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Assessment of the environmental and economic potential of biomass in Cambodia

BACHELOR'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled "Assessment of the environmental and economic potential of biomass in Cambodia" independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 20th of April 2023

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Nariputhisak Vong

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Abstract

These days, the global population has been speedily growing which led the world to a significant increase of energy consumption. The clamor for clean and sustainable energy worldwide has led to the development of sophisticated technologies which involve high cost and technical know-how in most cases. However, the same cannot often be the case in developing countries for obvious reasons. The usage of renewable energy such as biomass, is an efficient way for generating power as well has a small impact on the environment. Although Cambodia economy has increased significantly in recent decades, but the country is still lack with the necessary infrastructure in the energy sector in other to keep up with the pace of development. Most villages in Cambodia practice agriculture and are yet to fully maximize the use of the outputs therein, especially with energy usage. Charcoal, wood, and rice husk have been used in term of biomass as one of the main energy sources in different purposes such as household consumption, agriculture activities, and industrial activities. Despite the fact that the country has a lot of energy sources, hundreds of villages are still facing a shortage of electricity.

This Bachelor's thesis entitled "Assessment of the environmental and economic potential of biomass in Cambodia" in the format of literature review based on the study and information, which was published from most scientific articles, journals, databases, literature sources, national statistics, as well as many reports from various international organizations. The thesis was analyzed, summarized, reviewed the information and data related to renewable energy biomass in Cambodia. The content was divided into five main chapters and each chapter is focused on specific parts of biomass in general, introduction to Cambodia, energy situation and agricultural sector in Cambodia, and the last chapter is discussed on assessment of environmental and economic aspects of biomass use for energy.

Key Words: biomass, biogas, bioenergy, agricultural residues, rice straw, rural households, appropriate technologies

Contents

List of tables

List of figures

List of the abbreviations

ADB– Asian developing bank

CO_2 – Carbon Dioxide

EDC – Electricite du Cambodge

GDP – Gross domestic product

GHG – Greenhouse Gas

HFO – Heavy fuel oil

kW – kilowatt

LCA – The Life Cycle Assessment

LPG – Liquefied petroleum gas

MME – Ministry of Mines and Energy of Cambodia

MW – megawatt

NBP – The National Biodigester Program

REEs – Rural Electricity Enterprises

REF – Renewable energy facility

SHSs – Solar home systems

SVO – Straight vegetable oils

TERI – Tata Energy and Resources Institute

TFEC – Cambodia's Total Final Energy Consumption

USD – the U.S. Dollar

WB – World Bank

1. Introduction

The global population keeps rising at quite a rapid rate, with the current population being more than double that of 1960 and expected to reach 9 billion in 2050. According to forecasting models, developing countries will account for 99% of this population rise, with metropolitan regions seeing a 50% increase. As a result of this circumstance, the percentage of world energy consumption in cities is rapidly increasing, which were utilized less than half of all energy produced in the 1990s, but now consumes two-thirds of the global energy (Perea-Moreno et al., 2019).

In practically most developing countries, biomass is the primary fuel in the domestic sector. Biomass provides by far the biggest percentage of household energy in countries with substantial rural areas, and its use is highly connected with the amount of rural population (Ramsay, 1985).

Biomass is renewable energy, which includes all organic substances in the environment, either plant or animal, as well as those obtained by natural or artificial conversion (Perea-Moreno et al., 2019a). The usage of biomass is an efficient way for creating power and has a low cumulative carbon footprint, which helps to minimize greenhouse emissions. The direct combustion of biomass will produce a large quantity of power soon in the future (Munawar et al., 2021).

The Cambodian Ministry of Agriculture determined that almost 65% of the population works in agriculture in 2021 (USAID 2021). Most villages in Cambodia practice agriculture and are yet to fully maximize the use of the outputs therein, especially with regards to energy. In 2010, around 76% of Cambodia's 10,452 villages still have no electricity. The possibility of bio-gasification by alternative agricultural residues and wood biomass resources for rural energy supplies was studied by the Royal Government of Cambodia in its geographical and social-economic databases (Abe et al., 2007). The traditional biomass of wood and charcoal provides for around 80% of the overall country’s energy consumption. It is mostly utilized in rural cuisine and urban areas for a small section of the household. The burden has been heavy on Cambodia's forests (Poch, 2013).

Biomass provides both advantages and disadvantages for the environment and economy. The use of forest property, as a means of clearing forests and thereby preventing forestry fires and the capacity to generate jobs, are among its enormous benefits. Biomass offers permanent jobs, such as the exploitation of rural and bush raw materials. The usage of biofuel today is an area of major importance for the science establishment (Perea-Moreno et al., 2019). While the negative aspects are that natural habitats are being damaged, the supply of biomass feedstock is insecure, and markets for biomass are an underdeveloped and expensive investment (Vassilev et al., 2015).

All this, i.e., the description of the Cambodian energy situation, the agricultural sector, as well as the assessment of the energy potential of biomass, are the focus of the present bachelor's Thesis.

2. Aims of the thesis

The main objective of this Thesis was to analyze and summarize the data and information on biomass role and energy potential in Cambodia. Subsequently, the goal was to review biomass in general, the state of energy resources and their development in Cambodia, and Cambodian agriculture. Specific objective of the Thesis was to assess the biomass as an energy source from environmental and economic perspectives.

3. Methodology

This Thesis was written in the format of a literature review, with four main chapters separated into sub-chapters. The Thesis was prepared according to the guidelines for Bachelor Thesis of the Faculty of Tropical AgriSciences. In accordance with the FTA Citation Rules, all sources included in this Thesis were cited in English (2017 manual). The methodology of the Thesis was based on the study and discussion of secondary data sources, mainly from the articles and journals, which were mostly obtained from the scientific databases such as ScienceDirect, Web of Science, EBSCO, Google Scholar, including other literature sources and national statistics, were found by using specific keywords. The search for scientific information was accomplished using keywords such as: biomass, biogas, bioenergy, agricultural residues, rice straw, rural households, appropriate technologies, Cambodia. Following that, selected articles, technical reports, and other materials relevant to the Thesis topic were analyzed and processed.

4. Literature Review

4.1. Introduction to biomass

4.1.1. History of the biomass research

The traditional use of biomass resources is growing because of their economic value, as there are large volumes of agricultural production annually, the by-products of which can be used as a source of energy and are also marketed as the so-called energy crops, specifically for that reason. The main objective of the study by Miguelangel et al. (2019) was to examine the state of renewable energy biomass research and developments from 1978 to 2018 in order to help the research community to understand the current situation and future trends, as well as the international situation of countries, all of which in order to promote decision-making by those responsible for science policy, it offers basic knowledge (Perea-Moreno et al., 2019).

Biomass means all organic matter, whether from plant or animal origin, and materials obtained through natural or artificial transformation, which occurs in the biosphere. Firewood, wood shavings, pellets, some fruit stones like olives and avocados and nutshells contain biomass-derived organic fuels. The least processed of these is cut and chopped firewood, and it is normally directly burnt in domestic appliances like stoves or boilers (Perea-Moreno et al., 2019b). Biomass covers between 34 and 40% of total energy in developed countries only need. On the other hand, its contribution is very small in developing countries and biomass covers only 3% of primary energy utilization (Palazzo, n.d.). Biomass energy, in the form of wood, had powered the world economy for thousands of years before the introduction of coal and, eventually, oil, gas and uranium, which were easier to produce. In terms of its consideration as a meaningful energy supply alternative in both the developed and developing world countries, biomass energy is now making a serious comeback. A brief overview of the use of biomass energy as solid, liquid and gaseous fuels is basically intended to illustrate the scope of its continued use in the 20th, 21st and subsequent centuries. Until the latter part of the 17th century, for their energy needs, that depended almost entirely on wood and charcoal (wood heated in the absence of air) (Lewis, 1981).

4.1.2. Biomass in general

Many nations have shown an increasing interest in and ambition for the transition to a bio-based economy over the years, i.e., to expand the use of biomass to replace fossil fuels and materials. This could generate new demand for biomass resources, which in recent years has already been reflected in the rising production and trade of biomass for energy use. The vast majority of these foreign trade flows currently comprise biodiesel, bioethanol and wood pellets. A number of private and public entities have developed or adopted hundreds of certification and verification systems for biomass and biofuel sustainability. These systems may cover sectors of biomass production (e.g., forests, agricultural crops), bioenergy products (e.g., wood fuel, ethanol, biodiesel, electricity) and whole or segmental supply chains (e.g., production system, chain of custody from growers to energy consumers) (Goh et al., 2014).

4.1.2.1. Biomass feedstocks

If biomass logistics and the design of biomass feedstock systems are deliberately aimed at lowering the per-ton biomass supply cost, then the unknown effects of highly variable and reduced biomass feeds may well be achieved in such systems (Wilén et al., 1996).

Woody biomass is a significant energy source and is currently the world's most important green energy source. Woody biomass energy potential depends not only on the available woody biomass resources, but also on competition between alternative uses of these resources and alternative energy sources (Lauri et al., 2014).

In In Scandinavia, wood chips in small and medium size are commonly used. In heating canters and power stations in the area. The selected wood chips, particularly pine, are analyzed. The green sections (needles) are also included in these chips, and the proportion of bark is greater than that of chips made from whole trees. There are two types of chips with forest residue (conifer trees: spruce and pine, including bark, stems, needles, and branches) (Wilén et al., 1996).

As CO2 emissions produced by combustion are generally absorbed during the lifecycle of rice production, rice straw electricity generation is called carbon neutral (zero emissions). The Life Cycle Assessment (LCA) model, however, estimates greenhouse emissions for the supply chain of rice straw, which involves the transport and pre-processing of rice straw (Abdelhady et al., 2014).

4.1.3. Biomass Conversion

Four thermochemical biomass conversion methods are available: pyrolysis, gasification, direct combustion, and liquefaction. Each has a different product selection and employs different configurations of equipment operating in different modes (Bridgwater, 1994).

The product mix and product quality can be affected by several variables in all thermochemical processes, such as: catalysts, contact time, feed material, heating rate, feed pre-treatment, moisture content of feed, pressure, particle size of feed, reactor geometry, reagents, residence time, and temperature (Bridgwater, 1994).

Also, Biomass, in addition to the supply of food, feed and energy, was employed to extract useful materials in recorded history items such as medicinal and fragrances and flavors. It was only during the second half of the 19^{th} century; however, the century of large-scale industrial biomass conversion chemicals and materials began with the manufacture of oxidized linseed oil and cellulose esters (acetate and nitrate) linoleum (Gallezot, 2012).

4.2. Introduction to Cambodia

Cambodia is located in Southeast Asia. It is as big as 181,035 square kilometers in area, and borders. by Laos to the north, Thailand to the northwest, the Gulf of Thailand to the southwest and Vietnam to the east. Phnom Penh is the capital city in Cambodia (Strengthening of Hydrometeorological Services in Southeast Asia, 2021). The map of Cambodia is presented in the Figure 1 below.

Figure 1 Cambodia Map (Britannic 2021)

According to the World Bank, Cambodia has the population of 16,718,971, and GDP of Cambodia is 27.09billion USD in 2019 (WB 2019). The monsoon winds, which defines two distinct seasons in Cambodia, influence the climate. The southwest Monsoon's strong prevailing winds produce heavy rainfall and high humidity from mid-May to early October. The lighter and drier nature of the northern Monsoon’s winds offer changeable cloudiness, irregular precipitation, and lesser humidity from early November to mid-March (Bansok et al., 2011). Deepwater has been gradually replaced by dry season irrigated rice and/or receding rice. During the wet season, medium rice types occupy about 40% of rice producing areas. Many farmers continue to cultivate multiple rice types in the same field in distinct tiny plots as a risk-reduction and labor-distribution approach in rice production. After the harvest of the wet season rice harvests, additional crops, particularly vegetable crops, are planted wherever and whenever possible (FAO 2021).

As of 2020, agriculture accounted for 22.84 % of Cambodia's gross domestic product (GDP) (Statista 2021).

4.3. Energy situation in Cambodia

Cambodia's Total Final Energy Consumption (TFEC) climbed by around 7.2% each year between 2010 and 2018, according to the Ministry of Mines and Energy of Cambodia (2020), although commercial energy growth rates such as for oil and electricity were lower, i.e., 8.1% and 18.3% per year, respectively. Biomass continues to be the most widely used energy source in the residential sector, as well as in industry and electricity production to some extent (Mika et al., 2021).

The biomass proportion of TFEC was 25.5% in 2018, declining significantly comparing to the previous year. Commercial energy, such as natural gas, was predicted to replace it by 2020, when the value was 40.9% as well as gasoline and electricity (MME, 2018).

A total of 15.3 million people in Cambodia was without electricity in 2012. Around 24% of the population was electrified. Approximately 78.4% of the population lives in rural areas, while only 21.6% lives in urban areas, according to 2012 estimates from the World Bank. Agribusiness is the country's main source of revenue. It accounted for 27.5% of Cambodia's GDP in 2012. Agri-cultural subsector is dominated by crops, which account for 54.8% of its revenue (Pode et al., 2015)

The government of Cambodia was targeting to exploit mineral resources from 2014 until 2018; for instance, to manage and develop mineral resources in a sustainable manner, to benefit the people and the surrounding communities, to provide raw resources for infrastructure and construction development, and to develop a new revenue stream for the country. The ministry of Mines and Energy have always cooperated with other countries for investment on the energy situation in Cambodia, this investment can make more benefit for the people in the future (MME, 2018).

Cambodia is heavily reliant on coal, oil (petroleum products), and electrical imports. Between 2013 and 2016, Cambodia's import dependency increased from 50% to over 60%, according to the statistics found on secondary resource (Pode et al., 2015). Cambodia does not export much electricity due to rising local demand year after year.

The main challenge is that there is still no breakthrough in domestic electricity generation. Cambodia is a delicate country that imports electricity from other neighboring countries such as Thailand, Vietnam, and Lao PDR (MME 2020).

Cambodia is committed to reducing its CO_2 emissions in the energy sector by 16% by 2030 by converting to cleaner energy such as solar energy, windmills, biomass, and biogas according to the Ministry of Mines and Energy of Cambodia (EDC 2021)

Cambodia is exploiting both sources of energy including renewable and non-renewable resources to generate electricity. The Table 1 below briefly list down the main energy sources in Cambodia:

Table 1 Types of energy source and products in Cambodia

Renewable	Non-renewable
Solar Hydropower Biomass, Charcoal Biogas	Coal Liquefied Petroleum Gas (LPG) Kerosine

(Source: based on nationalgeographic.org 2021)

4.3.1. Renewable energy sources in Cambodia

4.3.1.1. Solar power

Several countries are pursuing solar energy solutions for remote rural electrification, with monthly average daily sun radiation levels in the range of 3–6 kW h/m^2. The average daily Cambodian sunshine is at its highest level in March during the dry season and the lowest between August and October (rainy or monsoon season) at a value of 4,5 kW/m^2 (Pagnarith and Limmeechokchai, 2009). In response, the government commissioned four new solar farms, as well as a new diesel power station and a dam. In the next few years, Cambodia plans to generate 20% of its electricity from solar, which is a significant increase from 1% in 2018. The peak solar resource in the center of

Cambodia, including the load core of Phnom Penh, which accounts for over 70% of national electricity demand, is over 1,900 kWh per square meter per year. Solar is also a viable choice for households in rural areas that do not have access to the grid. Cambodia had installed approximately 60,000 Solar home systems (SHSs) as part of the Renewable energy facility (REF)'s SHS initiative by the end of 2017 ADB, 2018).

4.3.1.2. Hydropower

The Mekong River runs through Cambodia, it is no surprise that hydropower is the country's primary source of energy, accounting for more than 40% of total electricity generation. Large dams from Chinese investors are a welcome opportunity for poor nations like Cambodia in Southeast Asia to receive sophisticated energy technologies that can help eliminate energy poverty, fuel the economy, and eventually lead to sustainable development (Baird and Barney, 2017). Hun Sen, Cambodia's Prime Minister, has recently unveiled the country's newest hydroelectric project. The Lower Sesan 2 power plant, which has a capacity of 400 megawatts, is estimated to have a cost of $800 million to develop and is being funded by Chinese investment (Seattletimes 2018).

Cambodia has dominated large-scale hydropower development ambitions. Despite being classified as renewable, large-scale hydropower has been questioned for its negative effects on the environment and society. Hydropower plants emit GHG emissions that are equivalent to those of other RES in most circumstances. However, Räsänen et al. (2018) reported that 18% of hydropower reservoirs, and 55% of irrigation reservoirs in the Mekong River Basin, have significantly increased emission levels. In addition, 14 of the emissions from the reservoir analyzed were equivalent even with fossil fuel plant emissions (Mika et al., 2021).

4.3.1.3. Biomass

Wood and charcoal account for almost 80% of Cambodia's overall energy consumption. In the last 10 years, 94% of people in rural areas using charcoal and wood for cooking. Agricultural leftovers such as rice husk, rice straw, corn cob, cassava stem, bagasse, groundnut shell and husk, and coconut shell and front remarkably provide the other significant biomass sources. Currently, biomass and biogas have a total installed capacity of roughly 23 MW. Additionally, Cambodia intends to develop 73 MW of installed both power by 2030 (Tun et al., 2019).

Fuelwood is the primary energy source in Sameakki Meanchey district, Kampong Chhnang province, Cambodia for cooking, heating water, preparing animal feed, and protecting cattle from insects. Approximately 96% of the district's households utilize fuelwood as their primary source of energy for cooking, along with charcoal, animal dung, crop waste, LPG, kerosene, and biogas. Locals used kerosene (60.5%) as their primary source of energy for lighting. Rechargeable batteries (57.9%) and electricity (5.1%) were the other energy sources used for lighting in the 767 houses surveyed. Although wood biomass is vital to the inhabitants of Sameakki Meanchey, nonplantation biomass is an alternative energy source that can help to reduce pressure on natural forests by reducing the need for fuelwood for cooking and boiling water, as well as reducing greenhouse gas (GHG) emissions (Environmental and Rural Development 2013).

Abe et al., (2017) reported that as energy generation using bio-digestion gas (animal excreta) and landfill gas is site specific. The most widely used method for generating energy from solid biomass is the direct combustion steam turbine, but this system is only suitable for higher scales (e.g., >1 MW). In rural Cambodia, mini grids would not necessitate such massive networks. Gasification systems, on the other hand, are commercially accessible for very small-scale generating, such as 4 kW. As a result, they believe that gasification is the best option for rural mini-grid electrification in Cambodia (Abe et al., 2007b). In Figure 2 is presented that, about 6,418 villages in Cambodia have been identified as suitable for biomass gasification small grids powered by energy from tree farming.

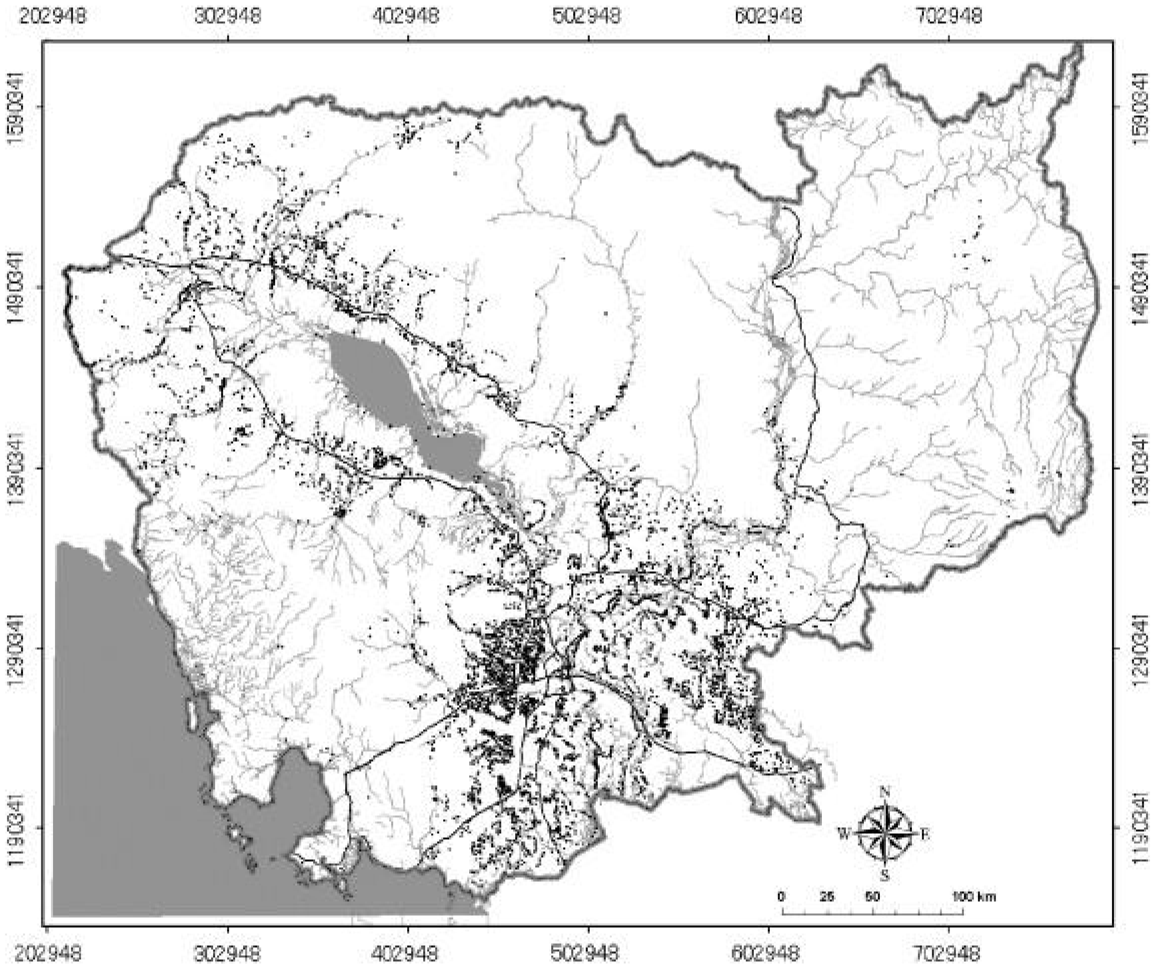

Figure 2 In Cambodia, 6418 communities have been identified as suitable for the installation of biomass gasification mini- grids powered by energy tree farming. (Abe et al., 2007).

According to the Ministry of Commerce, in 2017 the Japanese investment, which is based on the principle of establishing a processing plant for wood pulp, palm oil, and other plants, will be returned to Japan for incineration in the biomass power plant. The Japanese investor went on to inform that his team was scouting locations in Sihanoukville, Cambodia and that construction would start in the future (MOC 2017).

4.3.1.4. Biogas

In Cambodia, the projects make biogas plants available to rural households. Local builders install the systems on the recipient's property. The installation collects cow manure, digests it, and converts it to biogas. It can be used for cooking and illumination after being pumped into people's houses (Climate neutral group 2021).

While biogas is not yet widely used in Cambodia, there are a number of biogas development programs and projects, such as the National Biodigester Program (NBP). NBP successfully installed 19,173 plants between 2006 and 2012, with 95% of them now operational. People's lives are improved by having access to a growing number of energy services and carriers. Biogas has resulted in health benefits such as reduced indoor particulate emissions, improved sanitation, and increased agricultural productivity through the use of bioslurry from the digester, as well as environmental benefits such as reduced GHG emissions and wood consumption, and reduced women and children's workload. Furthermore, while deforestation is often caused by factors other than households collecting tree branches, switching to biogas reduces the strain on forest resources (Mustonen et al., 2013).

Biogas energy can be used to generate energy in three different ways, direct combustion (incineration), anaerobic digestion (biogas production), and CO_2 emission scenarios in Cambodia and Laos based on decomposition analysis Energy Dependence and Renewable Energy Potential, as well as biomass gasification vegetable oil (SVO), biodiesel, and bioethanol can also be used to replace petroleum. In Cambodia, direct biomass burning has a long history (Luukkanen et al., 2015).

4.3.2. Non-renewable energy sources in Cambodia

Several provinces in Cambodia have coal deposits that can be mined. Charcoal consumption soared to 40% in 2010 but will gradually fall to 30% between 2013 and 2030. Another common source is liquefied petroleum gas (LPG), which is primarily used by the upper class. LPG is now underutilized, but by 2030, it is predicted to account for half of all energy consumption. In the future, LPG will replace charcoal and wood; nevertheless, due to its limited supplies, it is preferable that it shall be replaced by other renewable energy sources in the long run (Sarraf et al., 2013).

4.3.3. Electricity production and consumption

The installed capacity of electricity in 2011 was 569 MW, an increase of more than half over the previous year's capacity due to the addition of new hydropower plants and other power plants. The installed capacity when could produce 1,018.5 GWh of electricity. Electricity was generated in 2011 by four types of facilities: hydropower plants, diesel power plants, coal-using thermal power plants, and wood/biomass power plants (Poch, 2013). Cambodia's domestic electricity generation is heavily reliant on oil, and Cambodia is a net oil importer. Diesel and Heavy Fuel Oil (HFO) continue to be the primary sources of power generation, even though power sources are quite diverse. In 2011, diesel and HFO accounted for 89% of all power sources used to generate electricity (Poch, 2013) (see Figure 4).

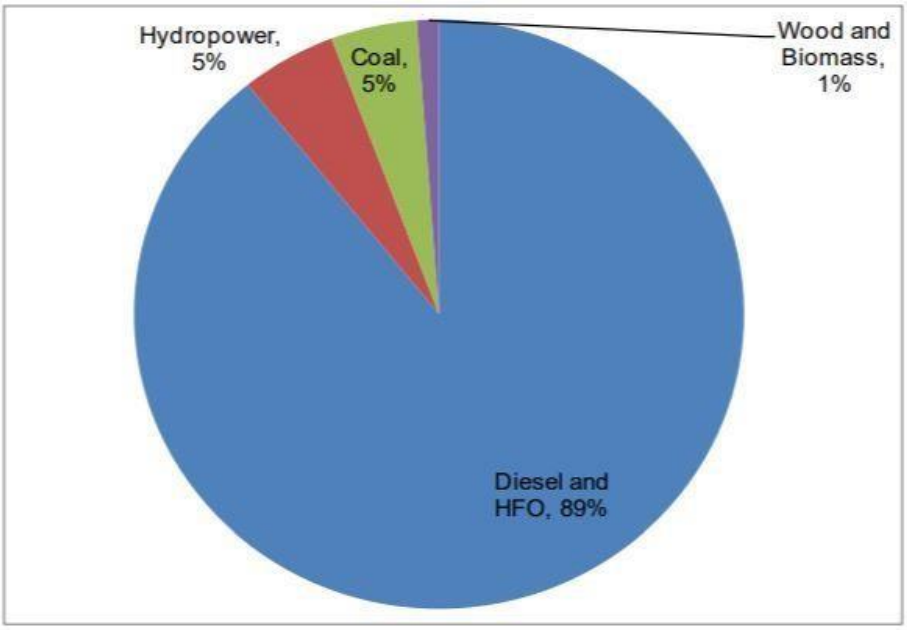

Figure 3 Energy sources used for electricity generation in Cambodia (EAC 2012)

Cambodia has had rapid economic growth during the last six years, averaging over 7% each year from 2014 to 2019. In 2019, the Asian Development Bank released the most recent economic data for Cambodia in comparison to other Southeast Asian countries. Cambodia's rapid and consistent economic expansion is followed by a surge in electricity demand (Han et al., 2020). The development trend of the electricity consumption is shown in Figure 4.

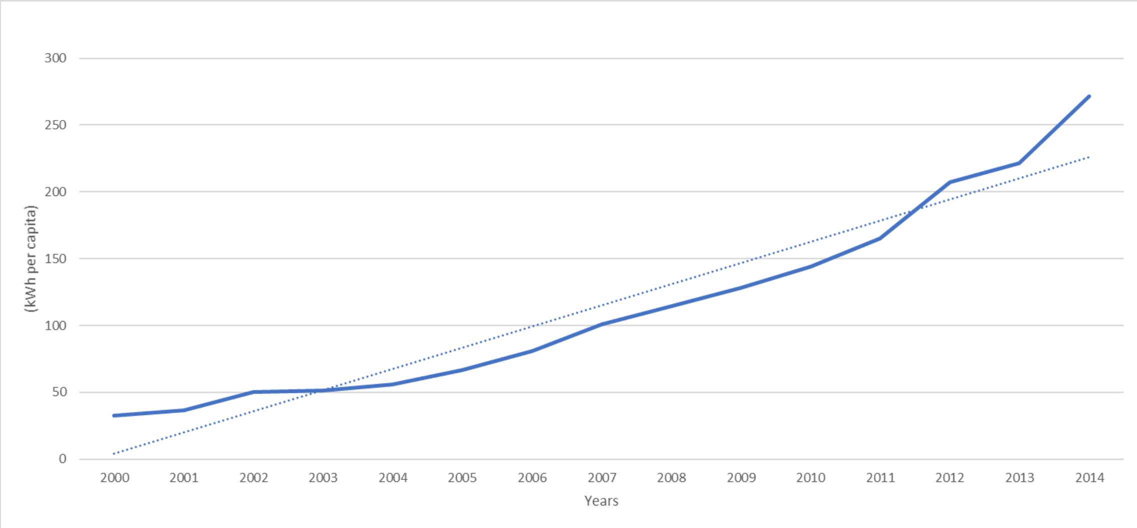

Figure 4 Electricity consumption per capita in Cambodia from 2000 to 2014 (WB 2021).

Cambodia has made a significant progress in providing electricity coverage, increasing the access to power from 49.7% in 2016 to over 80% in 2019. Power costs vary depending on the user and household; for example, in 2019, the electricity tariff was $0.185 per kilowatt-hour (kWh) for households with monthly electricity use of more than 201 kWh, and $0.173/kWh for businesses(Han et al., 2020)

According to the Electricite du Cambodge (EDC), 13,798 villages, or 97.39%, will have enough electric energy by 2020. However, 370 villages (or 2.61%) lack sufficient electricity (EDC 2021). Some sub-plans of the Ministry of Mines and Energy have been put in place for the stakeholders in the electricity sector to make more efforts. So far, the Ministry has not been able to achieve some tasks. The main problem that hinders the Ministry from not being able to achieve these objectives is because some areas are islands, floodplains, no roads, floating areas. The Electricite du Cambodge (EDC) finds it very difficult to apply for a loan, and Covid-19 also impact on the EDC (EDC 2021)

4.3.4. Energy challenges in Cambodia

Cambodia is a developing country; electricity usage is still limited. Natural forces, investment, and the usage of mechanical engineering are all obvious limitations. While the government and its development partners emphasize the benefits of hydropower generation, policymakers and decision-makers in Cambodia are less aware of the hazards connected with dam construction (EDC 2021).

As a result of all these problems, Cambodia does not have enough electricity to power the entire country. Also, as result, Chinese corporations are investing heavily in Cambodia. Cambodia, on the other hand, is looking for investment from the European Union and the United States (MME 2019).

Chinese investments in Cambodia are beginning to have a major impact on Cambodia's electricity projects such as the Kamchay Dam. With a capacity of 194 MW, the Kamchay dam is Cambodia's first significant hydropower dam. According to the Kampot Province Department of Environment, the dam may supply up to 60% of Cambodia's electricity consumption, at least during the rainy season. Other projects such as the Sola project is also present in the provinces of Cambodia, including the windmills in Kampot province (Siciliano et al., 2016).

The Cambodian and French governments will sign an agreement on the construction of a wind power road in Kampot. Electricity is the first step with the government's first wind power. The government is interested in diversifying its energy sources, especially clean energy (MME 2020).

4.4. Agricultural sector in Cambodia

4.4.1. Main facts about Cambodian agriculture

4.4.1.1. Land area dedicated to agriculture

According to the World Bank's collection of development indicators, compiled from officially recognized sources, Cambodia's agricultural land (percent of land area) was reported at 31.53% in 2018, (WB 2021). The percentage of land that is arable, under permanent crops, and under permanent pastures is called agricultural land. "Arable land" is defined by the FAO as land under temporary crops, temporary meadows used for mowing or as pasture, and land that is temporarily fallow. Double-cropped areas are counted only once. Excluded is land that has been abandoned as a result of shifting agriculture (FAO 2021).

4.4.1.2. Population employed in agriculture

During the ten years leading up to 2011, the labor force aged 15 to 64 accounted for 54% of the total population, according to the National Institute of Statistics. The unemployment rate has been approximately 83% of the entire labor force. Employment is defined in Dalis's study as working at least one hour each week. Agriculture absorbed 60% of total employment during the same period, followed by services (26%), and industry (14%). The manufacturing industry employed 8.7% of the total workforce (Dalis, 2014).

Agriculture employs a major portion of the labor force aged 15 to 25, with a proportion ranging from 41% in 2004 to roughly 35% in 2010. In 2011, youth employment in the sector fell to 32%. The percentage of people in the senior age group (41 to 64 years) increased from 29% in 2004 to 36% in 2011. Industry, in general, employed the greatest number of young people (around 45%) (Dalis, 2014).

It shows the distribution of employment in Cambodia from 2010 to 2010 based on the economic sector in which it was created. However, according to the newest data, in 2020, the agricultural sector employed only 31.15% of Cambodians, industry employed 29.64%, and the service sector employed 39.21% (Statista 2021).

4.4.2. Agricultural production

4.4.2.1. The most cultivated crops

Rice is the most important crop in Cambodia and rice production is central to Cambodia's agricultural sector. Not only do the majority of Khmer farmers rely on the success of the rice crop each year, both directly and indirectly, but rice production is also a big factor in the country's effort to promote food security, as it is the main food staple (Kea et al., 2016). Between the year 2000 and 2009, Cambodia's rice harvest per acre grew by 34%. However, for the study by Mustonen et al., 2013, which focuses on rural regions, the mean yield of 2,335 kg/ha for the years 2000–2009 was used to reflect the rice production of smallholder families, which is unlikely to have increased at the same rate (Mustonen et al., 2013).

Other food products include cassava, corn (maize), sugarcane, soybeans, and coconuts, in addition to rice. Bananas, oranges, and mangoes are the main fruit crops, which are all consumed locally, and are complemented by a variety of other tropical fruits such as breadfruits, mangosteens, and papayas (Kea et al., 2016). Table 2 below presents the top cultivated crops in Cambodia from 2015 to 2019.

Table 2 Five main crops cultivated in Cambodia

Year	Crops	Area harvested/ ha	Yield/ hg/ha
2019	Rice	3,001,313	36,271
	Cassava	504,940	272,070
	Maize	270,701	52,098
	Soybeans	108,704	16,189
	Sugar cane	29,703	222,509
2018	Rice	3,071,696	35,459
	Cassava	481,679	265,859
	Maize	242,237	50,859
	Soybeans	105,000	16,190
	Sugar cane	28,770	222,454
2017	Rice	3,035,700	34,648
	Cassava	457,305	259,648
	Maize	151,145	49,621
	Soybeans	104,000	16,154
	Sugar cane	28,950	222,403
2016	Rice	2,941,234	33,836
	Cassava	431,737	253,436
	Maize	137,032	48,383
	Soybeans	102,000	15,882
	Sugar cane	28,903	222,349
2015	Rice	2,799,126	33,350
	Cassava	388,017	260,825
	Maize	82,673	48,383
	Soybeans	102,000	15,882
	Sugar cane	29,130	219,995

(Source: based on FAOSTAT, 2021).

4.4.2.2. The most common livestock

According to the Ministry of Agriculture, Forestry and Fisheries, poor rural livestock producers are shifting from producing for their own needs to trading, due to vibrant market demand, thus reshaping the once backyard industry into a flourishing commercial business. Cambodia's 16 million people are consuming more meat due to rising incomes. Total animal production increased from 40.3 million heads in 2015 to 42.18 million heads in 2016. Buffalo production jumped by 41%, pork production grew by 7.07%, and poultry production increased by 3.52% (MAFF 2019)

4.4.2.3. Management of residual biomass from agriculture

Apart from Cambodia's vast biomass resources, which are a true gold mine, the country has few "traditional" energy sources. There are, however, several interesting, although not fully utilized, potential sources of renewable energy, such as hydropower. Therefore, all fossil fuels, especially gas and petrol, are imported for electricity and transport (Aurélien HERAIL, 2006).

Cambodian households make use of a variety of renewable energy sources that are readily available in their surroundings. A survey indicated that firewood is used in 86% of all households and in rural communities without power infrastructure, according to Mustonen et al., 2013. The value of 98% corresponds to the findings of San et al. and the Population Census of 2008. However, in urban areas, the survey indicated more charcoal consumption than the Census, which does not mention the use of plant leftovers as a cooking fuel. Plant leftovers, used by 74% of all households, are the second most extensively used residential bioenergy source. Animal dung usage for energy, on the other hand, is not as common in Cambodia as it is in India, for example. Animal dung is mostly utilized for energy in rural areas without access to grid electricity (Mustonen et al., 2013).

Agricultural plant leftovers are used for energy, compared to 35% in rural areas without access to electricity. Pursat (61%) and Kampot (54%) provinces have the greatest rates of plant residual energy consumption (Mustonen et al., 2013).

In 2003 and 2004, the need for Phnom Penh household wood was assessed: 26,000 tons per year and 100,000 tons per year. If current trends continue, charcoal usage will reach 21,000 tons per year in 2009, with wood consumption almost non-existent (Mustonen et al., 2013).

Biomass waste/residue is already being used in kilns by many families who are having trouble procuring wood supplies, buying it, or wishing to boost their wages. So, in certain circumstances, it may be more acceptable to enhance kiln output, while in others, a substitute combustible may be a viable option (Mustonen et al., 2013).

In fact, brick factories are the main industries that use wood. The factories in Cambodia are divided into two kinds. Those who utilize rice husk and those who use wood. Brick Kilns are powered by wood and have between 150 and 170 tonese with an average length of 1,1 meter every kiln and combustion cycle. Their average measurements are 5m wide, 40m long, and 3m high. A 100,000-brick cycle takes about 7 days per kiln (Mustonen et al., 2013).

4.5. Assessment of Environmental and Economic aspects of biomass use for energy

4.5.1. Environmental assessment

Carbon dioxide concentrations in the atmosphere have risen about 30% in the last 50 years, and other (GHGs) have also climbed dramatically (Joselin Herbert and Unni Krishnan, 2016).

Expressing concern for environmental and energy independence the interest in the utilization of biomass for renewable energy generation has developed substantially in recent years. Environmental impact should undoubtedly be considered when assessing the sustainability of renewable energy systems. Nevertheless, an analytical assessment of the economic and environmental performance of various bioenergy options is necessary to support environmentally friendly bioenergy plans (Bacenetti, 2020).

There is no access to electricity for almost 2 billion people in the developing countries. Low-income people use more wood as well as other traditional biomass fuels, whereas they use less electricity and gaseous fuels. The number of people who rely on traditional use of biomass is anticipated to increase from 2.5 billion in 2004 to 2.6 billion in 2015, and to 2.7 billion by 2030 without any powerful new and efficient measures (San et al., 2012).

4.5.1.1. Positive impact on environment

Biomass over fossil fuels: plant-based sources of fuels from renewable sources can be cultivated there and have less carbon emissions than fossil fuels. Although these gas levels are significantly smaller than that of fossil fuels, some GHGs are still manufactured. The local cultivation lessened the dependence of the nation on fossil fuels. A number of towns have started producing domestic waste biogas for transport purposes and agricultural waste. It restricts emissions from petrol-operated urban public transport vehicles. The sugar plant may help reduce GHG emissions by substituting biomass power stations with fossil fuelled thermal plants. Biomass has a far lower sulfur level than oil and coal fuels. This minimizes SO_2 emissions and reduces acidity of soil and water (Joselin Herbert and Unni Krishnan, 2016).

Biowaste: A major part of municipal solid trash is organic waste or biowaste. Its separate collection is a helpful measure in the development world to increase waste management systems (Pavlas et al., 2020). After six years of twelve plant species, fly ash is finally stabilised and environmental pollution decreased by fly ash is reduced (Joselin Herbert and Unni Krishnan, 2016).

Recycling of Biomass: Recycling contributes to reducing energy use, air and water pollution, new raw material usage, and GHG emissions. Furthermore, it helps to ensure the best-balanced protection of the environment. It also contributes to the conservation and optimization of essential natural resources, including wood. Other application: An environmentally friendly gasifier-based has been cremated by the Energy and Resources Institute, officially known as Tata Energy and Resources Institute (TERI). Their substantial fuel saving (more than 50%) and the pay-back period of around one year are anticipated to result in cultural and social acceptability. TERI has developed a new 60% energy efficiency, gasifier-powered silk reeling machine, which the production of silk grew by 3.7% (Joselin Herbert and Unni Krishnan, 2016).

4.5.1.2. Negative impact on environment

Biomass energy has a number of negative aspects, one of which being the amount of space it demands. Some biomass crops take a lot of land and water to develop, and once they've grown, the result requires a lot of storage space before it can be transformed into electricity. Another downside of biomass energy is that it is not completely clean. Even though some GHGs are still created, their quantities are much lower than those produced by fossil fuels (Hayley Ames, 2018). Although biomass fuels are natural, there are not quite as efficient as fossil fuels processed, such as petroleum and gasoline. Biodiesel and similar biofuels are commonly blended with tiny portions of fossil fuels to increase their efficiency. In consequence, this diminishes the efficiency of these biofuels to minimize the usage of fossil fuels (Ecavo, 2021). Before public concerns restrict the use of biomass technologies, the bioenergy community must solve these large-scale challenges of environment (Environmental Implications of Increased Biomass Energy Use: Final Report, 1992).

While biofuel is renewable, it must also be kept. If this is not done, massive deforestation may result. This is a significant environmental problem. It drastically reduces the amount of livable land available to a variety of wildlife species, resulting in extinction. This is a key stumbling block to the widespread use of biomass fuels, as replanting efforts may not be able to keep up with the amount of fuel required (Ecavo, 2021).

Work injuries and diseases linked with agriculture and the production of forest biomass are several times more severe than underground coal mining and oil mining. Forest biomass has 14 times more occupational injuries and illnesses per million kilocalories of output than underground coal mining and 28 times more than oil and gas extraction (Joselin Herbert and Unni Krishnan, 2016).

According to the government of Cambodia and the National Institute of Statistics, this research was inspired by households' combined use of electricity and biomass consumption, despite being connected to an electrical grid. Long-term health impacts of an increase in household biomass use, especially for young children and the elderly, can be expected in the future. The rural population consumes a higher percentage of biomass, which results in more forest and shrub wood destruction, resulting in an unsustainable environment (Han et al., 2020). figure 5 presents environmental implications of increased biomass energy use.

Impact/Category	Needed	Addressed
Production and		
Land Use	Local land suitability for intensive forest or woody crop production. Conversion of former wetlands.	Global availability.
Soils/ Productivity	Long-term residue effects. Long-term modeling and validation. Effect of whole tree harvesting.	Effect of residue removal.
Institutional and Social	Public policy and planning. Farmer changes to woody crop production, economics, social. Information systems, GIS, etc.	Reactions to potential increases. Coordinated planning systems.
Water Supply	Benefits/impact of increased production on water supply. Needs for water supply development.	Global problem definition.
Water Quality	Impact of intensive cultivation. Fertilizers, pesticides, disease. Cropland conversion.	Erosion protection, benefits. Nonpoint source pollution.
Wildlife and Ecosystems	Impact/benefits of increased shift from agriculture to woody crops or forestry.	Legislation, habitat conservation areas.
Air Quality	Regional impact. Solve operational problems of burning offset fuels.	Ambient regulation. Emissions offsets for open burn.
Conversion		
Land Use	Plant siting logistics.	Environmental permits, assessments.
Solid Waste Disposal	Permitting for urban wood fuels.	
Institutional and Social	Large-scale biomass facilities.	Facilities directories. Resource assessment.
Water Supply/ Water Quality	Needs for water supply development. Limits to water use, local.	Facilities regulation. Management and reuse/recycle.
Air Quality	Regional impact. Emissions and fuel classification (NO_x).	Facilities regulation.

Figure 5 Environmental Topics Important to Increased Biomass Use. (Environmental Implications of Increased Biomass Energy Use: Final Report, 1992).

4.5.1.3. Environmental assessment of biomass in Cambodia

Biomass is predicted to play a significant part in the future of energy worldwide as a renewable resource. The agricultural excess of rice straw in Asia is plentiful because rice is one of the country's primary food crops. Rice straw is frequently burned uncontrollably in the field, releasing huge amounts of short-lived air pollution, GHGs as well as other pollutants. In fact, Vietnam is facing enormous challenges in the energy and environmental protection sectors due of its quick urbanization and industrialization. To achieve energy security and CO_2 emission decrease, a national strategic option is to harness renewable energy, particularly biomass-derived carbon for energy (Cuong et al., 2021).

Many Cambodian businesses have constructed rice husk gasifiers to replace diesel in the generation of electricity to power rice mill machinery or give electricity to communities in recent years. According to Nguyen Hong et al., 2015 gasification technology works in Cambodia and helps in developing the rice-milling sector, but there are serious environmental challenges that need to be addressed. Cambodia's overall rice production in 2014 was estimated to be at 9.3 million tons. On a weight basis, rice husk contributed for about 20% of paddy cultivation, implying that 2 million tons of rice husk were produced. For domestic cooking and brick kilns just 10% of Cambodian rice husk is used as fuel. The rest must be thrown away by rice mills or burnt out. This produces environmental risks including environmental pollution. The husk of rice can become a valuable source of power generation. Rice husk conversion to power is 1.6-1.8 kg/kilowatt hour (kWh) which is equal to 1100 GWh of power (Nam Nguyen et al., 2015).

According to The New Energy and Industrial Technology Development Organization of Japan (NEDO) and the MME, in 2011, they decided to develop the project for energy and environmental technology Rice Husk Energy Generation Systems. This project will construct and test an eco-friendly, cheap, and small-and-light power generation technology at an existing or newly developed rice milling plant. This technology is used to run a powerful rice husk separator with heat and electricity. The rice husk biochar that was used to produce electricity in this system will now be used as a soil fertilizer to increase rice milling efficiency and rice husk supply capacity (NEDO, 2011).

Fuelwood was perhaps the most widely utilized fuel for cooking purposes in 85% of Cambodian households in 2007, according to the National Institute of Statistics' Statistical Yearbook 2008. Charcoal was used in 6% of houses, followed by LPG (5.2%), publicly provided electricity/city power (0.2%), and kerosene (0.1%). With less than 20% of homes was having access to power grid, Cambodia was one of the lowest rates of electrification in Asia. Only 6% of Cambodia's rural population had access to electricity, which is largely provided by REEs (Rural Electricity Enterprises), which frequently employ wasteful diesel generators, while the remaining 80% relied on kerosene lamps or car battery-powered fluorescent lights (San et al., 2012).

Phoumin et al. (2020) predicted that the dependency on biomass as a household energy source remained nationally about 87%. Even though the San, Sriv, et al. (2012) survey reported up to 96% of households in Kampong Chhnang province sampled with fuelwood for everyday usage. Petroleum fuel is generally utilized for more efficiently combustion than solid fuels like firewood, especially kerosene and liquid gas. Traditional fuel is usually inefficient and emits particulate air that is damaging to human health by burning it. Taking fuel into collection takes time off production and can lead, if is not controlled, to forest loss, which link it to a wide range of ecological and climatological challenges. The adverse impact on the well-being of Cambodia's households of the adverse health, education, and revenue effects of energy poverty, associated with biomass consumption, was found in Phoumin and Kimura (2019.). Cambodia also struggles by one of the province's highest electricity pricings at a price up to $1/kWh from private suppliers of electricity (Mika et al., 2021).

The evaluation of the exploitation potential of diverse sources of fuel, particularly in renewable energy sources like wind, solar energy, biomass, hydropower, and more, showed enormous potential in different areas of Cambodia. Household payment capacity and way of life on the other hand, limit energy consumption. Furthermore, either environment or economics benefits of energy use in Cambodia's rural areas have received scant attention. Households are impoverished in Sameakki Meanchey, fuel is very short, soil is deteriorated and costly (San et al., 2012).

4.5.2. Economic aspects of biomass use for energy

Energy is a necessary component of socioeconomic progress. The resources of renewable energy are locally available, non-polluting, and nearly limitless. The issues of providing appropriate food, water, shelter, hygiene and other health services are significant for energy services. The absence of accessibility to energy services, on the other hand, is directly linked to a large range of difficulties, including the economy, lack of jobs, urban development, low health and, in particular, illiteracy in women and children (San et al., 2012)

4.5.2.1. Positive impact on economy

Cambodia's trade balance could be improved if fossil fuel imports were reduced as a result of local biofuel production. It may also alleviate the strain on foreign currency reserves. Biofuel production would directly create new jobs and business opportunities, as well as attract foreign and domestic investment. If biodiesel can be produced at a lower cost than fossil diesel, the economy will benefit even more as other businesses become viable because of lower energy costs (Bank, 2009).

Families and communities that cultivate oil crops or who may be directly employed by private biofuel processing companies could benefit from the production of biofuels by creating new income opportunities. As well as offering rural families income opportunities with minimal investment costs and training, the cultivation of biofuel crops may also protect rural poor from external energy price fluctuations. By reducing Cambodia's reliance on regional neighbors and oil-producing nations on a long-term basis, Cambodia's economic and political situation will be more resilient. Biofuel, unlike diesel, is non-explosive and non-corrosive, making it safer to handle and transport (Bank, 2009).

4.5.2.2. Negative impact on economy

Compared to coal-fired plants, a wood-fired steam plant requires four times as many construction workers and three to seven times as many plants maintenance and operation workers to construct and maintain it. The labor required to produce one million kcal of ethanol, including corn production, is about 18 times greater than the labor required to produce an equivalent amount of gasoline. Biomass is not entirely clean; it necessitates a large amount of storage space, as well as a significant amount of land and water. Each individual need around 0.5 hectares of cropland to feed them (Joselin Herbert and Unni Krishnan, 2016).

As was mentioned above (in subchapter 4.5.1.2.-), the production of forest biomass is associated with a high rate of injuries as well as health problems from in-door biomass burning. Thus, higher expenditures on medical care are to be expected.

4.5.2.3. Economic assessment of biomass in Cambodia and border countries

Rice is Cambodia's principal agricultural crop and staple diet, and rice straw and husks have enormous potential for bioenergy production. According to Luu and Halog (2016), in general, there is good technical potential for rice-based biomass. Rice husk has a Residue to Product Ratio of 0.2. As a result of the large proportion of available rice husk, it is a technically feasible form of bio-based energy for small-scale electricity generation. The growth of renewable energy sources could be a significant answer to accelerating the development of the power sector, and the local economy as well (Luu and Halog, 2016).

Forests cover 10,094,000 hectares in Cambodia, accounting for 57% of the country's total land area (Akgün et al., 2011). Short-term and long-term changes in forest biomass can be tracked using multi-temporal biomass maps. Cambodian forests are categorized into three types: evergreen, mixed, and deciduous. Evergreen woods have the most biomass, followed by mixed and deciduous forests. The provinces of Mondulkiri, Ratanakiri, Koh Kong, and Kampong Thum have significant forest biomass density (Ninan, n.d.),

Transport biofuels can also be made from biomass. Jatropha (1,000 ha), palm oil (4,000–10,000 ha), and sugarcane (4,000–10,000 ha) provide the raw materials (20,000 ha). A joint venture with a Korean company, MH Bio-Energy Group, also produces 36 million liters of bio ethanol annually from cassava. Several experiments have showed the possibility for using animal waste to produce biogas for cooking and lighting; but, due to most farmers' small-scale livestock holdings, biogas may be limited to the home level (ADB, 2018). Abe et al, 2017 reported that Cambodia's large-scale forest plantations and small-scale tree farms produce relatively little biomass and nutrient sustainably, according to available information. The Department of Agriculture in Battambang province, on the other hand, has measured production of up to 80 t/-ha. An investigation into biomass production in 10- to 12-month-old infants was also conducted. Only 8.2 t/-ha of woody biomass was produced on a yearly basis. However, the first year's biomass production is usually relatively low. The coppiced branches were as large as they were pre-harvest three months after the survey, and annual productivity in the second year is predicted to be much higher. As a base rate of annual woody biomass production, we choose a cautious estimate of 10 t ha (Abe et al., 2007). The above-mentioned potential and rising trend of biofuel market development could have a positive impact on the country’s economy.

Similarly, to Cambodia, biomass currently provides roughly 19% of Thailand's total primary energy requirements. Residential cooking mostly involves the use of fuelwood and charcoal, whereas rural industries rely heavily on fuelwood and agricultural leftovers such as bagasse and rice husk(Sajjakulnukit et al., 2005).

Food and beverage, as well as nonmetallic industries such as ceramics and bricks, are the two most biomass energy-intensive businesses. In the old 1997, over 8.6 Mt of biomass was used primarily in traditional stoves for family cooking. The biomass savings potential was calculated by assuming that in 2010, all traditional cooking stoves would be replaced by better versions. The average efficiency in 2005 was calculated as the sum of efficiencies in 1997 and 2010. In 2005 and 2010, the annual biomass saving potential for cooking was projected to be around 1.8 Mt (35.2 PJ) and 3.0 Mt (58 PJ). Savings potential in 2010 is approximately 35% of total annual consumption in 1997 (Sajjakulnukit et al., 2005).

For example, on the 450 km^2 of the proposed Nam Theun 2 hydropower reservoir in Lao People's Democratic Republic, an assessment of the organic carbon stock existing in living or dead flora and in the soil was done. On the study site, nine land cover types were identified: thick, medium, light, degraded, and riparian forests; agricultural soil; swamps; water; and others (roads, construction sites, and so on) (Descloux et al., 2011). As a result, secondary forests, which include fallow areas, accounted for 63% of total forest cover in Southeast in 2005, and fallow areas in Laos reached approximately 6.5 million ha (28.2% of total land) in 2002, despite the primary forest area decreasing from approximately 1.6 million ha in 1990 to approximately 1.2 million ha in 2015. As a result, the dynamics of slash-and-burn agriculture regions in the region have a clear impact on forest biomass and decreasing the fallow time significantly reduces biomass. As a result, changing the length of the fallow period might affect the biomass of a given region (Hiratsuka et al., 2018).

In the spring of 2006, biomass burning emissions peaked in March–April, when the most intense biomass burning occurred in Myanmar, northern Thailand, Laos, and parts of Vietnam and Cambodia. Despite overestimation or underestimating happening in specific places due to significant uncertainties of biomass burning emission, model performances were sufficiently confirmed by comparing to both satellite and land measurements (Huang et al., 2013). Biomass fuels are the most important indigenous source of energy in Cambodia, Laos, Vietnam Bangladesh, Bhutan, Nepal and Sri Lanka. Despite their importance, little is known about how these energy sources are generated, harvested, exchanged, and consumed. As a result, there is a lot of ambiguity about the environmental repercussions of broad biomass use and the resource's long-term viability (Koopmans, 2005).

5. Conclusions

Energy shortage is an enormous challenge for developing countries, especially Cambodia. Even though the country has several energy sources including non-renewable and renewable ones, the exploitation of these sources is still limited due to the lack of capital invested, challenging geographic factors and limited mechanic engineering. To tackle this problem of energy shortage, developing only electricity plants and infrastructure is not the best solution. Since some population in Cambodia is living in rural areas, developing long-distance electricity infrastructure would be very costly. Hence, relying on renewable energy sources such as hydro, solar power and biomass is the most suitable solution for Cambodia.

To conclude, renewable energy sources, especially biomass can help developing countries, especially Cambodia to achieve sustainable supply of power throughout the country. However, the usage of biomass as the source of energy in Cambodia is still lacking in those rural areas in the country. Despite that fact, plant-based fuel is a very good solution due to its unique nature and advantages. Thanks to the fact that Cambodia is an agricultural country, it is fortunately rather rich in terms of necessary ingredients to create biomass. Agricultural plant leftovers are so much available as the majority of households in Cambodia are farmers.

Another reason that biomass is the practical solution to tackle the energy problem in Cambodia is that this plant-based fuel has many environmental benefits. This energy source emits way less SO_2 and reduce acidity in soil and water comparing to coal and oil fuel. Furthermore, recycling biomass is much less consuming in terms of energy used and materials while producing little pollution.

In order to improve the usage of biomass as the energy source in Cambodia, the government shall invite investors both from local and international to create biomass products and to serve people in those rural areas. In the meantime, the government should encourage farmers to use this type of energy source as it provides a very sustainable solution to the energy shortage problem that this country is facing as the population grows rapidly.

6. References

Abdelhady, S., Borello, D., Shaban, A., Rispoli, F., 2014. Viability study of biomass power plant fired with rice straw in Egypt, in: Energy Procedia. Elsevier Ltd, pp. 211–215. https://doi.org/10.1016/j.egypro.2014.11.1072

Abe, H., Katayama, A., Sah, B.P., Toriu, T., Samy, S., Pheach, P., Adams, M.A., Grierson, P.F., 2007. Potential for rural electrification based on biomass gasification in Cambodia. Biomass and Bioenergy 31, 656–664. https://doi.org/10.1016/j.biombioe.2007.06.023

Akgün, O., Korkeakoski, M., Mustonen, S., Luukkanen, J., 2011. Theoretical Bioenergy Potential in Cambodia and Laos.

ADB, 2018. CAMBODIA Energy Sector Assessment, Strategy, and Road Map. Manila, Philippines. https://doi.org/10.22617/TCS189801

Aurélien HERAIL, 2006. Study about biomass waste in Cambodia and processing them as alternative fuels.

Bacenetti, J., 2020. Economic and environmental impact assessment of renewable energy from biomass. Sustainability (Switzerland). https://doi.org/10.3390/su12145619

Bank, A.Development., 2009. Cambodia : Status and Potential for the Development of Biofuels and Rural Renewable Energy. Asian Development Bank.

Bansok, R., Nang, P., Chhun, C., 2011. CDRI-Cambodia’s leading independent development policy research institute Agricultural Development and Climate Change: The Case of Cambodia A CDRI Publication.

Bridgwater, A. v, 1994. A Catalysis in thermal biomass conversion.

Cuong, T.T., Le, H.A., Khai, N.M., Hung, P.A., Linh, L.T., Thanh, N.V., Tri, N.D., Huan, N.X., 2021. Renewable energy from biomass surplus resource: potential of power generation from rice straw in Vietnam. Scientific Reports 11. https://doi.org/10.1038/s41598-020-80678-3

Dalis, P., 2014. Links between Employment and Poverty in Cambodia.

Descloux, S., Chanudet, V., Poilvé, H., Grégoire, A., 2011. Co-assessment of biomass and soil organic carbon stocks in a future reservoir area located in Southeast Asia. Environmental Monitoring and Assessment 173, 723–741. https://doi.org/10.1007/s10661-010-1418-3

Ecavo, 2021. Biomass Energy Advantages And Disadvantages: What Are The Major Pros & Cons? [WWW Document].

EDC. 2021.News about Cambodia electricity. Available from https://www.edc.com.kh/new_page/newdetail/53 (accessed 30 July 2021).

Environmental and Rural Development, 2013.

Environmental Implications of Increased Biomass Energy Use: Final Report, 1992. Environmental Implications of Increased Biomass Energy Use: Final Report.

FAOSTAT, 2021. Crops data [WWW Document].

Gallezot, P., 2012. Conversion of biomass to selected chemical products. Chemical Society Reviews 41, 1538–1558. https://doi.org/10.1039/c1cs15147a

Goh, C.S., Junginger, M., Faaij, A., 2014. Monitoring sustainable biomass flows: General methodology development. Biofuels, Bioproducts and Biorefining 8, 83–102. https://doi.org/10.1002/bbb.1445

Han, P., Kimura, F., Sandu, S., 2020. Household-level analysis of the impacts of electricity consumption on welfare and the environment in Cambodia: Empirical evidence and policy implications. Economic Modelling 89, 476–483. https://doi.org/10.1016/j.econmod.2019.11.025

Hayley Ames, 2018. The Advantages & Disadvantages of Biomass Energy [WWW Document].

Hiratsuka, M., Tsuzuki, H., Suzuki, K., Nanaumi, T., Furuta, T., Niitsuma, K., Phongoudome, C., Amano, M., 2018. Living biomass of fallow areas under a REDD+ project in mountainous terrain of Northern Laos. Journal of Forest Research 23, 56–63. https://doi.org/10.1080/13416979.2017.1393605

Huang, K., Fu, J.S., Hsu, N.C., Gao, Y., Dong, X., Tsay, S.C., Lam, Y.F., 2013. Impact assessment of biomass burning on air quality in Southeast and East Asia during

BASE-ASIA. Atmospheric Environment 78, 291–302. https://doi.org/10.1016/j.atmosenv.2012.03.048

Joselin Herbert, G.M., Unni Krishnan, A., 2016. Quantifying environmental performance of biomass energy. Renewable and Sustainable Energy Reviews. https://doi.org/10.1016/j.rser.2015.12.254

Kea, S., Li, H., Pich, L., 2016. Technical Efficiency and Its Determinants of Rice Production in Cambodia. Economies 4, 22. https://doi.org/10.3390/economies4040022

Koopmans, A., 2005. Biomass energy demand and supply for South and South-East Asia - Assessing the resource base, in: Biomass and Bioenergy. pp. 133–150. https://doi.org/10.1016/j.biombioe.2004.08.004

Lauri, P., Havlík, P., Kindermann, G., Forsell, N., Böttcher, H., Obersteiner, M., 2014. Woody biomass energy potential in 2050. Energy Policy 66, 19–31. https://doi.org/10.1016/j.enpol.2013.11.033

Lewis, C.W., 1981. BIOMASS THROUGH THE AGES, Biomass.

Luu, L.Q., Halog, A., 2016. Rice Husk Based Bioelectricity vs. Coal-fired Electricity: Life Cycle Sustainability Assessment Case Study in Vietnam, in: Procedia CIRP. Elsevier B.V., pp. 73–78. https://doi.org/10.1016/j.procir.2016.01.058

Luukkanen, J., Akgün, O., Pasanen, T., Keskiväli, I., Panula-Ontto, J., Kaivo-Oja, J., Tuominen, V., Vehmas, J., Lakkala, H., 2015. Energy dependence and potential for renewables: Analysis of future trends and potential for renewable energy development in Cambodia and Laos, in: Energy Security and Development: The Global Context and Indian Perspectives. Springer India, pp. 410–422. https://doi.org/10.1007/978-81-322-2065-7_27

Mika, K., Minna, M., Noora, V., Jyrki, L., Jari, K. oja, Anna, A., Eliyan, C., Dany, V., Maarit, K., Nicholas, H., 2021a. Situation analysis of energy use and consumption in Cambodia: household access to energy. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-021-01443-8

Mika, K., Minna, M., Noora, V., Jyrki, L., Jari, K. oja, Anna, A., Eliyan, C., Dany, V., Maarit, K., Nicholas, H., 2021b. Situation analysis of energy use and consumption in Cambodia: household access to energy. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-021-01443-8

MME, 2018. KINGDOM OF CAMBODIA Nation Religion King The Royal Government of Cambodia NATIONAL POLICY ON MINERAL RESOURCES 2018-2028 Prepared by the Ministry of Mines and Energy.

Munawar, M.A., Khoja, A.H., Naqvi, S.R., Mehran, M.T., Hassan, M., Liaquat, R., Dawood, U.F., 2021. Challenges and opportunities in biomass ash management and its utilization in novel applications. Renewable and Sustainable Energy Reviews. https://doi.org/10.1016/j.rser.2021.111451

Mustonen, S., Raiko, R., Luukkanen, J., 2013. Bioenergy consumption and biogas potential in cambodian households. Sustainability (Switzerland) 5, 1875–1892. https://doi.org/10.3390/su5051875

Nam Nguyen, H., Ha-Duong, M., van de Steene, L., van de Steene, L.A., Hong Nam, N., Minh, H.-D., van de Steene, L., 2015. A critical look at rice husk gasification in Cambodia: Technology and sustainability, Vietnam Academy of Science and Technology Journal of Science and Technology.

NEDO, 2011. NEDO and the Government of the Kingdom of Cambodia Conclude Memorandum of Understanding-NEDO Chairman Furukawa and Cambodian Prime Minister Samdech Hun Sen Affirm Close Bilateral Relations.

Ninan, K.N. (Karachepone N., n.d. Environmental assessments : scenarios, modelling and policy.

Pagnarith, K., Limmeechokchai, B., 2009. Biomass and Solar Energy for Rural Electrification and CO 2 Mitigation in Cambodia, International Journal of Renewable Energy.

Palazzo, n.d. Biomass knowledge.

Pavlas, M., Dvořáček, J., Pitschke, T., Peche, R., 2020. Biowaste treatment and waste-to-energy-environmental benefits. Energies 13. https://doi.org/10.3390/en13081994

Perea-Moreno, M.A., Samerón-Manzano, E., Perea-Moreno, A.J., 2019. Biomass as renewable energy: Worldwide research trends. Sustainability (Switzerland) 11. https://doi.org/10.3390/su11030863

Poch, K., 2013. Chapter 7 Renewable Energy Development in Cambodia: Status, Prospects and Policies.

Pode, R., Diouf, B., Pode, G., 2015. Sustainable rural electrification using rice husk biomass energy: A case study of Cambodia. Renewable and Sustainable Energy Reviews. https://doi.org/10.1016/j.rser.2015.01.018

Ramsay, W., 1985. Biomass energy in developing countries.

Sajjakulnukit, B., Yingyuad, R., Maneekhao, V., Pongnarintasut, V., Bhattacharya, S.C., Abdul Salam, P., 2005. Assessment of sustainable energy potential of non-plantation biomass resources in Thailand. Biomass and Bioenergy 29, 214–224. https://doi.org/10.1016/j.biombioe.2005.03.009

San, V., Sriv, T., Spoann, V., Var, S., Seak, S., 2012. Economic and environmental costs of rural household energy consumption structures in Sameakki Meanchey district, Kampong Chhnang Province, Cambodia. Energy 48, 484–491. https://doi.org/10.1016/j.energy.2012.10.017

Sarraf, M., Rismanchi, B., Saidur, R., Ping, H.W., Rahim, N.A., 2013. Renewable energy policies for sustainable development in Cambodia. Renewable and Sustainable Energy Reviews. https://doi.org/10.1016/j.rser.2013.02.010

Siciliano, G., Urban, F., Tan-Mullins, M., Pichdara, L., Kim, S., 2016. The political ecology of Chinese large dams in Cambodia: Implications, challenges and lessons learnt from the Kamchay Dam. Water (Switzerland) 8. https://doi.org/10.3390/w8090405

Strengthening of Hydrometeorological Services in Southeast Asia, 2021.

Tun, M.M., Juchelkova, D., Win, M.M., Thu, A.M., Puchor, T., 2019. Biomass energy: An overview of biomass sources, energy potential, and management in Southeast Asian countries. Resources. https://doi.org/10.3390/resources8020081

Vassilev, S. v., Vassileva, C.G., Vassilev, V.S., 2015. Advantages and disadvantages of composition and properties of biomass in comparison with coal: An overview. Fuel. https://doi.org/10.1016/j.fuel.2015.05.050

Wilén, Carl., Moilanen, Antero., Kurkela, Esa., 1996. Biomass feedstock analyses. Technical Research Centre of Finland.