation payment as well as reoccurring fixed payments based on the size of the system. The M-POWER company offers to Tanzania rural people a solar home system (SHS) which includes: the hardware to generate solar energy (solar panel, storage and wires) and energy using products (EUP) (two lights and phone charger). Customers pay as a pay per period (daily fees). Off Grid Electric maintains proprietorship of SHS and EUPs and develops a network of local artisans/dealers for installation and technical support [17] (**Figure 2**).

The foregoing discussion illustrates that widespread electricity access is achievable as demonstrated by the two countries, Seychelles and Mauritius, with 100% electricity access; it also points to the complexities associated with tackling the problem of electricity access; for instance, three countries have less than 10% access and 50 of the 70 countries recorded have less than 50% access.

Figure 1. A 100 W solar home system with kit of DC appliances from Mobisol (source: Mobisol, 2017).

Figure 2. A client showing an M-power solar product based on a 'pay-per-period' concept.

It is also noted that several countries are taking measures to deal with the problem of electricity access. Some of these measures include market liberalisation and development of appropriate legislations. Other initiatives are the promotion of sub-regional integration and development of innovative financing capital and client flexible repayment schemes.

3. Clean and improved cooking technologies

Clean cooking solutions or clean fuels and technologies for cooking refer to combinations of clean cooking fuels and compatible improved cooking equipment; as well as the infrastructure for fuel production and distribution. Clean fuels are fuels which during combustion emit little to no pollutants that are harmful to health and the environment. They include ethanol, biogas and jatropha oil; liquid petroleum gas (LPG) and kerosene may also be admissible. Improved cooking stoves are safer to use and have higher energy efficiencies thus consuming less fuel. Examples of equipment for the production of fuel include biogas digesters, ethanol distillation equipment and jatropha oil extracting machinery, whereas examples of distribution infrastructure embrace local selling points for bottled LPG and pump stations for kerosene. Solar cookers and electricity are also considered clean cooking solutions but have not attained wide spread usage in the sub-Saharan Africa region [4]. Current statistics show that 3.04 billion people are living without clean cooking globally. Around 600 million people residing in sub-Saharan Africa, 76% of the populace rely upon conventional solid biomass fuels as their principal energy resource [18].

Traditional fuels produce dangerous emissions which are a health hazard especially when used indoors and under poor ventilation; in addition, these fuels have very low energy efficiencies,

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and the heat produced is highly difficult to control. Traditional biomass fuels mainly refer to non-processed or semi-processed solid biomass used mainly for generating heat for cooking and for space heating usually in the form of a simple open fire or with basic wood and charcoal stoves. Traditional forms of biomass energy mainly include wood, wood waste, charcoal, animal waste and other agricultural residues. These fuels are characterised by low efficiency, poor handling and storage. **Table 5** shows woodfuel usage patterns in some sub-Saharan African countries.

3.1. Improved traditional fuels and technologies

These are traditional biomass-based fuels that have characteristics of improved efficiencies and/or sustainably produced. They include improved biomass cookstoves, charcoal, fuel briquettes and sustainable woodfuel.

3.1.1. Improved cookstoves

Initial attempts at finding solutions to the inefficient traditional biomass fuels have been to integrate improved cookstoves into the traditional biomass fuels setting. In the absence of a formally agreed definition of an advanced cookstove, it for the most part implies a stove that cooks more effectively than the customary three-stone stove [1]. Potential benefits of adopting use of improved cookstoves are reductions in indoor air pollution resulting from improved combustion rates, and reduced cooking times and fuel requirements. Cookstoves that incorporate forced ventilation are capable of eliminating pollutants all together. Improved cookstove designs vary depending on the fuel being used; fuels used range from solid fuels such as fuelwood, charcoal, coal, fuel briquettes to liquid/gel fuel and gas fuels; as such local specific aspects need to be built into the stoves; in South Africa, for instance, there is wide spread use of coal for cooking and heating; thus necessitating research and development work on clean coal stoves such as those undertaken by the South Africa's council for scientific and industrial research (CSIR) and New Dawn Engineering's Mr. Crispin Pemberton-Pigott (website: www.pciaonline.org [19]). **Figure 3** shows some of the improved cookstoves exhibited at the people energy network **(**PEN) workshop 2009 at University of Johannesburg, South Africa.

Country	Percentage of total population living in rural and urban areas		Percentage of rural, urban and total population dependent on firewood		
	Rural (%)	Urban (%)	Rural (%)	Urban (%)	Total (%)
Tanzania	76.9	23.1	95.6	26.7	77.4
Uganda	87.7	12.3	91.3	22.1	81.6
Senegal	59.3	40.7	89.1	15.9	54.7
Zambia	65.4	34.6	87.7	10.1	60.9
Malawi	85.6	14.4	98.5	69.0	94.3
Kenya	64.1	35.9	88.4	9.6	68.8

Table 5. Firewood usage in some sub-Saharan African countries [18].

Figure 3. Pictures of combustors on exhibit at inaugural PEN workshop 2009. (source: Author).

3.1.2. Charcoal

Perhaps one fuel, among traditional biomass fuel types, requiring special mention is charcoal. It is a porous carbonaceous black solid fuel produced through the pyrolysis treatment of unprocessed solid biomass fuels. In sub-Saharan Africa, it is mainly produced through the slow burning of woodfuel in earth kilns and under restricted air flow. It emits fewer pollutants and has a higher energy density than firewood thus making is less bulk and relatively easier to transport. It has widespread usage especially among the low and middle income urbanites. It is, however, still not considered a clean fuel as it is inefficient and has levels of pollutants not ideal for household cooking. **Table 6** shows charcoal usage pattern in some sub-Saharan African countries.

3.1.3. Fuel briquettes

Fuel briquettes are made from powdery or granular industrial waste such as coal dust, charcoal dust, saw dust and wood shavings, waste paper and pulp, or bagasse, and so on. This powdery waste material is normally mixed with a binder; this is followed by moulding under pressure. It is then either simply dried or subjected to carbonisation process that is exposed to intense heat under limited airflow. The environmental performance and combustion efficiency of fuel briquettes are highly dependent on the type and source of materials used in its manufacture.

3.1.4. Sustainable woodfuel

Woodfuel is cultivable. One idea that is normally considered is that of sustainable woodfuel, implying that the forest stock used as fuel is replenished through tree planting thus contributing carbon neutrality of the type of fuel.

3.2. Modern fuels and technologies

Modern cooking fuels are so referred and distinguished from traditional cooking fuels on account of ease of handle ability and controllability during use, higher energy efficiency and clean burning with little or no harmful emissions and as such possessing health and

Country	Rural (%)	Urban (%)	Total (%)
Tanzania	3.6	52.9	16.7
Uganda	7.0	66.8	15.4
Senegal	1.8	12.1	6.6
Zambia	9.5	52.1	24.3
Malawi	0.4	15.5	2.5
Kenya	6.0	20.8	9.7

Table 6. Level of charcoal use for fuel in selected African nations [18].

environmental benefits. Both LPG and biogas are considered examples of gaseous clean fuels while ethanol and jatropha oil are examples of liquid clean fuels. The discussion also covers electricity and solar thermal for cooking, two clean cooking fuels that have not been successfully adopted in the region; kerosene is also discussed as it is considered relatively cleaner that the traditional fuels [20].

3.2.1. Kerosene

Kerosene is a fossil fuel produced as a distillate mainly from crude oil refineries. It is not considered a clean cooking fuel but considered a slight improvement on traditional biomass fuels in that its combustion does not produce as much harmful pollutants, and that it is easier to handle, transport, store and control during use. It is widely used in the urban areas of sub-Saharan Africa. It is predominantly used in two types of combustors, wick type and pressurised cookstoves.

3.2.2. Jatropha oil

Jatropha curcas is a small bush-like plant. The oil from jatropha seeds has a wide range of useful applications. It is traditionally used for medicinal purposes and could find some ground in the pharmaceutical industries. It is widely used for biodiesel production. Further advancements in biofuel stoves technology are needed in order for jatropha to become attractive as an alternative to traditional biomass fuels.

3.2.3. Biogas

Biogas is a clean gaseous fuel suitable for household cooking. It is a gaseous mixture rich in methane gas, produced through anaerobic digestion of biodegradable domestic waste, landfill/municipal waste or agricultural residues; it can also be used for lighting or at larger scales for electricity generation. However, its widespread uptake has been constrained by lack of reliable and adequate availability of feedstock such as in areas where farmers practice free range livestock keeping, as well as socio-cultural factors such as the acceptance of human excreta as feedstock.

3.2.4. Liquefied petroleum gas

Liquefied petroleum gas (LPG) is a mixture of hydrocarbon gases mainly propane and butane. Despite being a fossil fuel, LPG has low carbon content and a high calorific value of around 50 kilojoules per gram; it burns clean and completely with a blue smokeless flame, producing fewer soot particulates. It is also safe, nontoxic and considered relatively affordable. It is potentially a better substitute for traditional biomass fuels.

3.2.5. Ethanol and gelfuel

Several countries in Africa are currently distilling ethanol which is mainly used as an additive in transportation fuels. Ethanol is very well suited as a household cooking fuel. Ethanol production is a matured technology, though there are several controversies surrounding the use of food crops (cassava, sorghum, maize, wheat, etc.) for biofuels. Further conversion of ethanol to gelfuel is thought to improve its handle ability and reduce risks associated with burning ethanol for household cooking.

3.2.6. Electricity

Ideally, electricity would be the fuel of choice. It is a clean and highly efficient energy suitable for cooking; but sub-Saharan Africa's grid network is so underdeveloped and the installed capacity so low, the majority of households cannot access electricity supply.

3.2.7. Solar cooking

Solar cookers use sunlight for cooking, drying and pasteurisation. Solar cooking offsets fuel costs, reduces demand for fuel or firewood, and improves air quality by reducing or removing a source of smoke.

The simplest type of solar cooker is the box cooker. A basic box cooker consists of an insulated container with a transparent lid. These cookers can be used effectively with partially overcast skies and will typically reach 50–100°C.

Concentrating solar cookers use reflectors to concentrate solar energy onto a cooking container. The most common reflector geometries are flat plate, disc and parabolic trough type. These designs cook faster at higher temperatures (up to 350°C) but require direct light to function properly.

An example of a concentrating technology is that known as the Scheffler reflector. This technology was first developed by Wolfgang Scheffler in 1986. A Scheffler reflector is a parabolic dish that uses single axis tracking to follow the Sun's daily course. These reflectors have a flexible reflective surface that is able to change its curvature to adjust to seasonal variations in the incident angle of sunlight. Scheffler reflectors have the advantage of having a fixed focal point which improves the ease of cooking and are able to reach temperatures of 450–650°C. The world's largest Scheffler reflector system is found in Abu Road, Rajasthan India and it is capable of cooking up to 35,000 meals a day. A number of pilot solar cooking systems have

Figure 4. A collection of solar cookers at international conference on solar cooking, Kimberley-South Africa 27-27 November 2000 (source: Author).

Figure 5. Preparing meals using SK12-Improved version of SK14 Kimberley-South Africa 27-27 November 2000 (source: Author).

been constructed in sub-Saharan Africa, such as those installed in Botswana and South Africa. A company called Rural Industries Innovation Centre (RIIC) made six installations of a 7m^2 Scheffler cooker in Botswana in the late 1990s; 16 units of smaller version cooker, SK14, were also distributed to families in the mining town of Jwaneng in Botswana [21]. **Figures 4** and **5** show solar cookers on exhibition and in-use, respectively.

From the preceding discussion, it is evident that a diversity of improved and clean cooking technologies is available in varying formats and mixes for different parts of the sub-continent. Barriers to effective adoption of these technologies are quite wide-ranging and include lack of technological support (localised technology manufacture and maintenance, localised fuels production and distribution networks), higher costs and lack of flexible purchase and repayment schemes, as well as lack of information and awareness. Some efforts are being undertaken to address these barriers; for instance, the Global Alliance for Clean Cookstoves, an initiative hosted by the UN Foundation in support of Sustainable Energy for All, a public-private partnership that seeks to save lives, improve livelihoods, empower women, and protect the environment by creating a thriving global market for clean and efficient household cooking solutions; the alliance has a goal of enabling an additional 100 million homes to adopt clean and efficient stoves and fuels by 2020 (website: www.unfoundation.org [22]).

4. Biofuels for transportation

Transportation energy technologies refer to all forms of energy and corresponding infrastructure for facilitation of mobility of vehicular objects. As such they include fossil based fuels technologies, biofuel-based technologies, electricity based technologies and nuclear energy-based propulsion technologies. Clean transportation fuels technologies refer to various fuel-technology combinations in the transport sector characterised by reduced or no greenhouse gas (GHG) emissions. Electrically powered transportation in the form of electric trains and ships has been in existence for centuries, from the 1830s when the Scottish, Robert Anderson invented the first crude electric carriage to the (website: www.pbs.org [23]) to the futuristic notion of all-cars-electric by 2040 (website: news.nationalgeographic.com [24]); numerous efforts for electric automobiles are currently under consideration or development by several technology and manufacturing companies. Efforts for replacement of fossil fuels by biofuels have also been widely explored.

Biofuels are liquid and gaseous fuels produced from biomass, used in the transport sector. Biofuels can be classified into conventional and advanced forms [25]:

- Conventional biofuels (also referred to as first generation) are well-established technologies that are, currently, under commercial production; they include ethanol (processed from corn, sugarcane, wheat, sugarbeet, cassava, etc.), biodiesel (from rapeseed, soybean, oil palm, sunflower, etc.) and biogas (produced via anaerobic digestion of energy crops such as maize silage and waste such as bio-waste including manure).

- Advanced biofuels, also referred to as second generation biofuels, are to a larger extend still at developmental stage, and are mainly produced from non-edible biomass such as cellulose (plant stalks), non-food crops such as jatropha and tobacco, and bio-waste or by-products of food industries such as molasses from sugar processing. Third generation (biofuels from algae) and fourth generation (microbial biotechnology) are still at conceptual stages.

Bioethanol and biodiesel are the most common types of biofuels. The use of bioethanol and biodiesel as transport fuels is very attractive due to reduction of combustion emissions, accessibility from renewable resources, and biodegradability [12, 18, 26]. Over the past decade, the production of bioethanol and biodiesel has been extensively investigated worldwide and their production methods have proved successful in the USA and Brazil [4, 18, 27]. However, in sub-Saharan Africa (SSA), large-scale industrial production and commercialization are stagnant. This section provides a brief review on the potential for biofuels as a transportation fuel in SSA [4].

Access to reliable and affordable transportation infrastructure and services, although, and probably justifiably so, not considered as critical as access to electricity and/or clean cooking technologies, has a greater bearing on any meaningful developmental initiatives, including on the development of infrastructure for adequate provision of electricity and clean cooking. Access to affordable and reliable 'fuel' cannot be divorced from transportation and in turn to socio-economic development. Many countries, in SSA, face insecure fuel supplies due to fluctuating fossil fuel prices, inadequate distribution networks, civil wars, as well as lack of foreign currency. A well-developed biofuels industry will contribute to solving the transportation problem; in addition a number of spin-off benefits to be gained from a well-developed biofuels industry will include:

- ensuring availability of affordable fuel to rural communities for household electrification, powering farming machinery, and transportation;
- stabilising the sub-continent's energy supply and diversifying its fuel options and reducing the burden on oil importing countries;
- creating opportunities for exports of biofuel feedstocks to industrialised countries by African farmers;
- providing many employment opportunities to African people and boost the continent's economy; and
- assisting industrialised sub-Saharan Africa countries, such as Egypt, Nigeria, and South Africa that are among the leading carbon emitters in the continent in mitigating carbon emissions.

In closing the discussion under this section, it suffices to point out that sub-Saharan Africa presents greater potential for development of a strong biofuel industry. There are several ongoing and commenced initiatives regarding biofuels development in sub-Saharan Africa. **Table 7** shows some of such initiatives:

Country	Biofuel initiatives
Burkina Faso	A Dutch funded government project, Fondation Fasobiocarburant (FFB) has promoted planting of 70,000 trees of jatropha oil seeds in 2009.
Ghana	Ghana's bioenergy policy aims at attaining 20% blend of biofuels with petroleum fuels by 2030. Initial production of ethanol has been from cassava and sugarcane. Other feedstocks considered are maize and jatropha oil seeds.
Mali	an NGO, Mali-Folkecenter Nyetaa has developed an innovative project whereby the local farmers of Garalo village, in the vicinity of the centre, have grouped themselves into cooperatives for growing of jatropha, intercropped with other cereals; the jatropha seeds are pressed into oil that is supplied to the centre; in turn the centre operates a 300 kW installed capacity plant with a 15 km mini-grid supplying electricity to the 10,000 inhabitants of the village.
Malawi	Bioethanol for fuel is produced by two captive distilleries at Dwangwa and Nchalo sugar estates at annual capacities of 15–20 million litres and 12 million litres, respectively. The fuel grade bioethanol is blended at 20% (v/v) with petrol by the petroleum industry. Local farmers are also involved in the sugarcane production under out-growers schemes; local farmers have also been engaged to grow over ten million jatropha trees under a 5 years project.
Mozambique	Mozambique Government has implemented a 5–10% (v/v) blend for bioethanol with petroleum. Ndzilo plant delivers close to two million litres of ethanol from cassava. Biodiesel is produced from jatropha oil seeds by two companies, Petromoc and SunBiofuels.
Nigeria	Five big companies distil about 134 million litres of ethanol every year in Nigeria. Biodiesel is produced by companies such as Biodiesel Nigeria Limited in Lagos State, Aura Bio-Corporation in Cross River State, and the Shashwat Jatropha in Kebbi State.
South Africa	Government plans to reduce fossil fuels imports by substituting it with biofuels. It has thus passed legislation that requires a mandatory 2% blend for all petrol and diesel products as of 2015; with plans to increase the blend proportion as the biofuels industry grows. A few companies have been issued licences for the production of bioethanol and biodiesel. Biomethane, bioelectricity and biohydrogen are also under consideration for incorporation in the mix for clean fuels for transportation.
Tanzania	Seven companies and NGOs include Diligent Tanzania Ltd., Kakute Ltd., ARI-Monduli, MVIWATA, Kikuletwa Farm, Jatropha Products Tanzania Limited, and Tanzanian Traditional Energy Development and Environment Organisation are involved in jatropha tree planting and production of biodiesel

Table 7. Biofuel initiative in sub-Saharan Africa [28].

5. Conclusion and a way forward

Lack of access to clean and modern energy, including energy poverty, is quite prevalent in sub-Saharan Africa, with the majority of the population relying on traditional biomass fuels. Traditional biomass fuels are associated with low energy efficiencies, difficult to control and are a health hazard. Electricity supply and connectivity is far outstripped by demand and is beyond the means of the majority poor people. It is widely acknowledged that access to affordable, reliable, sustainable and modern energy for all is a common necessity for socio-economic development as espoused by the sustainable development goal number seven (SGD 7).

More than half of all Africans have no access to electricity; regrettably, this also represents more than half of all people without electricity globally. The traditional electricity system in most countries evolved as large, centralised, fossil fuel or large hydropower systems operating on a monopolistic, state-owned, vertically-integrated model characterised by inefficient management and poor performance. Some of the efforts aimed at redressing this situation include liberalisation of the electricity market, development of market and legal frameworks, streamlining the performance of state-owned electricity utilities, promoting sub-regional electricity trade, as well as development of innovative financing and revenue repayment and collection mechanisms.

Improved traditional cooking technologies include improved cookstoves and higher energy-content traditional fuel forms. These, generally, do not meet the requirements clean, modern cooking technologies. Modern fuels and cooking technologies include cleaner fossil fuels (kerosene and LPG), biofuels (jatropha oil, biogas and ethanol), and electricity and solar cooking. Lack of awareness, lack of technological support and higher costs are the main barriers to the widespread adoption of modern cooking technologies.

Biofuels for transportation are at different developmental stages with bioethanol and biodiesel being the most advanced and commercialised globally. In sub-Saharan Africa, however, the biofuel industry remains largely underdeveloped, although isolated significant developments have been recorded. Substantial potential for the biofuel industry is substantial and so are the potential benefits.

As an ending to this chapter, it worth noting the following:

- There is no 'One-Size-Fits-All' or 'Cut-and-Paste' solution to the problems of energy access and poverty in Sub-Saharan Africa; each scenario requires a unique solution apt to its details; that is, the stakeholders (users included), available energy resources, level of socio-economic and industrial development, and so on.
- Lessons can be learnt from success stories such as the 100% electricity access in Mauritius and Seychelles, LPG roll out program in Senegal (website: stoves.bioenergylists.org [29]), Free Basic Electricity (FBE) scheme in South Africa (website: flash.co.za [30]).
- Notwithstanding the merits of a competitive and profitable energy model, it remains governments' obligation to develop systems that ensure universal modern and sustainable energy access is availed to those that cannot afford.

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Electric Vehicle Promotion Policy in Taiwan

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Additional information is available at the end of the chapter

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Abstract

The developmental patterns of automotive industries in developing countries differ from those in developed countries. Nations should actively and effectively develop an electric vehicle (EV) industry to reduce carbon dioxide emissions and energy consumption, especially during this period of increasing fuel prices and emphasis on saving energy and reducing carbon emissions. From interdisciplinary perspectives, this study analyzed the promotion methods of the EV industry in Taiwan. In addition, we suggest that the Taiwan government should use its advantages in Central Taiwan to assemble mature suppliers of precision machinery in this area to facilitate long-term research and development for the EV industry. This study provides an empirical experience for emerging cities in developing countries regarding the development of the EV industry and is an appropriate reference for the creation of EV industry clusters.

Keywords: EV, electric vehicle, EV industry, carbon-reducing policy, green transportation

1. Introduction

Because China's economy and other developing countries are experiencing rapid development, the automotive industry has become one of the most quickly developing industries and is a major source of air pollution. To improve air quality, numerous governments of developed countries have established relevant laws and policies [1] to decrease the number of active old vehicles and actively develop the low-pollution or low-emission automotive industry through subsidization. McElroy [2] argued that subsidies are a constructive option for the development of relevant industries and for reducing our dependence on traditional energy sources.

Traditional studies regarding gaseous pollutants from automobile emissions have focused on microcosmic or technical discussions, such as the improvement of internal combustion engine efficiency (e.g., see [3]). Macroscopic perspectives on industrial development are scant, as are comprehensive studies on the EV industry. However, because they are constrained by financial and market factors, developing countries should identify a novel pattern for developing automotive industries that differs from those of developed countries and should actively and efficiently develop EV industries to reduce carbon dioxide emissions and energy consumption. These are particularly pressing issues because of increasing fuel prices and the current emphasis on saving energy and reducing carbon emissions.

Taiwan government eagerly promotes the low-carbon policy in recent years. Since being selected by the Environmental Protection Administration (Executive Yuan) of Taiwan as a low-carbon model city, the Taichung city government issued the "Regulations of task force for the promotion of low-carbon city, Taichung city government" on October 24, 2011. This study uses that experience to explain the EV promotion policy in Taiwan.

To foster and initiate low-carbon industries, the city government founded the "economic development and agriculture team" within the promotion task force to evaluate related carbon-reducing policies and plans for the development of Taichung industries. The results of these measures led to Taichung's emergence as the best city in Taiwan. Regarding the experience pattern or model of Taichung's development, this study examined Taichung's efforts in assisting the EV industry and in transforming local industries into low-carbon industries from interdisciplinary perspectives. In addition, this study also evaluated and analyzed the feasibility of future plans. The developmental patterns that we examined can be used as a reference for industrial planning by similar cities in developing countries and can contribute to creating a low-carbon and green industry environment.

2. Literature review

Regarding the policies adopted by governments for industrial development, Rothwell and Zegveld [4] suggested that innovation in emerging technologies and industries can facilitate national economic growth. From the perspective of industry, policies are a practical means for governments to become involved in the technological development system. Governmental innovation policies should include technological and industrial policies, and, according to their influence or effects on technological activities, policies are categorized as bellow:

- Supply policies: manpower, finance, public services, and technical support are the determinants of a government's direct involvement in technology supply.
- Demand policies: governments establish market-centered policies that provide demands for technology and, thereby, affect technology development, such as purchases and contracts regarding technological products by central or local governments.
- Environmental policies: governments draw up related laws, including industry districts or parks, taxes, and patents, that regulate the economy and indirectly affect the technology

development environment. To achieve their various goals, governments should adopt different methods and means to execute their policies.

Therefore, governments should implement the establishment of EV industry clusters using the above policy facets. Porter [5] provides the following definition of the "clustering effect": If the upstream and downstream of a specific industry tend to correlate in terms of regions, they will progressively evolve into a structure of economic benefit that elevates mutual efficiency and professionalism. Consequently, a cluster of enterprises dramatically enhances the overall competiveness of industries through self-development and flexible adjustment using internal forces. Kotval and Mullin [6] indicated that clusters have become planning behaviors conducted and adopted by nations, governments, and local authorities. Many nations include industry clusters as a national policy to enhance their international competitiveness. For example, the U.K. promotes the information and technology industry in the Thames Valley, develops engineering-related clusters in the Northeast, promotes aviation industry clusters in Bristol, and develops biochemical technology near Cambridge [7]. In addition, numerous other areas have had similar success in the establishment of clusters [8, 9], such as the most acclaimed example of a successful cluster: Silicon Valley in California.

Furthermore, in terms of law and technology law, legislation regarding energy laws and regulations has gained increasing attention from developed countries. Specifically, during the energy crisis in the 1970s, governments in developed countries exercised peak control of energy-based commercial activities [10]. Elliott [11] cited the UK as an example, which amended its Building Regulations in 2004 because of carbon trading concepts. Bührke [12] approved of the German federal government's action of reducing 40% of Germany's carbon dioxide emissions by enacting the Renewable Energy Sources Act (EEG). In 1992, the United States passed the Energy Policy Act (EP Act 92), which has played a critical role in the restructuring of the power and electricity industry. The act was amended in 2005 (EP Act 2005) to reinforce the influence of the Federal Energy Regulatory Commission (FERC) in the power and electricity industry. The American Recovery and Reinvestment Act (ARRA) of 2009 perpetuated the strength of the federal government in energy and power policies and regulations. Therefore, powerful interventions from the government and legislative support are necessary for energy and power policies and regulations [10].

Preparations for developing EVs, such as regulatory administration that can limit traditional vehicles, or supply administration that rewards and subsidizes the EV industry, cannot be ignored. Relevant departments must conduct a regulatory impact analysis (RIA) [13–15] to judiciously plan the comprehensiveness of legislation for regulatory and supply administration. Similar to business impact analysis (BIA), RIA requires that administrative sections or agencies clearly specify regulative backgrounds (e.g., the overall economic environment and market structure of industries), controversies regarding acts and laws caused by social demands and conflicts relevant to existing laws, expected efficacy or function of acts, and the relationships among issues during the legislative operations process. These sections and agencies should also propose and draft plausible measures (including concrete regulative contents for all possible legal and non-legal alternatives, and clarification of their necessity) and analyze and evaluate the related efficiency and costs influenced by people, enterprises, and governments for the implementation of these measures, which provides a reference standard for governmental legislation. Staroňová et al. [16] proposed that the quality of legislative drafts could be enhanced using RIA, and Hertin et al. [17] maintained that RIA ensures appropriate policy deliberations and provides for effective problem-solving within policy design.

In addition, because the regulatory administration that limits traditional vehicles is a violation of people's freedom and rights, according to Articles 102 and 164 of the Administrative Procedure Act, Taiwan's government is responsible for holding hearings in which public opinions and feedback are consulted. Noland [18] argued that proper assessment procedures are a means to keep the rhetoric surrounding decision-making honest, both by providing the best information and analysis to the public and by establishing a framework for examining this information.

Based on evaluation information regarding industrial environments and external markets, this study provides a guide for market strategy positioning and an analysis of industrial innovation requirements and industrial portfolios. Furthermore, we provide advices regarding the developmental strategy of the EV industry in Taichung, Taiwan, and these suggestions can be expanded as reference standards for industrial development in similar cities in developing countries.

3. The practical EV experience in Taiwan

3.1. The current status and operations of EV in Taichung, Taiwan

Being the second large city in Taiwan, Taichung city government takes lots of measures to promote innovations. In recent years, numerous innovations and advancements, such as the development of broadband infrastructure and the construction of an intelligent city, were implemented by the Taichung city government. As a first-time applicant, Taichung was named one of the top seven intelligent cities in the World in 2012 by the Intelligent Community Forum (ICF). Furthermore, Taichung city was nominated Smarter City in "Smarter Cities Challenge" plan by IBM in 2015, the only city in Taiwan. The Taichung city government is enthusiastically constructing a "carbon free, trouble free" world-class city, and establishes low-carbon city promotion task force to implement the related policies, especially the EV policy.

The most notable measure on the part of the Taichung city government was the distribution of 64 intelligent EVs to government departments for official use on February 7, 2012. The government also created 64 charging stations, demonstrating Taichung's determination to create a leading low-carbon model city in Taiwan. Furthermore, to promote Taichung as an EV model city, the mayor proclaimed an exemption for vehicle license taxes, fuel taxes, parking fees, and charging fees for EVs. One week later, it was announced that free shuttle EVs would be available to citizens and officials for use between three major civic centers in Taichung.

Regarding administrative work, the Environmental Protection Bureau of Taichung city government has enacted the "regulations for applications and verifications of air pollution prevention funds for establishing air quality purification areas and low-carbon city facilities." These regulations provide subsidies for Taichung city government offices and public schools to establish EV charging stations, with an amount of NTD$ 100–200 thousand provided based on the construction process for each station. Therefore, Taichung has made a firm step in better utilizing government vehicles and public services for citizens. Research for relevant industries indicates that the 2009 greenhouse gas emissions caused by fuel combustion in Taichung comprised 4285.8 thousand metric tons, which was 42.9% of the total greenhouse gas emissions. Compared with the emissions from 2000, we determined that the increased rate of greenhouse gas emissions during these 10 years was 31.05%. The government of Taichung plans to achieve its mid-stage goal for energy and resource reduction before 2020 by actively developing the EV industry and relevant complementary measures. The goal of the Taichung city government is to reduce the consumption of diesel fuel and gasoline by 42.09 and 21.99%, respectively, with a total greenhouse gas reduction rate of 28.98%.

3.2. Prospects of the EV Industry in Taiwan

According to an evaluation report published by the Intergovernmental Panel on Climate Change (IPCC), current global warming, which is chiefly caused by human activities, manifests a clear tendency that will result in a greenhouse effect that induces famine, water shortages, and the extinction of one third of existing species [19]. After the Kyoto Protocol took effect in 2005, the signatories created various compulsory or flexible regulatory mechanisms, such as carbon levies or taxes and carbon trading, to achieve the goal of reducing greenhouse gas emissions. Taiwan is not a member of the United Nations and did not sign the Kyoto Protocol. However, Taiwan cannot ignore the responsibility of being a global citizen. Taiwan should comply with relevant environmental protection conventions and regulations because it adopts trading and commercial relationships with numerous countries and relevant industries in the country experience the pressure of globalization and internationalization.

The central government of Taiwan has responded to this trend, and the Intelligent Electric Vehicle Promotion Office, Industrial Development Bureau, Ministry of Economic Affairs, was officially established in 2010. In addition, the Executive Yuan has listed intelligent EVs as a priority among the four major emerging intelligent industries. The Ministry of Economic Affairs created and drafted the "Intelligent Electric Vehicle Development Strategies and Promotion Plan" and five explicit major promotional strategies to popularize the use of EVs by actively constructing environmental facilities and providing tax concessions. By assisting industrial development, the government intends to make the development of EVs in Taiwan a global model and to fulfill the policy goal of creating a low-carbon Taiwan. It is expected that by 2016, over 60 thousand intelligent EVs will have been produced, an output value for manufacturing greater than NTD$ 120 billion and an output value for the service industry of NTD$ 31.2 billion achieved, and more than 24,000 jobs created. In the future, the Ministry of Economic Affairs will dedicate itself to developing a prototype for the EV industry chain by proposing solutions for green transportation, ranging from upstream batteries, charging stations, mid-stream motors, controllers and other components, and downstream vehicle manufacturing.

Boyer and Verma [20] explained that, to improve capacity management abilities, appropriate measures should be devised. In addition, Greenhalgh and Rogers [21] suggested that governments should establish innovative policies, create parameters for intellectual property right systems, and provide research funds to industries. Therefore, the prospective development of Taichung should refer to the mentioned suggestions. Furthermore, Taichung as a direct-controlled municipality can induce inter-regional momentum for nearby cities and counties, accommodating long-term developmental strategies for governance mechanisms in administrative regions.

Regarding geographic location and environment, the complete transportation network of Taichung includes Taichung Harbor, the airport, highways, and railways. If geographic and transportation resources can be properly managed and adopted, these can catalyze the growth of industries in Central Taiwan. The Taichung city government manifested its determination to "promote green transportation" and to "build a convenient and friendly green transportation environment" in its 2011–2014 medium-term policy and project outline and environmental health policy planning goals. To achieve this goal, Taiwan government must utilize its advantageous location in Central Taiwan. The central region includes developed machinery industries with complete satellite factories. Consequently, the Taiwan government should assemble mature precision machinery suppliers in the central area to develop and foster the EV industry, and connect with other suppliers in nearby cities and counties such as Changhua and Miaoli to create a green-transportation environment.

3.3. Technology developments and limitations of the EV industry in Taiwan

Presently, power is not the only focus of EV development in advanced countries. The computer technology and added intelligent functions have also been integrated. The major directions for EV research and development comprise two areas: intelligent safety systems and EV systems. Intelligent safety systems, which allow drivers to control their vehicle with greater ease, include forward collision prevention for urban areas, intelligent integrated displays of screen information; driver status monitoring that is integrated with vehicle signals, complete moving object detection, intelligent parking guidance systems, and integrated torque sensors. EV systems include advanced and chic technologies such as full vehicle control systems, constant electricity leakage detection, adjustable air conditioning (including heating and cooling), vacuum brake booster systems, and rapid and flexible battery installation structures. Rechargeable batteries available in the EV market consist of four major types, Ni-MH, LiMn, LiFePO4, and LiNiCoMn, each with respective pros and cons. Scholars believe that LFP batteries, which are extremely safe and long-lasting, will be the choice of the next generation and will be directly used in EVs.

However, EVs' limited power causes doubt for customers when purchasing, for which the wide-spread construction of charging stations and pillars are solutions that can be implemented currently. During the 64th Frankfurt Motor Show in 2011, TÜV Rheinland, Germany, published its "Global Electric Vehicle Survey." The survey was an extensive international research on 12 major global vehicle markets, including China, Denmark, Germany, France, India, Israel, Italy, Japan, Portugal, Spain, the United Kingdom, and the United States. This study indicated that most respondents regarded pricing as the primary intervening factor when considering EV purchase; limited mileage or range was the second factor [22].

Responding to this "range anxiety," some of the battery replacement technologies on the market, such as that developed by Better Place, enable the replacement of the original rental battery in an EV with a fully charged one within 1 minute using robotic arms installed in replacement stations [23]. If related technologies can be introduced, the Taichung City Precision Machinery Innovation Technology Park, with its accomplished experience and ability in precision machinery, could realize this possibility. However, technologies for wireless charging remain in the preliminary stages. The proposals for these technologies, such as those regarding the Alliance for Wireless Power and Plugless Power [24, 25], are too immature to be adopted in practice.

To accommodate this trend, Taiwan must conduct research on pertinent technologies and devise appropriate plans. The core cluster of precision machinery industries in central Taiwan, which has the highest production or output value and density per unit area worldwide, is located in Taichung. The central region's efforts in precision machinery have made Taiwan the fourth leading country in machine tool manufacturing and the third leading country in exports. Machine tool manufacturers in Taichung have developed hard power for manufacturing complete sets or machines and critical parts, especially in areas such as the critical technologies of machine tools for 3C and automobile parts processing, virtual machine tools, computer visual recognition and positioning, and intelligent automation and robotics. In the future, a characteristic EV industrial environment can be established if the industry can further understand trends and accommodate user demands, and employ soft power technologies, such as digital analysis and design, mechatronic integration, and value-added software, from a perspective of system integration.

According to data and statistics from the Taiwan Industrial Technology Research Institute, a total of 37 factories or vendors are currently developing 9 major EV battery related products, including cathode materials, anode materials, battery modules, electrolytes, battery systems, separators, battery cells, current converter modules, and management systems. In addition, because it became a directly-controlled municipality in 2010 and the leading region in Central Taiwan, Taichung should be able to effectively cooperate with nearby cities and counties to expand and develop the EV industry market. As an example, nearby Changhua County possesses more than 200 factories or vendors that produce automobile parts and comprise 10% of related factories in Taiwan. Sales in the tire and rubber industry in Changhua County constitute 50–60% of all automobile part sales in Taiwan (ARTC, 2012). As the largest cluster of automobile parts industries in Taiwan, more than half of all automobile parts are manufactured in Changhua County, including lighting systems, automotive multimedia audio-visual systems, mirrors, tires, seat belts, lamp rims, straps and belts, HID lamps, rear-view mirrors, gear sticks or knobs, windshield wipers, steering wheel covers, headlight rims, car cigarette lighters, carbon removers and cleaners, and decorative accessories. The largest automaker in Taiwan, Yulon Motor, is located in Miaoli County, which is north of Taichung. In 2009, Yulon Motors combined "luxury" and "genius" to create its private brand, "Luxgen," which is the primary EV brand used by the Taichung city government. The Luxgen brand EV run a good start in test project, and it will be the first choice of

Taiwan government use that will be benefit to cultivate the consumer habit of EV. In conclusion, Taichung possesses sufficient qualifications, including advantages in population, geographic location, and industrial environment, for developing the EV industry.

4. Findings and suggestions

4.1. Findings

Mainstream choices in the current automobile market are European, American, and Japanese vehicles, and developing countries should determine custom paths that differ from those of developed countries when developing automobile industries. In light of increasing fuel prices and the emphasis on saving energy and reducing carbon emissions, this study suggests that developing countries, because they are newcomers to the automobile industry, resist endeavors to improve the performance of traditional internal combustion engines. Rather, they should actively and effectively advocate the development of the EV industry, which not only represents a transformation in the form of automobile power, but can be revolutionary in people's lives and in governments' efforts regarding the blue ocean strategy.

Taiwan has actively promoted the EV industry, according to the proclamation of the intelligent EV scheme issued by the Department of Industrial Technology of the Ministry of Economic Affairs: "This scheme aims to promote the technology development of critical parts and the enhancement of product performance for intelligent EVs, and also to refine the verification standard of critical parts for intelligent EVs and the establishment foundation for vehicle verification platforms. The results will be adopted as industry regulations for technological development of intelligent EVs and critical parts to lead the world in the establishment and development of EV specifications".

Although Taichung was selected by Taiwan government as a low-carbon model city and has made a preliminary step in developing EV operations, this study believes that Taichung should dedicate itself to the development of the EV industry as soon as possible, using its advantages in industrial environments and immense EV-related industry chain. The enhancement of the technological competence of existing traditional automobile manufacturers is not the only possible gain. With the assistance of digital technologies, Taiwan could achieve advanced levels similar to those worldwide, and job opportunities for employees with digital talents can be created. Consequently, we offer the following suggestions:

4.2. Suggestions

4.2.1. Administration

- For proper planning of policies, dedicated units should reinforce contact between government organizations:

The dedicated unit of the "low-carbon office" is a high-level unit that makes comprehensive plans and supervises the promotion of green policies in related government organizations in

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Taichung. However, dedicated units should appropriately and promptly consider and detect shifts of external industrial environments and technology and strengthen horizontal contact and communication between governmental organizations to assist the transformation of local industries (e.g., when adopting the goal of building a low-carbon city, the office should promote EVs while simultaneously considering the concept of intelligent houses and consulting the Urban Development Bureau, Economic Development Bureau, Construction Bureau, Transportation Bureau, and Environmental Protection Bureau). Because it is restricted by various organizational positions and capacities, administration is frequently censured for its inability to offer macroscopic opinions with foresight even if each organization has its own responsibilities. Therefore, appropriate policy planning and execution can be achieved by following the example of the operation of the interagency climate change adaptation task force of the U.S. Federal Government.

- Government organizations should actively cooperate with the plans developed by dedicated organization for the superior execution of policies:

The current execution regarding EV promotion policies is under the direction of the Environmental Protection Bureau. However, as mentioned, the bureau is deficient in both its ideas and other duties. To solve this problem, policy instruction and appropriate levels of novel technical ideas can be provided by the low-carbon office. In addition, executive units should deliberate on methods for accommodating policies (e.g., regulation amendments, budgeting, and environment construction) and cultivate core abilities to respond to, and fulfill, policy demands.

- Appropriate reward and incentive measures should be provided to stimulate consumer demand:

The four exemptions of vehicle license taxes, fuel taxes, parking fees, and charging fees that are offered by the Taichung city government, despite their benefits, fail to generate sufficient inducement for consumers to purchase EVs. We believe that consumer demands could be stimulated and the sales and supply of EVs could be enhanced if superior subsidies for vehicle purchasing are provided. An additional means of generating incentive is to follow the example of the policy subsidy of USD$43 million provided for battery manufacturers by the U.S. Department of Energy in August 2012. These subsidies will initiate the advanced emergence of the golden cross for supply and demand curves.

4.2.2. Industries

Following decades of development and transformation, the precision machinery industry has evolved into an essential target for development in Central Taiwan, and the Taichung Precision Machinery Innovation Technology Park is qualified to become a cluster for the EV industry. There are approximately more than 1000 precision machinery manufacturers and tens of thousands of suppliers that comprise an industry population greater than 470,000, accounting for 18% of the employed population, in the central region. The gross output or production value of the precision machinery industry will reach 905.8 billion dollars in 2012 and is an emerging trillion-dollar industry, according to data provided by the Industrial Economics and Knowledge Center of the Industrial Technology Research Institute. Upstream, mid-stream, and downstream industries concentrate in Central Taiwan and the presence of neighboring schools and research institutions encourages the enhancement of research and development for technologies and the frequency of employee and personnel exchange, creating enhanced prospects for industry. The Taichung city government decided to make the Taichung Precision Machinery Innovation Technology Park an intelligent industry cluster (i-Park) after Taichung was named one of the top seven intelligent cities in the beginning of 2012. An intelligent industry service platform for Taichung precision machinery was planned for establishment and will provide companies and the public with a convenient information exchange platform for the promotion of applications such as intelligent energy saving. Based on the above analysis, our suggestions regarding industries are as follows.

- Advanced technologies imports and well-established environmental infrastructure:

The technology in the overall supply chains requires enhancement by providing favorable investment environments to attract investments from foreign hi-tech vendors, and by cultivating local enterprises by strengthening technology transfers through joint ventures. In addition, environmental infrastructure should be strengthened, including the wide-spread establishment of smart meters with bi-directional communication functions, to effectively restrict user loads. Furthermore, no negligence can occur if a smart grid is constructed that incorporates vehicle design, power supply, and electricity grid systems with overall planning. Kim et al. [26] argued that planning and investment for electricity distribution grids and infrastructure should begin as soon as possible. In addition, a well-planned intelligent energy management system (IEMS) is capable of ushering industries into mature and comprehensive stages, increasing opportunities for industry growth.

- Assembling industry clusters and providing rewards and incentives when appropriate:

Based on the aforementioned findings, the Taichung city government should construct an exchange platform for the EV industry and provide necessary technologies and up-to-date information to empower companies. It should also collect and post energy-related knowledge and disseminate information such as relevant websites. Furthermore, for the formation and development of the EV industry, the government should establish industry districts or park and rewards and conveniences such as free transportation and tax subsidies.

4.2.3. Laws and regulations

The RIA indicates that, for the Taichung city government to establish suitable policies and conduct administrative matters in accordance with the law, it should request that its subordinate organizations conduct evaluations on adaptation statements and legislation. These evaluations refer to lists in which affected areas, such as existing plans, activities, traffic or transportation, industrial environments, and land use, are organized based on analyses of various factors, including societal, economic, and industrial environments, from the perspectives of regulatory administration and supply administration. The regulatory administration for restricting traditional vehicles (e.g., restriction on carbon emissions for vehicles of a specific age, fees or taxes on vehicles older than a specific age) is to be regulated by self-government ordinances because, according to Article 28, Paragraph 2 of the Taiwan Local Government Act, “issues that create, deprive, or restrict the rights and duties of residents of local self-governing bodies” should be restricted by self-government ordinances. Comparatively, supply administration regarding rewards or subsidies for the EV industry (e.g., the amount of subsidies, length of subsidies, and benefits or discounts given to EV consumers) should be based on interpretations No. 614 and No. 443 of the Justices of the Constitutional Court for the Judicial Yuan. Supply administration includes less restrictive legislation and does not require regulation by self-government ordinances.

Letcher [27] argued that governments, playing a critical role in traffic planning, should endeavor to solve issues of supply and operation such as externality and fairness. The State of California, for example, has limited the minimum tolerance of the environmental impacts of vehicles through legislation. Furthermore, the California Air Resources Board (CARB) has organized the California zero emissions vehicle (ZEV) program, which, through strict policies and legislation, has a goal of zero carbon emissions and seeks to reduce the level of greenhouse gas emissions to their levels before 1990 by 2050 [28].

To resolve the financial and legislative difficulties encountered by local governments, this study further suggests that the central government issue regulations and rewards through legislation. The Executive Yuan should establish and integrate regulations that can be followed by the entire country. To match the speed of technology's rapid development, related legislation should be more efficient in accommodating these changes than in other fields. Summarizing the above, this study's suggestions regarding laws and regulations are as follows.

- Establishment of an effective environment for policies and laws:

For newly proposed green industries to be successful, an amenable environment for investment and industry is essential. After communicating with relevant companies to understand their demands, governments should create enhanced environments for assistance and subsidies, increase the rewards for industry transformation, and actively establish relevant laws and regulations to legalize and standardize administrative work.

- Attention to the legality of the adoption of international and central government standards:

Central regulations and international treaties and conventions should always be observed in addition to the mentioned legislative demands for the supply administration regarding rewards and subsidies. Article 30, Paragraphs 1 and 2 of the Taiwan Local Government Act, in particular, should be complied with: "Self-government ordinances shall become invalid if contradictory to the Constitution, laws, regulations promulgated in accordance with law, or self-government ordinances of the superior self-governing bodies"; "Self-government regulations shall become invalid if contradictory to the Constitution, laws, regulations promulgated in accordance with law, self-government ordinances of the superior self-governing bodies, or the self-government ordinance of the self-governing body concerned." Overall planning for administration should comply with Articles 163 and 164 of the Administrative Procedure Act in accordance with the principle of "law-based administration."

5. Conclusion

In recent years, Taiwan has suffered from air pollution, especially in Central Taiwan. One of the major sources of pollution is the vehicle, causing a lot of PM2.5 pollutant. The monitoring results of the daily average PM2.5 concentration for the Taichung area frequently reaches 80 μg/m^3 in 2017 winter, according to the data of the Environmental Protection Administration of Taiwan. The WHO standard for the daily average has been established as less than 25 μg/m^3. This type of highly concentrated air pollution has caused damage to the environment and people. Consequently, the Taiwan government is now attempting to reduce the air pollution concentrations in the Taichung area using various methods, and energy consumption is expected to decrease because of the inducement of tax reform incentives and environmental improvements. The development of the utilization of, and subsidies for, electric motorcycles in Taiwan has matured, and Taichung is the most active city in Taiwan striving for EV development. In November 2017, Taiwan's Transport Minister announced that it will replace gasoline vehicles with electric vehicles by 2040 [29]. In the future, Taichung should appropriately employ its advantageous position in Central Taiwan and assemble mature precision machinery suppliers in the area to plan the construction of energy-saving facilities and to cultivate the EV industry. By doing so, Taichung will benefit its citizens and improve Central Taiwan's overall development. After development, the theory of paradigm shifts must be employed, allowing the empirical experience of Taichung to serve as a reference for the development of EV industries and the establishment of EV clusters in emerging cities in developing countries with similar environments and conditions.

5.1. Research limitations and suggestions for future research

Due to relevant limitations, this study was only able to perform analyses through the perspectives of law, public administration, and management, neglecting analytical models in other disciplines and fields. We believe that interdisciplinary research methods can overcome the limitations of traditional research methods that are based on a single academic discipline. However, this research approach lacks quantitative analyses and cannot provide thorough statistics regarding EV development in Taichung.

Furthermore, as an emerging industry, the EV industry displays insufficiency in its independent developmental potential and requires improvement and expansion in its transitional stage and product positioning (e.g., current hybrid vehicles). Although there is an increasing amount of relevant essays being published, studies on zero-emission EVs, particularly on EVs in Taiwan, are scant. This study succeeded in employing the mentioned research methods and conducting interdisciplinary research, but failed to make parallel comparisons between the background factors of developing cities and countries of a similar scale. Various differences, such as those between local and unique customs and traditions or laws and regulations, can be integrated in future related research.

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Section 2

Technologies and Industries

Clean Energy Management

Ali Samadiafshar and Atiyye Ghorbani

Additional information is available at the end of the chapter

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Abstract

Energy is at the heart of most critical economic, environmental and developmental issues facing the world today. Clean, efficient, affordable and reliable energy services are indispensable for global prosperity. Energy management and optimization solution can help reduce energy costs while improving mill operational performance. Therefore, the focus of this chapter is on energy-related issues and it discusses dedicated technological solutions to the growing global needs for sustainable development. In addition, there are a number of other issues, including the latest innovations in terms of clean energy in industry and infrastructure, and improving operational efficiency will be discussed in this chapter.

Keywords: green energy, clean energy, renewable energy, hybrid energy systems, energy management, optimization energy recovery

1. Introduction

Access to reliable, affordable and sustainable energy is essential for improving living standards, development and economic growth [1]. To overcome poverty and improve people health in developing country, it is essential to expand access to reliable and clean energy. In this way, they will be able to increase productivity and promoting economic growth. [2]. Challenges such as fuel shortages, high energy costs, global warming and environmental issues must drive policies that target more affordable and sustainable energy solutions [3]. In essence, one way to overcome poverty, promote health and educational services and enhance socioeconomic development is to ensure reliable, sustainable and affordable energy for everyone. Thus, by considering the mentioned issues, at first clean energy including geothermal energy, biogas and biomass, fuel cells, water-dependent energy, hydrogen energy, hybrid energy systems and in continuation, energy management and optimization are discussed in this chapter.

2. Clean energy

Today, the political and economic crises and other issues, such as the limitation of fossil fuels, environmental concerns, population congestion, economic growth, and consumption rates, are all subjects of the inclusive world, which, with all its widespread implications, have led thinkers to find the right solutions for the proper resolution of world energy problems especially the environmental crisis, has been involved. Obviously, today, the economic and political backing of the countries depends on their productivity from fossil sources, and the depletion of fossil resources is not only a threat to the economies of the exporting countries, but also has created a major concern for the importing economies of the nations. Fortunately, most countries in the world have recognized the importance and role of various energy sources, especially renewable (new) energies, in meeting current and future needs, and broadly exploit these resourceful resources in the development of extensive research and fundamentals [4]. The global tendency toward the exploitation of renewable energy and environmental impacts requires that many organizations and centers interested in implementing projects in this field. Energy is a major requirement for the continuation of economic development and the comfort of human life. At present, world energy consumption is about 10 billion tons of crude per year, and it is expected that this figure will increase to 14 billion tons in 2020. These numbers indicate that the world's energy consumption is huge in the future, and this important question is whether the sources of fossil fuels will meet the world's energy needs for survival, evolution and development in the next century. For at least three main reasons, the answer to this question is negative and old resources should replace new sources of energy. These reasons include limitation of fossil fuels, combustion quality and environmental problems.

Increasing the concentration of carbon dioxide in the atmosphere and its consequences has exposed the world with irreversible and discriminating changes. Increasing the temperature of the earth, climate change, rising sea levels, and eventually intensifying international conflicts are among the consequences. On the other hand, the impending end of fossil resources and the anticipation of rising prices encourage policy makers to propose policies for controlling the environment and researchers to develop less polluting and incendiary resources that have the potential to substitute for the current energy system. For this reason, renewable energies take on a larger share of the global energy supply system. These resources provide the opportunity to respond simultaneously to both the basic form of fossil resources. Renewable energies are essentially adaptable to nature and do not have contamination, and since they are not renewable, there is no end to them. Other features of these resources such as their dispersal and their spread throughout the world, the need for lower technology, make renewable energy, especially for developing countries, more attractive, and therefore, in international programs and policies, the role of the United Nations in promoting sustainable global development has given a special role to renewable energy sources.

2.1. The importance of clean energies

Today, new energies are rapidly expanding and penetrating in spite of the unknown, and neglecting it will be irreversible. Solar energy, wind, water, biomass, biogas, and geothermal energy are the main sources of clean energy. The conventional energies such as oil cuts, which is currently the main source of energy supplies in the world, have environmental and irreversible pollutants in the earth and space, such as increasing CO_2, increasing ground temperatures, melting ice poles, eliminating the ozone layer, and so on, so the human knowledge movement in the future should provide energy for the world toward the world's energy supply of clean energy and its substitution with pollutants.

The occurrence of the three factors in 1995 has created a turning point for renewable energy, especially wind energy.

- First, climate change due to the accumulation of greenhouse gases in the atmosphere;
- Second, increased demand for energy from electricity worldwide;
- Third, suitable vision on renewable energies

It should be taken into account that, in fact, for every kilowatt-hour of electricity produced from renewable energy instead of coal, about 1 kg of CO_2 will be prevented. So, for example, for every 1% of the energy used to be replaced by wind energy, about 13% of CO_2 emissions are reduced. In addition, the reduction of sulfur and nitrate oxides (acid rain agents) is another source of environmental energy sources.

2.2. Type of clean energies

Nowadays, importance of greenhouse gas emission encourages many industries to concentrate on clean and renewable energies. It grows rapidly these years and generates hundreds of billions in economic activity. Dominant focuses are on solar, wind, geothermal, bioenergy and nuclear energies. These are clean energy ensure sustainable development in countries. To continue, some of them are summarized.

2.2.1. Geothermal energy

Heat generated and stored in the earth is the origin of a clean energy named geothermal energy. Formation of the planet and radioactive decay of material generates the energy of earth's crust. [4]. Temperature difference between core and surface of earth results in continues conduction of thermal energy from core to surface [5]. Temperature at core–mantle boundary may reach over 4000°C (7200°F) [6].Some rocks melt and Solid mantle behave plasticity because of high temperature and pressure inside earth and it is a suitable source of energy. The high temperature and pressure in Earth's interior cause some rock to melt and solid mantle to behave plastically, resulting in portions of the mantle convicting upward since it is lighter than the surrounding rock. Rock and water is heated in the crust, sometimes up to 370°C (700°F) [7]. The Earth's geothermal resources are theoretically more than adequate to supply humanity's energy needs, but only a very small fraction may be profitably exploited. Drilling and exploration for deep resources is very expensive. Geothermal energy comes in either vapor-dominated or liquid-dominated forms. Larderello and The Geysers are vapor-dominated [8]. Vapor-dominated sites offer temperatures from 240 to 300°C that produce superheated steam (**Figure 1**).

Hot dry rock reservoirs are generally hot impermeable rocks at depths shallow enough to be accessible. Although hot dry rock resources are virtually unlimited in magnitude around the world, only those at shallow depths are currently economical. To extract heat from such formations, the rock must be fractured and a fluid circulation system developed. This is known as an enhanced geothermal system (EGS) [9]. The water is then heated by way of conduction as it passes through the fractures in the rock, thus becoming a hydrothermal fluid. Hydrothermal plants in the western states now provide about 2500 megawatts of constant, reliable electricity, which meets the residential power needs for a city of 6 million people. Over 8000 megawatts are currently being produced worldwide. A variety of industries, including food processing, aquaculture farming, lumber drying, and greenhouse operations, now benefit from direct geothermal heating. The technology used to convert geothermal energy into forms usable for human consumption can be categorized into four groups. The first three: dry steam, flash steam, and binary cycle, typically use the hydrothermal fluid, pressurized brine, or EGS resources to generate electricity. The fourth type, direct use, requires only hydrothermal fluid, typically at lower temperatures, for direct use in heating buildings and other structures [10]. The addition of a small-scale electric heat pump into the system allows the use of low-temperature geothermal energy in residences and commercial buildings. Geothermal heat is used directly, without involving a power plant or a heat pump, for a variety of applications such as space heating and cooling, food preparation, hot spring bathing and spas (balneology), agriculture, aquaculture, greenhouses, and industrial processes. Uses for heating and bathing are traced back to ancient Roman times. Currently, geothermal is used for direct heating purposes at sites across the United States. U.S. installed capacity of direct use systems totals 470 MW or enough to heat 40,000 average-sized houses. Geothermal heat pumps take advantage of the Earth's relatively constant temperature at depths of about 10 ft. to 300 ft. GHPs can be used almost everywhere in the world, as they do not share the requirements of

Figure 1. Geothermal energy plant [12].

fractured rock and water as are needed for a conventional geothermal reservoir. GHPs circulate water or other liquids through pipes buried in a continuous loop, either horizontally or vertically, under a landscaped area, parking lot, or any number of areas around the building. There are many advantages for geothermal energy. It is a renewable source of energy, and it is non-polluting and environment friendly. In addition, there is no wastage or generation of by-products. Geothermal energy can be used directly. In ancient times, people used this source of energy for heating homes, cooking, and so on. The maintenance cost of geothermal power plants is very less, and geothermal power plants do not occupy too much space and thus help in protecting natural environment. It should be noted that unlike solar energy, it is not dependent on the weather conditions. Beside these advantages, there are some disadvantages of geothermal energy. For example, only few sites have the potential of geothermal energy and most of the sites, where geothermal energy is produced, are far from markets or cities, where it needs to be consumed [11]. Total generation potential of this source is too small, and there is always a danger of eruption of volcano. In addition, installation cost of steam power plant is very high and there is no guarantee that the amount of energy, which is produced, will justify the capital expenditure and operation costs. Finally, it may release some harmful, poisonous gases that can escape through the holes drilled during construction (**Figure 2**).

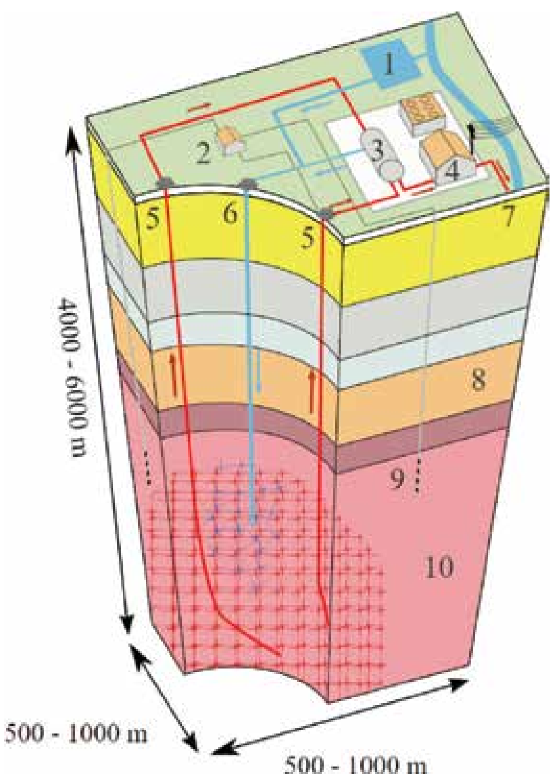

Figure 2. Geothermal system [12]. (1: reservoir, 2: pump house, 3: heat exchanger, 4: turbine hall, 5: production well, 6: injection well, 7: hot water to district heating, 8: porous sediments, 9: observation well, 10: crystalline bedrock).

2.2.2. Biogas

Biomass is considered the renewable energy source with the highest potential to contribute to the energy needs of modern society for both the industrialized and developing countries worldwide. One way to get rid of waste is converting them to biogas. Biogas can be produced from raw materials such as agricultural waste, manure, municipal waste, plant material, sewage, green waste or food waste are raw materials for biogas production. This reaction takes place in the absence of oxygen. Process consists of four steps: first, raw material preparation; second, digestion (fermentation), consisting of hydrolysis, acetogenesis, acidogenesis and methanogenesis; third, conversion of the biogas to renewable electricity and useful heat with cogeneration/combined heat and power; and finally, digestate post-treatment. Methane (CH_4) and carbon dioxide (CO_2) may have small amounts of hydrogen sulfide (H_2S), moisture and siloxanes are primarily biogas in second step. Then biogas can be combusted or oxidized with oxygen and the heat release from combustion is a kind of energy and use for any heating purpose. It can also be used in a gas engine to convert the energy in the gas into electricity and heat [13] (**Figure 3**) (**Table 1**).

Biogas can be compressed, the same way as natural gas is compressed to CNG, and used to power motor vehicles. Between 2009 and 2015, the number of biogas plants in Europe increased significantly from around 6000 to nearly 17,000 [18]. It has been estimated that global biomass use was around 50EJ (14000TWh) in 2010 and could more than double to around 100–150EJ by 203,037, of which 20-35EJ will be in Europe [15] In the UK, for example, biogas is estimated to have the potential to replace around 17% of vehicle fuel [16]. Biogas can be cleaned and upgraded to natural gas standards, when it becomes bio-methane. Biogas is considered a renewable resource because its production-and-use cycle is continuous, and it generates no net carbon dioxide. Organic material grows, is converted and used and then regrows in a continually repeating cycle. It should be noted that as less carbon is released when the biomass is ultimately converted to energy as carbon dioxide is absorbed from the atmosphere in the growth of the primary bio-resource, therefore overall carbon emission decreases. Biogas, with the ability to control timing of generation, will provide a useful low carbon complement to intermittent renewable power generation from wind and solar [17].

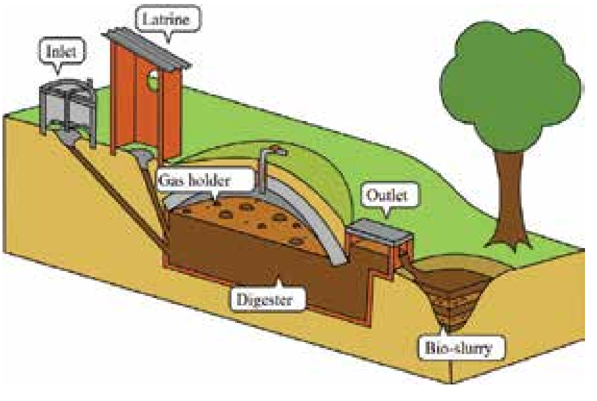

Figure 3. Schematic of biogas plant [12].

Compound	Biogas from anaerobic fermentation	Natural gas
Methane	50–85%	83–98%
Carbon dioxide	15–50%	0–1.4%
Nitrogen	0–1%	0.6-2.7%
Hydrogen	traces	—
Hydrogen sulfide	Up to 4000 ppmv	—
Oxygen	0–0.5	—
Ammonia	trances	—
Ethane	—	Up to 11%
Propane	—	Up to 3%
Siloxane	0–5 mg/m^3	—
Wobbe Index	4.6–9.1	11.3–15.4%

Table 1. Typical composition of biogas [14].

2.2.3. *Fuel cell*

A fuel cell is a device that generates electricity by a chemical reaction. Every fuel cell has two electrodes called, respectively, the anode and cathode. The reactions that produce electricity take place at the electrodes. In addition, there is a media called electrolyte that transfer charged particles (proton exchange membrane) from one electrode to the other and a catalyst, which speeds the reactions at the electrodes. Fuel cells also require oxygen. First developed by William Grove in 1839, Grove was experimenting on electrolysis (the process by which water is split into hydrogen and oxygen by an electric current), when he observed that combining the same elements could also produce an electric current 1930s–1950s Francis Thomas Bacon, a British scientist, worked on developing alkaline fuel cells. He demonstrated a working stack in 1958. The technology was licensed to Pratt and Whitney where it was utilized for the Apollo spacecraft fuel cells. One great appeal of fuel cells is that they generate electricity with very little pollution because much of hydrogen and oxygen ultimately combine to produce water. The electricity produced in this way is direct in the cell. If alternating current (AC) is needed, the DC output of the fuel cell must be routed through an inverter. Fuel cells are used for primary and backup power for commercial, industrial and residential buildings and in remote or inaccessible areas. They are also used to power fuel cell vehicles, including forklifts, automobiles, busses, boats, motorcycles and submarines. There are six fuel cell technologies. Polymeric electrolyte membrane fuel cells (PEMFC), direct methanol fuel cells (DMFC), alkaline fuel cells (AFC), phosphoric acid fuel cell (PAFC), molten carbonate fuel cell (MCFC), solid oxide fuel cell (SOFC).each of them has their own advantages and disadvantages [18]. Future development of each type will depend on them [18].

Fuel cells have three main applications so far. Transportation applications, portable electronic equipment and combined heat and power systems [19]. As compared with conventional fossil fuel propelled electric generators, the use of fuel cells had many advantages. Some are higher volumetric and gravimetric efficiency, low chemical, acoustic, and thermal emissions and maintenance, modularity and siting flexibility. Also this type of fuel is flexible depending on its type. Finally, most important advantage of fuel cells is that it has no pollution [20]. Some limitations should overcome to increase fuel cell application. Fuelling fuel cells is still a major problem since the production, transportation, distribution and storage of hydrogen are difficult. Moreover, reforming hydrocarbons via a former to produce hydrogen is technically challenging and not clearly environmentally friendly. The refueling and starting time of fuel cell, vehicles are longer and the driving range is shorter than in a "normal car." Fuel cell units are still handmade; therefore, it is so expensive (**Figure 4**).

2.2.4. Hydrogen energy

Hydrogen energy makes many world dreams comes true like no chimney for stove, so clean fuel vehicles that exhaust water or an energy storage device that does not cause pollution and does not produce greenhouse gas, acid rain and chemical corrosion effects, and does not smoke, it does not have any radioactive waste, and in practice it does not use any natural fuel source. Hydrogen and fuel cells are seen by many as key solutions for the twenty-first century, enabling clean efficient production of power and heat from a range of primary energy sources [21]. Hydrogen is not a primary energy source like coal and gas. It is an energy carrier. Initially, it will be produced using existing energy systems based on different conventional primary energy carriers and sources. In the longer term, renewable energy sources will become the most important source for the production of hydrogen. Regenerative hydrogen, and hydrogen produced from nuclear sources and fossil-based energy conversion systems with capture, and safe storage (sequestration) of CO2 emissions, are almost completely carbon-free energy pathways. Like other clean energies, advantages and disadvantages of hydrogen energy should be considered. High energy yield (122 kJ/g), production from many primary energy sources, low density (large storage areas), most abundant element, wide flammability range (hydrogen engines operated on lean mixtures), high diffusivity, water

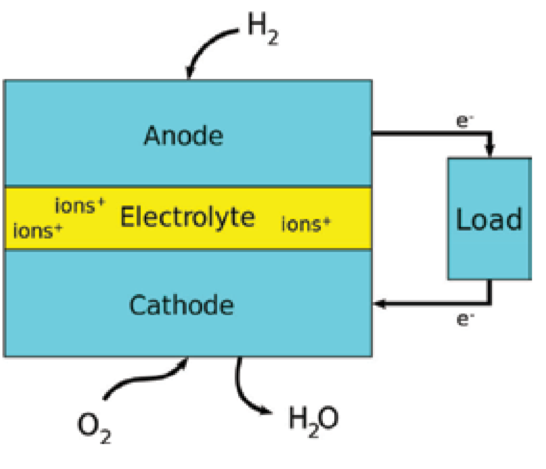

Figure 4. A block diagram of a fuel cell [13].

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vapor as major oxidation product are main advantages. Beside these, hydrogen does not found free in nature and its ignition energy is low (similar to gasoline) and is currently expensive [22]. Hydrogen storage and transport is a critical issue involving intense research. Potential hydrogen delivery systems include compressed tube trailers, liquid storage tank trucks, and compressed gas pipelines, and they have high capital costs [22].

2.2.5. Hybrid energy systems

Hybrid power systems combine two or more energy conversion devices, or two or more fuels for the same device, that when integrated, overcome limitations inherent in either. Hybrid systems can address limitations in terms of fuel flexibility, efficiency, reliability, emissions and/or economics. A hybrid program can create market opportunities for emerging technologies before they are mature. Incorporating heat, power, and highly efficient devices (fuel cells, advanced materials, cooling systems, etc.) can increase overall efficiency and conserve energy for a hybrid system when compared with individual technologies. For implementation of hybrid energy system, it is essential to follow determined methodology [23]. In the methodology demand assessment, resource assessment and determination of barriers and constraints should be done that is fulfilled by hybrid renewable energy system. This can be done by combining one or more renewable energy sources with conventional energy sources. Some hybrid renewable system configurations are as follows:

- PV/Wind/diesel generator
- PV/wind/fuel cell
- Wind/battery
- Biomass/wind/diesel generator
- PV/Wind/Biomass/fuel cell

Once the system configuration is selected, optimization is performed with suitable optimization technique [24]. Though a hybrid system has a bundle of advantages, there are some issues and problems related to hybrid systems have to be addressed. Most of hybrid systems require storage devices which batteries are mostly used. These batteries require continues monitoring and increase the cost, as the batteries life is limited to a few years. It is reported that the battery lifetime should increase to around years for the economic use in hybrid systems. Due to dependence of renewable sources involved in the hybrid system on weather results in the load sharing between the different sources employed for power generation, the optimum power dispatch, and the determination of cost per unit generation are not easy. The reliability of power can be ensured by incorporating weather independent sources like diesel generator or fuel cell. As the power generation from different sources of a hybrid system is comparable, a sudden change in the output power from any of the sources or a sudden change in the load can affect the system stability significantly. Individual sources of the hybrid systems have to be operated at a point that gives the most efficient generation. In fact, this may not be occurring due to that the load sharing is often not linked to the capacity or ratings of the sources.

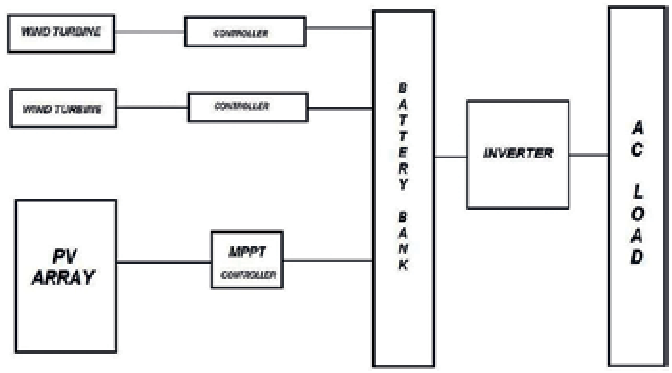

Figure 5. Block diagram of a PV/wind hybrid energy system [12].

Several factors decide load sharing like reliability of the source, economy of use, switching require between the sources, availability of fuel etc. Therefore, it is desired to evaluate the schemes to increase the efficiency to as high level as possible [25] (**Figure 5**).

3. Clean energy management

According to DIN EN 16001 or ISO 50001 definition, the ratio between achieved performance or the profits from services, goods or energy, and the energy used to achieve this is energy efficiency and based on DIN 4602, energy management is the predictive, organized and systematic coordination of the procurement, conversion, distribution and use of energy to cover requirements while taking account of ecological and economic aims. The term thus describes actions for the purpose of efficient energy handling. [26] Energy management and optimization solutions can help reduce energy costs. Energy use of buildings presents 40% of the total primary energy consumption in the United States [27]. Often, this energy is consumed inefficiently. Most of the problems predominantly arise from building technical operation and energy management. A study on commercial buildings has found that 50% of the buildings have control problems. Savings of up to 77% have been achieved by correction of control problems [28]. For optimization energy use, there should be a planning and scheduling. Real-time data form monitoring systems and production planning are necessary for scheduling. This information coupled with price and availability information from energy markets used to optimize power generation plant [29]. Significant challenges arise from the increasing connection of variable renewable energy generation. Despite their long-term benefits in terms of sustainability, renewable resources such as solar and wind powers are not only highly variable but also partially unpredictable. They, therefore, present operational challenges in assessing and mitigating risk, including issues of imbalance between generation and demand and network constraints. Additionally, there is longer term uncertainty over the technology costs and environmental policies associated with renewable generation, among other factors. These uncertainties at various time scales may imply the need for significant investment in new, more flexible 'smart grid' technologies capable of adaptation to a range of future scenarios. As laid out in [30], examples are:

- Controllable distributed energy assets including storage;
- More flexible transmission systems;
- Corrective control following network outages;
- Wide area monitoring and control equipment and communications;
- Controllable demand and the active participation of end users in, for example, system balancing and congestion management [30]. Beside all software and methodology to manage energy consumption, ISO 50001 is a sustainable business tool that helps organizations implements a flexible and robust energy management system (EMS). Effective energy management is not just good for business; it is also becoming a requirement. ISO 50001 will help organization understand how they are using various types of energy and identify realistic ways of reducing consumption, emissions and costs. The international standard outlines energy management practices that not only save the organization money today, but also in the long term; all while helping shield the bottom line from the increasing cost of energy. ISO 50001 also shows the commitment to reducing environmental impact which can help the businesses stand out from their competition. For implementing ISO 50001, first, management responsibility should be determined. After that, energy review should be done to identify baselines. Performance indicators will be used to evaluate how successfully the EMS is operating. In the next step, specific guidance on what needs to be communicated to whom as an EMS is being planned, implemented, maintained or improved. Documentation is essential for EMS and supporting information such as energy consumption bills. Non-conformities are identified via the audit process as the non-fulfillment of a requirement of the standard; corrective actions are what the actions an organization must take in order to fulfill the requirement. Finally, management review should be done to evaluate the progress and achievements of the EMS.

4. Conclusion

The untapped use of one-dimensional energy sources such as oil in the world will definitely cause irreparable international damage to future generations in the not-so-distant future. The main objective of the evaluation and review of renewable sources is to find a suitable and cheaper place for consumable resources. The focus of this concern is between 2000 and 2020. Therefore, consideration of the environmental effects of the use of renewable energies is obvious and vital. Fortunately, the use of renewable energy sources has a much lower environmental impact than fossil fuels. Therefore, the recognition of the nature and process of formation and the interaction necessary for the exploitation of renewable energy sources should be the first priority. Each of these sources varies according to the type of energy and climatic conditions. Therefore, attention to this important point of use in which of the above fields is easier and economically more economical is one of the most important prerequisites for using these resources and the necessity of prioritizing the type of renewable resources is selected.

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Chapter 6

Renewable Energy of Biogas Through Integrated Organic Cycle System in Tropical System

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Margaretha Arnita Wuri

Additional information is available at the end of the chapter

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Abstract

Energy is a critical requirement for economic development and specifically to improve the conditions that influence all aspects of human welfare. However, the majority of people in developing countries have no access to reliable and affordable domestic energy sources. Development of organic material as sources of renewable energy through biomass, biogas, biofuel, bioreactor, algae fuel, biohydrogen, and so on, with better biotechnology by genetic improvement, environmental manipulation, purification, packing, compressing, are important for sustainable development. Biogas becomes one of the solutions to meet the energy need in rural areas of developing countries. However, the implementation of biogas has many challenges. Biogas produced from different biosources may contain pollutants that should be removed. The quality of biogas, represented by methane enrichment, can be improved with biogas purification technology. Removing the pollutants is recommended to avoid severe downstream damage and to increase the calorific value. This chapter discusses biogas purification.

Keywords: biogas purification, methane enrichment, organic cycles, renewable energy, sustainable development

1. Integrated organic cycle system

Tropical bio-geo-resource has high biomass productivity but still less economical values [1]. Integrated Bio-cycle Farming System (IBFS) is an alternative system of agriculture which harmoniously combines agricultural sectors such as agriculture, horticulture, plantation, animal husbandry, fisheries, forestry with nonagricultural aspects, such as settlements, agro-industry, tourism, industry which are managed based on landscape ecological management under one integrated area [2, 3]. The cycles of energy, organic matter and carbon, water, nutrient, production, crop, money was managed through 9R (reuse, reduce, recycle, refill, replace, repair, replant, rebuild, reward) to get optimal benefits for the farmer, community, agriculture, and global environment. The system has multifunction and multiproduct (food, feed, fuel, fiber, fertilizer, pharmacy, edutainment, ecotourism) [2, 3]. They will meet with the expected basic need for daily-, monthly-, yearly- and decade's income at short-, medium- and long- term periods. IBFS was expected to provide additional benefits for farmers with small, medium and big capital, through the recycling of organic waste into renewable resources to produce high-value production, such as organic fertilizer (liquid and solid), animal feed, and sources of biogas energy [2–4].

IBFS was developed by UGM through Integrated Crop Management (ICM), Integrated Nutrient Management (INM), Integrated Soil Moisture Management (IMM) and Integrated Pest Management (IPM). The system should collaborate and develop networking system between Academic, Business, Community and Government (ABCG) with economic, environmental and sociocultural approach as a characteristic of Education for Sustainable Development [2–4]. This model facilitates the learning needed to maintain and improve our quality of life and the quality of life for generations. It is about equipping individuals, communities, groups, businesses and government to live and act sustainably as well as giving them an understanding of the environmental, social and economic issues involved. Integrated farming could support for better sustainable life and environment.

The key characteristics of IBFS developed in UGM University Farm are (1) an integration of agriculture and non-agriculture sector, (2) value of environment, esthetics and economics, (3) rotation and diversity of plants, (4) artificial and functional biotechnology, nanotechnology, pro-biotic, (5) management of closed organic cycle and integration in an integrated area among ICM, IPM, IMM, INM, IVM, (6) management of integrated bioprotection and ecosystem health management, (7) landscape ecological management, agro-politan concept, (8) specific management of plant and (9) holistic and integrated system [2–4]. The IBFS has more advantages compared to the other various types of sustainable agricultural system such as: low input agricultural, integrated farming, organic farming, biodynamic, or agroforestry system.

IBFS is expected to be one alternative solution for improving land productivity, program development and environmental conservation and rural development in an integrated management [5–7]. They will meet with the expected basic need at short-, medium- and long-term for food, clothing and shelter. Thus, IBFS could provide income at daily-, monthly-, yearly- and decade's term for farmers. The role of micro-, meso- and macro-organisms on biogeochemical and nutrient cycling in increasing of land productivity is very important. Microorganisms are able to provide essential nutrients to plants through both mutualistic symbiotic and nonsymbiotic.

IBFS was expected to provide additional benefits for farmers with small, medium and big capital through the recycling of organic waste into renewable resources to produce high-value production, such as organic fertilizer (liquid and solid), animal feed, and sources of bio-gas energy [2–4]. That will be a good prospect that organic farming can provide sustainable economic, environment and sociocultural aspect. IBFS can produce "gold of life," such as yellow gold (food, rice, corn), green gold (vegetables), brown gold (plantation wood), red gold (meat), white gold (milk, fish), black gold (organic fertilizer), transparent gold (water), gas gold (oxygen), blue gold (biogas, biomass energy, biofuel), king gold (herbal medicine), prosperity gold (tourism) and inner gold (mystic) [2, 3].

2. Renewable energy of biogas

Biogas is a combustible gas mixture which has methane as its main composition. It is formed by anaerobic decomposition process of organic compounds. Naturally, biogas is produced in swamps, bogs, rice paddies and in the sediment at the bottom of the lakes or ocean in anaerobic condition. Van Helmont recorded that the decaying organic compounds produced flammable gases so that biogas construction could be engineered. Biogas construction had been known in several centuries. In 10th century BC, biogas was used for heating bath water in Assyria [8]. The combustible gas, methane, was produced by John Dalton and Humphrey Davy's works during 1804–1808 [9]. In the 1890s, biogas was used to power street lamps in the UK and China. Since then, biogas technology began to be commercialized.

Methane production pathways by anaerobic decomposition consist of four stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis [10]. At hydrolysis stage, the long-chain molecules of biomass such as carbohydrate, protein and fat are broken down into monomers. These monomers (monosaccharides, amino acids, and long-chain fatty acids) are then broken down into long-chain acids at acidogenesis stage and converted to acetic acid by acetogenic microorganism at acetogenesis stage. Lastly, the acetic acid is converted to methane by methanogens at methanogenesis stage (see **Figure 1**).

Biogas composed of methane (CH_4), carbon dioxide (CO_2), and other gases in very small amount, such as nitrogen (N_2), hydrogen sulfide (H_2S), hydrogen (H_2), and water vapor. Biogas composition is presented in **Table 1**.

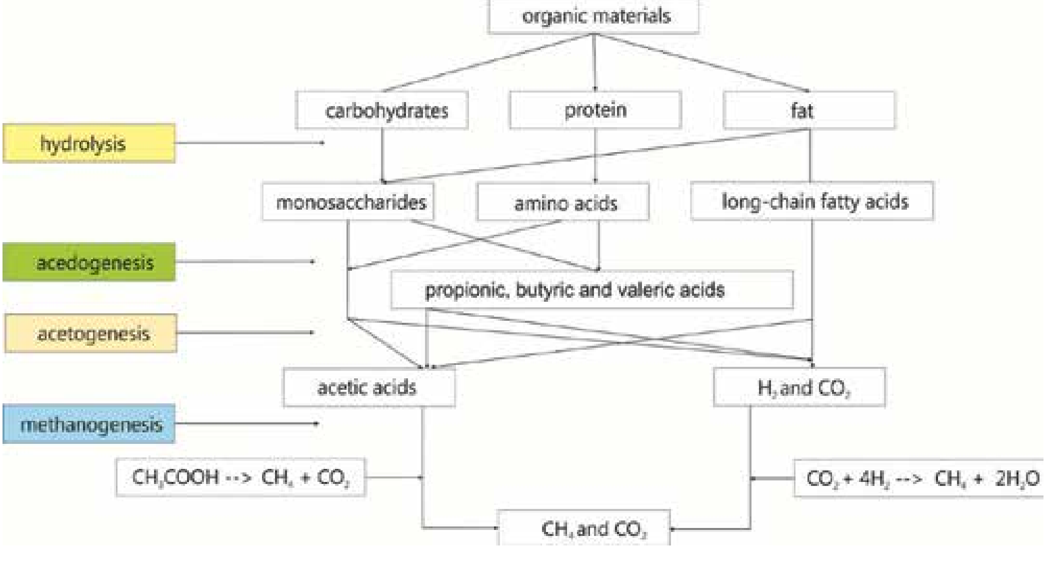

Figure 1. Conversion pathways of biogas production from biomass [10].

Gases	% composition	
	A	B
Methane (CH_4)	55–70	50–70
Carbon dioxide (CO_2)	30–45	30–40
Hydrogen sulfide (H_2S)	1–2	small amount
Hydrogen (H_2)		5–10
Ammonia (NH_3)		—
Carbon monoxide (CO)	Small amount	—
Nitrogen (N_2)	Small amount	1–2
Oxygen	Small amount	—
Water (H_2O)	—	0.3

Table 1. Biogas composition [11, 12].

The spread of biogas technology gained momentum in the 1970s, when oil price became higher. It became the motivation for finding alternative energy sources such as biogas. The intensive effort in developing biogas began in the 1900s. The fastest growth of biogas was found in developing countries such as Asian, Latin American and African countries. In developing countries, where energy was in short supply and expensive, anaerobic decomposition had a far relevance to meet energy needs. Stoves, refrigerators and engines were appliances commonly fuelled by biogas. India and China became the role model countries of biogas development in Southeast Asia. India had built their first anaerobic digester in 1897, utilized human waste to generate biogas to meet the lighting needs. China had the largest biogas progam in the world. Until 2006, there were more than 18 million biogas plants built in China [13]. By the end of 2011, the number of domestic biogas installations grew to 41.68 million [14].

When fossil fuel-based energy is abundant and inexpensive, people are not enthusiastic about the use of biogas as energy source. The higher installation and maintenance cost of biogas make people choose fossil fuel energy. Some people prefer to use fossil fuel-based energy than biogas because fossil fuel-based energy is inexpensive, ready to use, and has high calorific value. However, in several years, biogas exists along with the increase of energy needs in the world every year, and fossil fuel energy is expected to be depleted. In addition, global warming that was caused by the emissions in the use of fossil fuel-based energy also becomes the driving force behind the implementation of biogas technology as clean energy. Microbially controlled production of biogas is an important part of the global carbon cycle [13]. This is one of the efforts in mitigating the global warming disaster. Methane, the main component of biogas, is greenhouse gases (GHGs) with a much higher global warming potential than carbon dioxide. Biogas is able to isolate methane and convert it into clean energy. According to Cuellar and Webber [15], biogas from livestock waste was able to reduce GHGs emissions at 3.9% of the total emission from electricity production by fossil fuel with the same capacity. A researcher said that biogas from cow manure was able to reduce carbon dioxide emissions and replace the consumption of kerosene and firewood for cooking [16]. Based on the study conducted by National Electricity Company of Indonesia, around one million units of biogas plant were able to save 900 million liters of kerosene or 700,000 tons of LPG per year [17].

Biogas also has benefits in mitigating and overcoming organic waste issue [18]. Anaerobic decomposition of biogas is a suitable and efficient technology for organic waste management [3]. Organic wastes that are commonly used as substrate to produce biogas are from livestock manure, agricultural waste, sewage sludge, human waste, and so on [19]. If these wastes are not handled properly, they will decompose naturally and emit GHGs. Moreover, the untreated organic waste will cause bad smell and potentially contaminate the aquatic life [15]. On the other hand, the organic waste has the potential to generate energy. Therefore, many researchers investigated the best way to convert organic waste into energy. Moreover, biogas implementation can be integrated with agriculture and livestock development. It means that no waste is generated from the life cycles of agriculture and livestock sectors (close loop). Organic waste is directly used as substrate in biogas production, and the waste from biogas production can be used as organic fertilizer (see **Figure 2**).

Benefits of biogas system for users, society and environment in general are as follows [20]:

- Production of energy (heat, light and electricity)
- Transformation of organic waste into high-quality fertilizer
- Improvement of hygienic conditions through reduction of pathogens, worm egg and flies
- Reduction of workload, mainly for women in firewood collecting and cooking
- Positive environmental externalities through protection of soil, water, air and woody vegetation
- Economic benefits through energy and fertilizer substitution as income sources

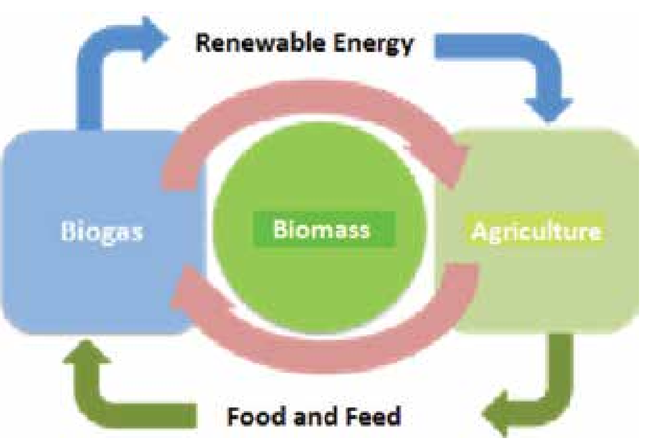

Figure 2. Integrated biogas installation [17].

Biogas can substantially contribute to the conservation and development in developing countries. However, the required high-level investment of capital and other limitations of biogas technology should also be considered.

Energy-cost-effective production and utilizing bioenergy is the key to improve the living standard of developing countries. Biogas can effectively reduce fuel consumption per capita in rural community by partly replacing coal, oil and fuelwood with straw and livestock manure-based energy [21]. Besides meeting the energy supply, biogas is expected to be integrated with biowaste management such as biogas installation in Germany (see **Figure 3**). Many programs had been done to promote the implementation of biogas technology in developing countries. In India, the Ministry of Non-Conventional Energy Sources (MNES) continues to implement the National Biogas and Manure Management Programme. Nepal, through Alternate Energy Promotion Centre (AEPC) with donor support from the Netherlands and Germany, promotes the use of biogas to rural community [20]. Ethiopia was able to disseminate 57.6% of total 14,000 domestic biogas plants planned in period 2009–2013 [14].

With the issues of global warming and the depletion of fossil fuel, the development of biogas has larger portion to disseminate, especially in developing countries. Many reports informed that biogas installations had been developed. However, the amount in many developing countries was still low. Moreover, biogas implementation is not sustainable. In Uganda, a large number of biogas installations were installed, but 29% of them had been dis-adopted, and this was within the average time period of 1.8 years after the installation [22]. Total number of biogas digesters is low in Indonesia compared to other developing countries [23]. Many people

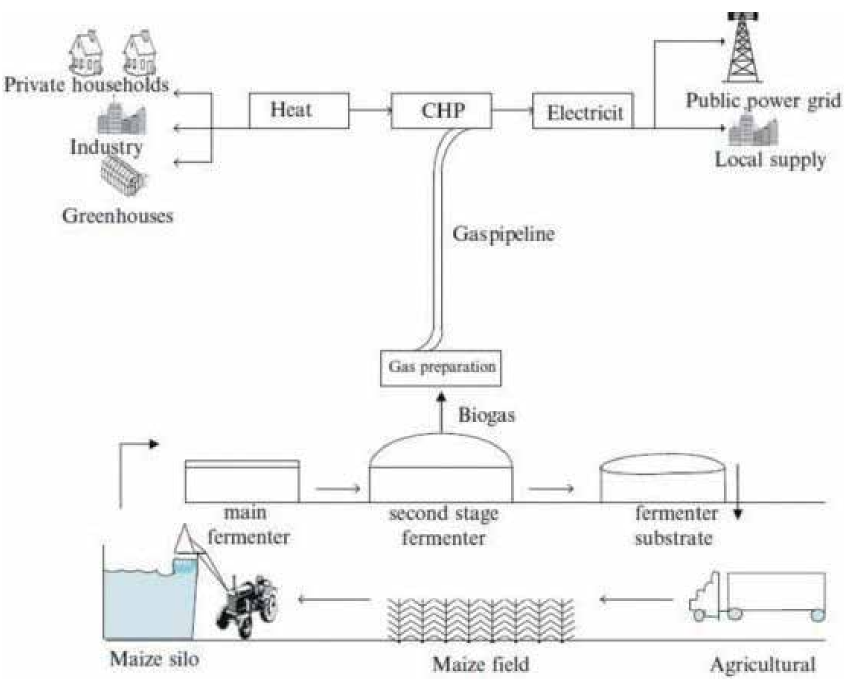

Figure 3. A typical maize-based biogas plant in Germany [20].

prefer to consume fuelwood, gas and/or oil as their household energy supply because they do not think that the price of biogas is lower than fossil fuel-based energy.

The dissemination of renewable energy technologies in general and biogas technology is constrained by a number of factors including policies, institutions, financial constraints, subsidies, availability of input and awareness about the technology [14]. For example, financial constraint is one of most frequently cited challenges limiting the expansion of biogas technology. Thus, financial incentives are needed such as soft loans and subsides for renewable energy. Government subsidies are able to enhance the speed of biogas adoption. The low price and practicality in using fossil fuel-based energy are the reasons why people are not interested in using biogas.

In fact, subsidies are not enough to encourage the expansion of biogas technology. Another factor that influences biogas implementation is technical factor. Biogas did not meet the cooking and electricity needs of household [22]. His report informed that the use of biogas could not fully replace the use of fossil fuel. In addition, there was also a lack of motivation among the community to operate and repair the installation. Biogas cannot fully replace fossil fuel because it has low calorific value. The average calorific value of biogas is about 21–24 MJ/m^3, lower than the calorific value of fossil fuel (see **Table 2**). The lower energy of biogas is caused by the presence of impure gases in biogas [24], for example carbon dioxide, hydrogen sulfide, nitrogen, and so on. The negative effects of impurities gases were explained by the authors mentioned in refs. [8, 25, 26], as shown in **Table 3**.

Fuels	**Biogas**		**Fossil fuel**		
Gases	Biomethane	Purified biomethane (90%)	Propane	Butane	Methane
Calor (MJ/m^3)	21.5	32.3	90.9	118.5	35.9
	21–24				31–40[c]
	23				

Table 2. Comparison of calorific value between biogas and fossil fuel [8, 25, 26].

Gases	**Effects**
Carbon dioxide (CO_2)	• Inflammable gas, decreasing calorific value
	• Corrosion (contain carbon acid) if biogas is in wet condition
Hydrogen sulfide	• Inflammable gas, decreasing calorific value
(H_2S)	• Corrosion
	• Poison
Ammonia	• Emits NO_x emission after combustion
(NH_3)	• Anti-knock properties of engines
Water vapor	• Corrosion
Nitrogen	• Decreasing calorific value
N_2	• Antiknock properties of engines

Table 3. Effects of impurities in biogas [2, 25, 26].

The presence of impurities in biogas can be minimized through biogas purification. This method has also been a highlighted topic in recent years [24]. Biogas purification focuses on the removal of contaminants in biogas. Biogas purification methods used for biogas cleaning are discussed in Section 3.

3. Biogas purification

3.1. Biogas purification methods

Biogas purification is a process of removing the impure gases in biogas that affects the gas transmission grid, appliances or end user, and the increasing calorific value [27]. The impure gases are carbon dioxide, hydrogen sulfide, nitrogen and trace elements. The increase of calorific value affects the increase of biogas energy efficiency so it is able to compete with fossil fuel-based energy. In developing countries, biogas purification technology has been a site-specific and case-sensitive one, depending on local circumstances [24]. There are many methods of biogas purification that have been developed and investigated: physico-chemical methods and biological methods. Physico-chemical methods are consisted of absorption (water and chemical scrubbing), cryogenic separation, adsorption and membrane technology (see **Figure 4**).

3.1.1. Absorption

In the absorption technique of biogas purification, the raw biogas is brought into contact with nonvolatile liquid phase. The purpose is the mass transfer of contaminant from the gas phase to liquid phase [18]. The main idea in cleaning biogas using absorption is to transfer carbon dioxide to stationary liquid phase. There are two types of techniques depending on the types of the absorbent:

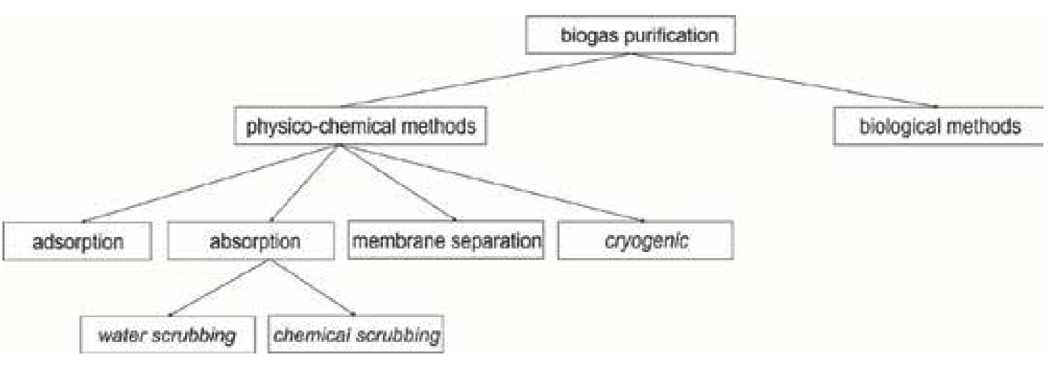

Figure 4. Biogas purification methods [27].

a. Water scrubbing

Water is used as solvent in scrubbing. The solubility of methane in water is much lower than that of carbon dioxide and hydrogen sulfide. In principle, carbon dioxide and hydrogen sulfide can be removed. However, because hydrogen sulfide is poisonous and dissolved hydrogen sulfide can cause corrosion, the pre-treatment of waste is required.

The disadvantage of this method is the large amount of water needed so it must be treated in wastewater to minimize the water consumption. Water scrubbing is the most commonly used method to clean biogas, and plants are commercially available in a broad range of capacities.

b. Chemical scrubbing

It is very similar to water scrubbing. The difference is that the carbon dioxide is absorbed in chemical solvent. Chemical scrubbing involves the formation of reversible chemical bonds between the pollutants and the solvent. The chemical solvents used in biogas cleaning are alkaline solutions such as potassium hydroxide (KOH), sodium hydroxide (NaOH) and alkanolamine solutions such as mono ethanol amine (MEA), di-methyl ethanol amine (DMEA) or tertiary amines [18, 27]. In carbon dioxide absorption by chemical solvent, the following reactions take place as given in Eqs (1)–(3):

$$CO_2 + 2\,OH^- \rightarrow CO_3^{2-} + H_2O \tag{1}$$

$$CO_2 + CO_3^{2-} \rightarrow H_2O \rightarrow 2\,HCO_3^- \tag{2}$$

$$CO_2 + R - NH_2 + H_2O \rightarrow R - NH_3 + HCO_3^- \tag{3}$$

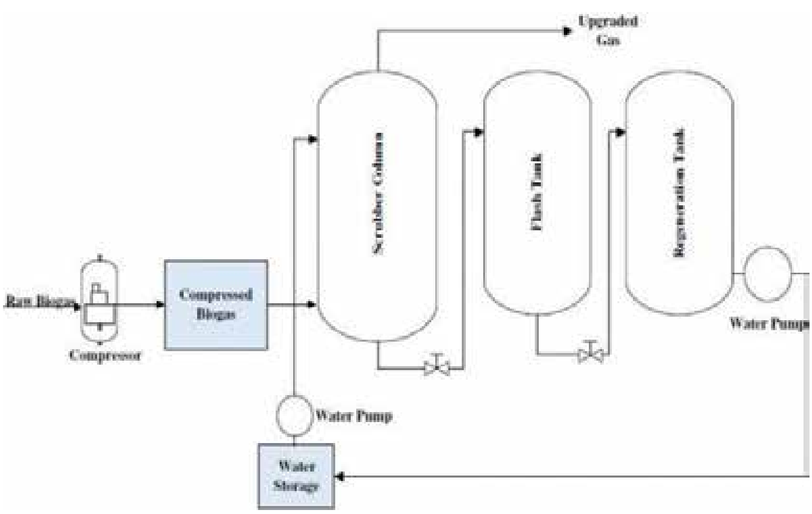

Figure 5. Schematic of chemical scrubber [28].

The advantage of this method is that the solvent can be regenerated. However, the downside of this technology relates to the energy consumption to regenerate the chemical solvent (see **Figure 5**).

3.1.2. Membrane technology

Membrane technology is a separation method at molecular scale. In biogas cleaning, carbon dioxide and hydrogen sulfide can be removed selectively through membrane column so it is able to enrich methane component in biogas.

Membrane used in this technique is made of materials that are permeable to carbon dioxide, water, ammonia and other contaminants.

3.1.3. Adsorption

Adsorption is a method to separate certain gas from gas mixtures based on the affinity to a solid adsorbent. In biogas purification, the adsorptive materials are zeolite, active carbon, silica gel for carbon dioxide and hydrogen sulfide adsorption. The adsorption process relied on the fact that at low pressure, gases tend to be attracted to adsorbent and at higher pressure, more gas was adsorbed (see **Figure 6**) [28].

The advantage of adsorption method is that when solid adsorbents are saturated, it can be replaced by regenerated adsorbent by washing with water or heating at high temperature [18].

Physical-chemical biogas purification is the most commonly and frequently implemented method. **Table 4** shows the results of evaluation of biogas purification method by many researchers. Regarding the technology adoption, biogas purification technology that requires a lot of operations is always not sustainable in rural areas or developing countries. Therefore, a cheap and easy biogas purification method needs to be operated independently by the communities. From the summary of **Table 4**, we can conclude that the adsorption method is a

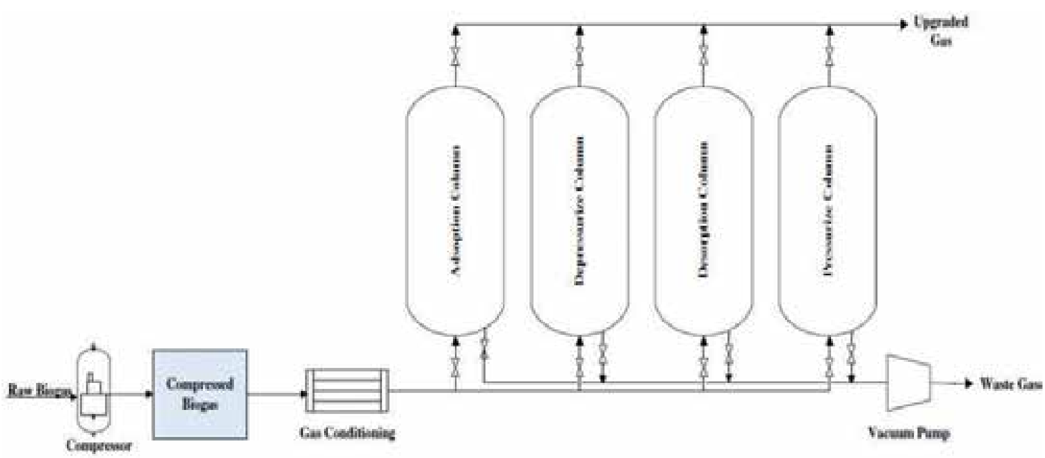

Figure 6. Schematic of adsorption in biogas purification [28].

good candidate for the technology implementation in rural areas because of the low cost and easy operation of the installation.

3.2. Methane enrichment through adsorption method

Adsorption is a separation method involving the transfer mechanism of soluble molecules in a fluid to the surface of solid material. Adsorption occurs on porous solid material that has a

Methods	Principles	Advantages	Disadvantages
Water scrubbing	Separation based on solubility	• Methane recovery at 80–99% • Methane loses 3–5% • No chemical solvent • Lower operational cost	• High energy consumption to regenerate solvent • High water consumption • Dissolved H_2S causes corrosion • Clogging due to bacterial growth • Corrosion
Chemical scrubbing	Separation based on solubility	• Methane recovery up to 95% • Methane loses 0.1–0.2% • Higher absorption capacity than *water scrubbing* • Operational time is shorter than water scrubbing	• Energy intensive • Corrosion • Large amount of solvent • Chemical waste may require treatment • Solvent is expensive
Cryogenic Separation	Separation based on condensation temperature	• Methane recovery up to 98% • Methane loses <1% • Side product is pure carbon dioxide for *drying ice*	• High energy consumption • Need more pre-treatment to remove H_2O and H_2S • Uses lots of process equipment • High operational and maintenance cost
Membrane technology	Separation based on molecule selectivity on membrane	• Methane recovery up to >96% • Simple operation • Low energy required • Membrane is able to be generated	• Some membrane has low selectivity • Often yields lower methane • High-cost membrane
Adsorption	Separation based on the different selectivity of gases on adsorbent	• Methane recovery between 96 and 98% • Methane loses at 2–4% • Can use common and cheap adsorbent • Simple installation and operation • Adsorbent can be generated	• Some adsorbents are expensive, for example *metal organic materials* (MOMs) • Methane loses in malfunctioning of valves

Table 4. Advantages and disadvantages of biogas purification methods.

partial attraction force on soluble molecule. In adsorption, there are adsorbate, adsorptive and adsorbent. Adsorbate is soluble molecule, which has been adsorbed by the surface of solid material; adsorptive is a molecule that is capable of being adsorbed on solid material [29]; and adsorbent is a solid material on which the soluble molecules accumulate.

Related to biogas purification, adsorption becomes a technology that may be suitable to adopt in developing countries. Adsorption is an easily handled technique. In rural areas, a cheap, simple and viable method becomes more attractive, and the implementation can be made sustainable. An adsorption process can be done in a variety of equipment, namely, fixed bed, moving bed, rotary bed and fluidized bed reactors. Each device has advantages and disadvantages. The main advantages of fixed bed system are the simplicity and inexpensive equipment needed, and the adsorbent is only reordered because of its position in the column. There are many related studies discussing the ways to enrich the methane level in biogas by removing carbon dioxide, hydrogen sulfide and other compounds that decrease the calorific value of biogas using zeolite, fly ash, biochar, and so on.

Saputri and Pertiwiningrum [30] have been evaluated bagasse fly ash (BFA) to adsorb H_2S in biogas from tofu waste. The preparation of BFA was conducted by its activation in 3% H_2O_2 for 5 h. The experiment was conducted in cylindrical adsorption column. The result showed that activated BFA was able to adsorb H_2S with the capacity between 1.28 and 2.42 mg/g. From this study, we saw that the difference of particle size and flow rate influenced the adsorption capacity of H_2S. The smaller the particle size was, the greater the H_2S adsorption capacity became, and the optimum capacity of the particle size was 200 meshes at 1.81 mg/g. Recycled BFA was also reusable as adsorbent although it had slightly lower adsorption capacity. Yuniarti and Pertiwiningrum [31] also used recycled BFA derived from the residue of sugarcane.

The utilization of zeolite as an adsorbent has been widely applied in oil industry for CO_2 adsorption [32]. It means that zeolite can also be used as CO_2 adsorbent in biogas purification. Mofarahi and Gholipour [33] have investigated the use of zeolite as CO_2 adsorbent in simulated biogas. This study reported that the adsorption capacity increased with the decreasing temperature and increasing pressure. **Figure 7** shows that at low pressure, the slopes of the isotherms for CO_2 are very high but then decrease very fast with the increasing pressure as the adsorbent approaches saturation.

Carbon dioxide adsorption on zeolite has been reported by Alonso-Vicaro et al. [34] at 173.9 mg/g. Zeolite is also able to adsorb H_2S with the capacity at 1.4 mg/g. Additionally, zeolite is completely regenerable and stable through several adsorptions. Bezzera et al. [28] tried to use zeolite and activated carbon to uptake CO_2 gases. They confirmed that zeolite had higher adsorption capacity than AC at 1 bar (206 mg/g and 83 mg/g, respectively). The different performance types of adsorbents are shown in **Table 5**.

From **Table 5**, we can conclude that zeolite has the best performance in carbon dioxide adsorption in biogas. However, the drawback is that not every rural area has natural resource of zeolite. As a consequence, the cost for adsorbent becomes expensive because of the packaging and distribution process.

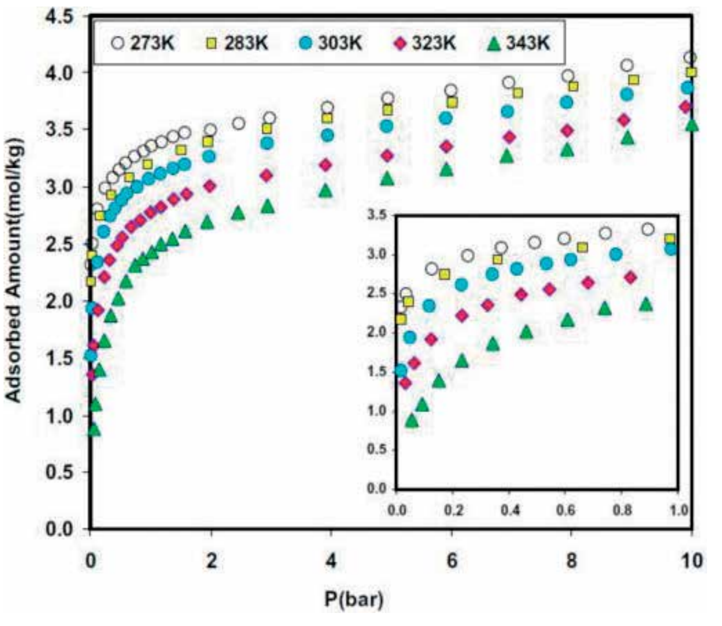

Figure 7. Carbon dioxide adsorption by zeolite [33].

Researchers	Solid materials (mg/g)				
	Zeolite	Activated carbon	Biochar	Kaolin	Silica
Bezzera et al. [35]	205.9	83.16			
Kacem et al. [32]	176	66			
Hauchhum [36]	187	124			
Bkour et al. [37]				79.6	
Mofarahi and Gholipour [33]	145.2				
Huang et al. [38]			77		
Creamer et al. [39]			73.48		
Minelli et al. [40]					26.4

Table 5. Carbon dioxide adsorption capacity of solid materials.

Biochar has been proposed as one of the substitute adsorbents for natural zeolite due to its low cost, and it is more environmental friendly. According to some researchers, biochar is proved to be capable of adsorbing carbon dioxide. Therefore, biochar is a potential adsorbent to capture CO_2 in biogas application. Huang et al. [38] investigated rice straw-based biochar to capture CO_2. The rice straw had been processed by microwave pyrolysis and conventional pyrolysis. The biochar produced by microwave pyrolysis at the power level of 300 W and maximum temperature of 300°C could adsorb CO_2 with the capacity up to 80 mg/g, higher than the biochar produced by conventional pyrolysis. Biochar produced from sugarcane bagasse was able to adsorb 73.55 mg/g of CO_2. In addition to agricultural waste, biochar can also be produced from livestock waste such as cow manure, pig manure and chicken manure.

4. Future of biogas energy

Biogas is an alternative and clean energy that replaces fossil fuels and enhance energy security. Biogas is one of the most promising and plentiful resources and is easily found in developing countries [41] especially in countries with abundant biomass resources. Biogas utilization was reported to be very important in mitigating GHGs from economic activities in rural areas, for example, fuelwood and agriculture sector. Moreover, crude oil stock decrease and cannot fulfill energy demand of countries, so there is a need to find new alternative energy for example biogas. In the future, biogas will be one of the most important alternative energy in developing countries as self-sufficient energy [42]. Biogas has developed opportunities as the demand of fossil fuel increases but the fuel stock decreases.

Biogas performance can also be compared with fossil fuel and the other renewable energy. Wahyuni [43] reported comparative study between kerosene and biogas, a case in Indonesia. By using comparison data of biogas production from livestock waste and energy from kerosene, we got comparison of cost needed to get biogas and kerosene energy in **Tables 6** and **7**.

Number of animals	Biogas production (m^3)	Conversion to kerosene (liter)
1 cow	2	1.24
2 horses	2	1.24
8 pigs	2	1.24
20 goats	2	1.24
620 chickens	2	1.24

Table 6. Conversion biogas energy to kerosene [43].

Fuel	Amount	Unit	Cost/unit (Rupiah)	Cost (Rupiah)
Biogas	1	m^3	1,620	1,620
Kerosene	0.62	liter	8,000	4,960
LPG	0.46	12 kg	75,000	2,872
Gasoline	0.8	liter	4,500	3,600
Fuel wood	3.5	kg	3,000	10,500

Table 7. Comparison of cost that is needed to get biogas and the other energy source in Indonesia [43].

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5. Conclusion

Renewable energy generally gets cheaper, while fossil fuels generally get more expensive. Integrated Bio-cycle System (IBS) is a close-to-nature ecosystem on landscape ecological management to manage land resource (soil, mineral, water, air, microclimate), biological resources (flora, fauna, human) and their interaction to have more high added value in environment, economic, socioculture and health. The biocycles chain should be managed through 9A (agro-production, technology, industry, business, distribution, marketing, infrastructure, management, tourism) with 9R (reuse, reduce, recycle, refill, replace, repair, replant, rebuild, reward). IBFS could produce food, feed, fuel, fiber, fertilizer, water, oxygen, pharmacy, edutainment, ecotourism for sustainable life and environment. Development of organic material as sources of renewable energy through biomass, biogas, biofuel, bioreactor, algae fuel, bio-hydrogen, and so on with better biotechnology by genetic improvement, environmental manipulation, purification, packing, compressing, are important for sustainable development. In rural areas, the reliable and affordable technology in biogas purification should produce less waste, has less energy requirements, low cost and simple in operation and maintenance. Adsorption becomes a recommended technology in biogas purification. Adsorption is easy to operate and less expensive because it uses alternative low-cost biomass waste-based adsorbents, such as fly ash and biochar.

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Conflict of interest

The authors have declared that no conflict of interest exists.

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Sustainable development is the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs—Brundtland Report (1987)

We are more aware of the need to achieve sustainable development than ever before. It is fair to say that two of the most important factors affecting sustainability are the ways of both producing and using energy. In this sense, this book provides a forum to articulate and discuss energy management issues in the frame of achieving sustainable development. And undoubtedly, we are also deeply concerned about these issues in the recent times.

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