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Enhancing the Electricity Generation Mix for Sustainability of Cambodia

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Enhancing the Electricity Generation Mix for Sustainability of Cambodia

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Abstract

This master's thesis sought to analyze energy alternative technologies for Cambodia. Moreover, this study compared and evaluated the fuel alternative technologies with a high probability of being introduced in 2025 as they related to energy security, electricity generation cost, carbon dioxide (CO_2) emissions from fossil fuels and secured capacity of renewable energy sources (especially hydropower).

In this research, the energy security price index of electricity generation (ESPIgen) was used to measure the electricity supply security. The levelized cost of electricity (LCOE) was then used to compare the electricity generation cost from each fossil fuel for 2025 while the average cost data of the non-OECD countries were used in the case of Cambodia. Furthermore, the CO_2 emissions from alternative technologies were estimated and were arranged according to the Intergovernmental Panel on Climate Change (IPCC) inventory guidelines. Moreover, the generation capacity balance was used to measure the secured adequate supply for electricity generation.

The results of this study show that the hydropower-oriented scenario was better than the introduction of the integrated gasification combined cycle (IGCC) and combined cycle gas turbine (CCGT) scenarios. In addition, during the rainy season, the secured capacity of hydropower energy can supply more than three times the power peak demand by 2025 while in the dry season, hydropower and gas energies are needed to meet the peak demand. Therefore, the Cambodian energy policymakers need to decide the proper hydropower and gas energy supply proportion in the country's fuel mixes.

Cambodia's specific conditions, such as in relation to the domestic fossil fuel reserves, import dependence, national renewable energy potential, and load duration curve, are very important factors that must be considered by the Cambodian energy policymakers to find the least-cost generation capacity mix in the electricity generation supply side. In addition, all these important factors can help the energy policymakers find the best development strategies for attaining the goals of Cambodia.

Finally, the improvement of the hydropower technology in the electricity generation with higher energy efficiency can increase the future energy supply security of Cambodia, but the environmental impact of hydropower plants should be a main concern when start doing the feasibility study of hydropower projects.

Keywords: Enhancing, electricity generation mix, sustainability, Cambodia
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Abbreviations

CCGT	Combine Cycle Gasification Turbine
CL	Consolidated Licensees
EDC	Electricite du Cambodge
ESPI	Energy Security Price Index
$ESPI_{gen}$	Energy Security Price Index of Electricity Generating
ESMC	Energy Security Market Concentration
GWh	Giga watt hour
HFO	Heavy Fuel Oil
IPCC	Intergovernmental Panel on Climate Change
IGCC	Integrated Gas Combine Cycle
IEA	International Energy Agency
IPP	Independent Power Producer
LCOE	Levelized Cost of Electricity
MIME	Ministry of Industry, Mines and Energy
MW	Mega watt
NEDO	New Energy and Industrial Technology Development Organization
OECD	Organization for Economic Co-operation and Development
PCC	Pulverized Coal Combustion
PSDP	Power Strategy Development Plan

REE	Rural Electricity Enterprises
TC	Ton of Carbon

Chapter 1. Introduction

1.1 Background

Energy sustainability is an important factor for the economic, social and environmental dimensions. Regarding sustainability's economic dimension, energy availability is a key driver for the economic growth and development prospects of a country. In terms of social sustainability, energy is a basic human need, and access to reliable and affordable energy sources can greatly improve people's living standard. As regards environmental sustainability, energy is closely associated with carbon and other emissions that contribute to global warming and air pollution. Access to modern energy services, including electricity, at affordable prices is widely agreed to be essential for poverty eradication and economic development within developing countries.

The rapidly increasing growth of fossil fuel use in Northeast Asia (especially in China and India) is already having ramifications on global energy, and capital markets relying on energy security have become a major concern of national policy [1]. To meet the demand, energy policymakers trying to ensure an undisrupted energy supply. In addition, due to the global agreement to respond to climate change, energy policies have been adjusted of late to address the issue of energy security without detriment to the environment. While energy security has been a pillar of energy policy for a century, the recent concerns about climate change are radically changing the landscape of energy policy [2]. Therefore, both the reduction of carbon emissions and the improvement of energy security are key drivers and important targets for the governmental energy plan. Country-specific conditions such as the domestic fossil fuel reserves, import dependence, national renewable energy potential, specific technology specialization, and energy security threats affect the interactions between energy policy targets. Cost is also an important factor to be considered by decision makers when comparing alternatives for policy targets, which is a less expensive solution that has become another important policy concern.

The electricity sector is currently the largest single contributor to the global greenhouse gas emissions due to its heavy reliance on fossil fuels, primarily coal and gas. Carbon dioxide (CO_2) is the most significant greenhouse gas, and the electricity sector produced around 41% of the global CO_2 emissions in 2010 [3]. In addition, the electricity sector relies heavily on coal, the most carbon-intensive fossil fuel, amplifying its share in the global emissions. Countries like Australia, China, India, Poland, and South Africa produce between 68 and 94% of their electricity and heat through coal combustion [3].

Security of supply encompasses all links in the value chain of electricity supply, including the provision of energy fuel resources, the generation of electric energy, the distribution of electric energy, and trading and retail. Security of supply is said to exist if “the consumer demand for electric energy is covered today and in the future in an uninterrupted and sustainable manner” [4]. During the peak hours, “the ability of the electric system to withstand sudden disturbances” characterizes the reliability of supply. Intermittent electricity generation from renewable energy sources such as wind, solar, and hydropower energy is increasing the challenge of providing a reliable and secure supply of electricity from such sources [4].

The energy sector has a essential role to play in the country’s continued development, but the current situation in Cambodia with respect to energy costs, service provision, sustainability, and security may prove to be a barrier to development. This situation has serious implications for a country like Cambodia, which does not have enough reserve stocks of fossil fuels to insulate the domestic consumers from price shocks. Consequently, the Cambodians are facing fossil fuel’s price fluctuation, which is considered a main source of energy insecurity.

1.2 Research Objective

The main purpose of this paper is to analyze the different ways by which the energy conditions affect the interactions for the future energy policy targets of Cambodia. The fuel alternative technologies with a high probability of being introduced by 2025 will be compared as they relate to energy security, electricity generating costs, CO_2 emission from fossil fuels, and secured capacity of renewable sources. Finally, some recommendations will be made to the Cambodian government to improve Cambodia's security of energy supply with affordable prices.

1.3 Research Question

This paper seeks to answer the following specific research question: What technologies can provide more advantages for the future energy development of Cambodia with regard to energy security, cost of electricity generation from alternative technologies, CO_2 emission, and secured capacity of renewable sources?

To answer this question, the least-cost generation capacity mix scenario was used to evaluate the total costs of electricity generation from each power generation technology that has been introduced in Cambodia. Furthermore, the energy security price index of electricity generation (ESPIgen) was used to measure the electricity supply security of Cambodia, and the levelized cost of electricity (LCOE) was used to compare the electricity generation cost per megawatt hour from each fossil fuel or technology for 2025, and the average cost data of the non-OECD countries for Cambodia was used, and the quantities of CO_2 emission from fossil fuel combustion technologies that have low CO_2 emissions were estimated and compared. Finally, generation capacity balances were used to measure the secured adequate supply of hydropower energy for electricity generation.

1.4 Research Problems

The rapidly increasing growth of fossil fuel use in Northeast Asia (especially in China and India) is already having ramifications on global energy and capital markets, and profound impacts on the global greenhouse gas emissions. The major sources of power generation in Cambodia are diesel and heavy fuel oil (HFO), which are imported from the neighboring countries. A change in the structure of the international market or in the political situation in the exporting country will affect the energy security of the countries in the region. Thus, energy security has been a major concern of national energy policy.

Most of the existing power generation facilities in Cambodia are oil-based diesel generation facilities that depend on oil imported from the neighboring countries, and there have been large losses and low efficiency in the distribution line. The unit cost of electricity generation varies from one area to another, such as USD0.18 per kWh in Phnom Penh (capital city), USD0.25-0.40 per kWh in the towns and urban areas, USD0.50-1.00 per kWh in the rural areas with diesel generators, and USD0.16 per kWh in cross-border communities connecting with Vietnam, Lao PDR, and Thailand. All these issues have made the price of electricity higher in the country.

With the current supply capacity, reliability remains a major concern for the consumers. Blackouts have been routinely reported, especially in the capital city, as the demand capacity has reached the peak level, particularly in the dry season, with the supply still below the demand. The electricity demand has been increasing in the country. On the other hand, during the dry season, the amount of water for generating electricity has decreased; thus, the Royal Government of Cambodia (RGC) decided to import electricity from its neighboring countries through a high- and medium-voltage transmission line, for short-term supply.

The hydropower energy potential of Cambodia was estimated to be approximately 10,000 MW, 50% from the Mekong mainstream, 40% from its tributaries, and the remaining 10% from the southwestern coastal area, outside the Mekong River basin. At present, however, the electricity generated from hydropower energy is contributing less than 5% of the total amount.

1.5 Limitation of the study

This study was limited to the security of primary energy supply for electricity generation in Cambodia by the year 2025. The greenhouse gas emissions from fossil fuel combustion for electricity generation focused solely on CO_2; other types of greenhouse gases were not included in the study due to the lack of available information pertaining to such gases. The methane emissions from the power dam will be discussed in relation to the environmental impact of the hydropower section.

Moreover, this study projected the electricity generation costs in 2025 in accordance with the current situation. Due to the lack of available information, a portfolio standard was not applied in this study.

1.6 Organization of the study

The study is organized into six chapters. Chapter one gives the introduction, research objective, research question, research motivation, limitation of the study and organization of the study. Chapter two provides an overview of electricity generation of Cambodia. Chapter three reviews relevant literature on energy supply security, electricity generating costs, carbon emission mitigation targets and secure capacity of renewable sources. Chapter fourth introduces the research methodologies such as measuring the energy security, cost analysis of fuel mix, carbon dioxide emission from fossil fuel technology and secure capacity of renewable sources. Chapter fifth presents the study data, scenario analysis and the results. Finally, chapter sixth presents the conclusion and recommendations.

Chapter 2. Energy Situation in Cambodia

2.1 Energy Resources

Cambodia is endowed with abundant fuel source potentials which including 10,000 MW of hydropower energy and less than 5% of total capacity which has been exploited; potential of mini hydropower energy estimated within a range 500 kW to 5 MW; 120 to 150 million metric tons of coal which the coal's quality is 3,000 kcal; 140 billion cubic meters of natural gas; 700 million barrels of oil; 5 kWh per square meters day of solar energy; a wind speed potential estimated to be within the range of 3 to 5 meters per second; a biomass potential of about 18,852 GWh of annual electricity generation.

Table 1. Summary of fuel source potentials in Cambodia

Source	**Potential**
Hydro power	10,000 MW
Mini hydro power	500 kW to 5 MW
Coal	120 million metric tons
Natural gas	140 billion cubic meters
Oil	700 million barrels
Solar	5 kWh/m^2.day
Wind	5 m/s
Biomass	18,852 GWh (annual electricity generation)

Source: Ref. [5], [6], [7].

2.1.1 Oil and Gas Energy

Oil and gas sector is relatively new sector in Cambodia and its present a huge potential for boosting the country's economy. Royal Government of Cambodia (RGC) is planned to produce oil and gas in the next decade.

The Cambodians' government has been seeking to promote the oil and gas sector. It has established the Cambodian National Petroleum Authority (CNPA) to responsible the upstream and downstream petroleum activities in Cambodia. Areas for hydrocarbon exploration are classified into 6 offshore (A-F) and 19 onshore blocks. Around Tonle Sap region, which located in the central of the country presents a large hydrocarbon potential of onshore exploration. In addition, total of oil reserves for all 6 blocks is approximately around 700 million barrels [5].

Another zone of offshore areas lies in the overlapping claimed by Cambodia and Thailand. It is estimated that the overlapping area contains up to 11 trillion cubic feet of natural gas and an under-determined quantity of condensate oil. In 2001, a Memorandum of Understanding (MoU) was signed between the these two countries, which set a joint development regime over this area.

Since the announcement of offshore oil discovery, many blocks have been issued licenses to E&P companies. Production Sharing Agreement (PSA) for all 6 offshore blocks had been signed. Block A appears to be the only block that has been actively explored with the Chevron, Moeco and GS Caltex owns this block (55%, 30% and 15% respectively). In 2005, Chevron announced that it had discovered oil in four wells and gas in one well of the Block..

2.1.2 Coal Energy

Cambodia's mineral potential is still unknown as most areas of the country have hardly been surveyed for resources. Mineral potentials in Cambodia, as indicated by the Department of Geology and Mines (under the Ministry of Industry, Mines and Energy) were for bauxite, coal, gemstones, gold, iron ore, kaolin, limestone, manganese, phosphate rock, quartz, silica sand, and tin [6].

Based on the given information by the coal mine licensee, the coal deposit for the two sites are 34 million tons and 120 million tons respectively (totally over 150 million tons). The quality of the coal is similar to the Thai’s coal, which is 3,000 kcal and it is suitable for boiler or kiln fuel. Due to lower calorific value, there is little marketability in the international markets. However, it is still attractive enough for an onshore sources of Cambodian’s power generation.

2.1.3 Renewable Energy

Since renewable energy resources in Cambodia are sustainable energy development sources which is found that there are a large amount of available renewable energies that can be utilized for electricity generation. There are several types of renewable energy sources in Cambodia such as hydropower, biomass, solar and wind energies. It is also estimated that renewable energy sources of Cambodia can generate potentially 67,388 GWh of energy per annum [7]. It can be seen that the largest potential for electricity generation is estimated to belong to hydropower energy.

2.1.3.1 Solar Energy

Cambodia received a relatively high level of solar radiation throughout the year with the average sunlight is available for 6.8 hours per day and consequently 2490 hours per year [8]. Solar radiation in Cambodia starting to increase from January reaches a maximum value in March and April. The average Cambodia sunshine hour is shown in Table 2.

Based on the new energy and industrial technology development organization (NEDO) that used a 10 year annual average solar irradiation of 5.0 kWh/m^2.day and considering 0.02% of Cambodia’s land area is suitable for installing PV modules with the preliminary solar power generation potential is estimated to be around 21 GWh per day [7]. The current utilization of solar power in the country is still low compared the potential of solar energy resources. The total installed capacity solar home system (SHS) throughout eight provinces was 205 kW in 2002 and was increased to over 650 kW by the end of 2011.

Table 2. Cambodia’s sunshine average hour.

Month	**Sunshine hour**	**Month**	**Sunshine hour**
January	8.4	July	4.6
February	8	August	5.6
March	8.6	September	4.3
April	8	October	6.5
May	6.5	November	7.1
June	6.4	December	7.8

Source: Ref. [8].

2.1.3.2 Wind Energy

The total wind energy potential in Cambodia based on Atlas Report in Southeast Asia that covers Cambodia, Thailand and Vietnam is reported to be around 1,380 MW. The detailed potential capacities based on the wind characteristics are presented in Table 3. However, the southern coastal area (Sihanouk Ville, Kampot, Kep, Koh Kong province) and mountainous areas in the southwest and northeast of the country, as well as on the southern part of the great lake Tonle Sap, have favorable wind condition with average speed of 5-7 m/s. So after the installation of a 400 W wind generator in these areas for half of rural households, the ultimate total capacity would approximately become equal to 22 MW resulting in a 39 GWh generation per year. Wind energy is subjected to great seasonal variations, besides the electricity generation application, wind energy has been utilized for water pumping in the central part of Cambodia as well (Prey Veng province) which is supported by a non-governmental organizations (NGO) with installed capacity of 700 kW.

Table 3. Wind energy potential in Cambodia.

Wind characteristic	**Poor (< 4 m/s)**	**Fair (4–5 m/s)**	**Good (5–6 m/s)**	**Very good (6–7 m/s)**	**Excellent (> 7 m/s)**
Percentage of total land areas (%)	96.4	3.4	0.2	0	0
Potential capacity (MW)	NA	24,620	1,260	120	0

Source: Ref. [8].

2.1.3.3 Hydropower Energy

Cambodia's hydropower energy potentials was estimated at 1995 with the theoretical potential of about 10,000 MW, which is 50% in the Mekong mainstream, 40% in its tributaries and remaining 10% is in the southwestern coastal area outside the Mekong River Basin. The hydropower assessment has shown that it would help Cambodia meet all its electricity requirements for several decades from water. Some parts of the country, micro/mini hydropower energy may provide opportunities for electrification to reduce the consumption of fossil fuel energy.

Table 4. Hydropower potentials in Cambodia.

No.	Project	Install capacity (MW)
1	Hydro power plant, Kirirom I	12
2	Hydro power plant, Ochum	1
3	Hydro power plant, Komchay	194.1
4	Hydro power plant, Kirirom III	18
5	Hydro power plant, Atay	120
6	Hydro power plant, Ressei Chhrum	338
7	Hydro power plant, Tatay	246
8	Hydro power plant, Lower Sesan II	400
9	Hydro power plant, Sambor	2600
10	Hydro power plant, Lower Sesan III	375
11	Hydro power plant, Lower Srepok III	330
12	Hydro power plant, Lower Srepok IV	235
13	Hydro power plant, Stung Pursat I	75
14	Hydro power plant, Prek Liang I	64
15	Hydro power plant, Prek Liang II	64
16	Hydro power plant, Stung Treng	900
17	Hydro power plant, Stung Sen	40

Source: Ref. [9].

2.1.3.4 Biomass Energy

Biomass energy resource in Cambodia includes agricultural residues, fuel wood, animal wastes, municipal wastes and other fuels derived from biological sources. Biomass resources are estimated to sustain an annual electricity generation of more than 18,000 GWh (all sources of biomass that are most likely to be available for commercial energy generation at 34% average conversion efficiency).

The available type of biomass resources in Cambodia is categorized into agricultural residues that include rice husks and other agricultural residues, woody biomass that comprise old rubber trees, natural forest and forest plantations [8]. Some selected biomasses in Cambodia and their higher heating value (HHV) are summarized in Table 5. It is estimated that the wood energy demand will increase from 73,637 TJ in 2007 to 35,522 TJ in 2030 [8].

Table 5. HHV of selected biomass in Cambodia.

Simple name	**HHV (MJ/kg)**
Agricultural residues	
Cashew nut shell	23.62
Bagasse	15.68 – 19.50
Corn cob	17.72
Rice husk	15.38
Peanut shell	18.92
Coconut shell	18.56
Cassava stem	18.59

Source: Ref. [8].

2.2 Current Situation of Power Generation

The electricity generation sector in Cambodia is supplied by different sources such as heavy fuel oil (HFO), diesel, coal, hydropower, wind and solar energy (but wind and solar energy is very few amounts). The major source of power generation are diesel and HFO. Cambodia actively seeks other alternative sources which have a high possibility for power generation. Hydropower energy is a main considerable potential for power production in Cambodia and it will become the major source in the long term supply.

Electric power supplied throughout the country is sourced from three different types of licenses included the state-owned Electricite du Cambodge (EDC), IPPs and consolidated licensees (CL) including REEs. However, REEs supply electricity typically in the rural areas. In Figure 1 shows the capacity of electricity sent out by IPPs, EDC and CL accounts for approximately 90.95%, 4.82% and 4.22% of electricity supply in Phnom Penh city.

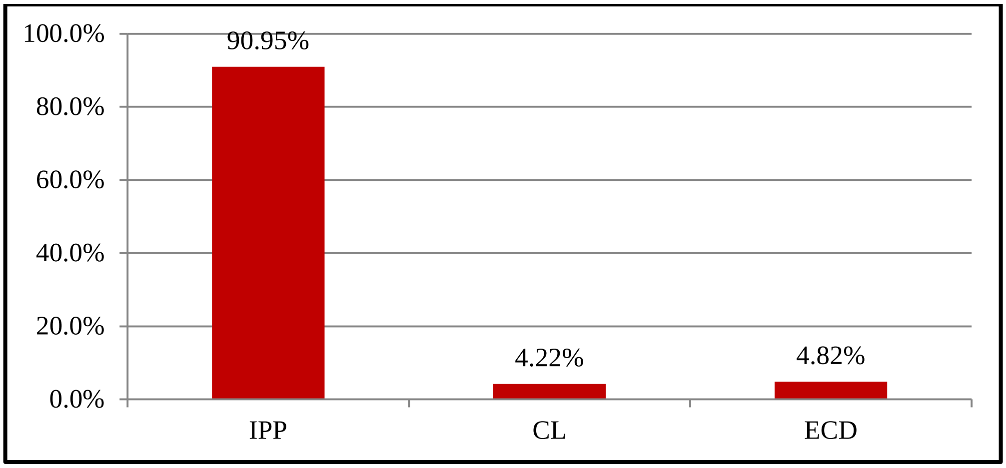


Figure 1. Proportion of Energy Sent Out by Licensee in 2010 in Phnom Penh.

Source: Ref. [10].

The electrification rate in Cambodia remains low. The majority of the population is not connected to electric power networks [11]. Presently, 23.7% of electrical energy in the country produced from fossil energy which from heavy fuel oil (HFO); 15.6% from hydropower energy and 60.6% is imported from neighboring countries such as Thailand, Lao PDR and Vietnam [12]. The trend of heavy fuel oil consumption to generate electricity dramatically decreased from 100% of the total primary energy supply in 2005 to 22.6% in 2012. The declining share of HFO caused by the Ministry of Industry, Mines and Energy (MIME) initiated a new power development plan in 2011 which is trying to increase the proportion share of hydropower energy source in fuel mixes.

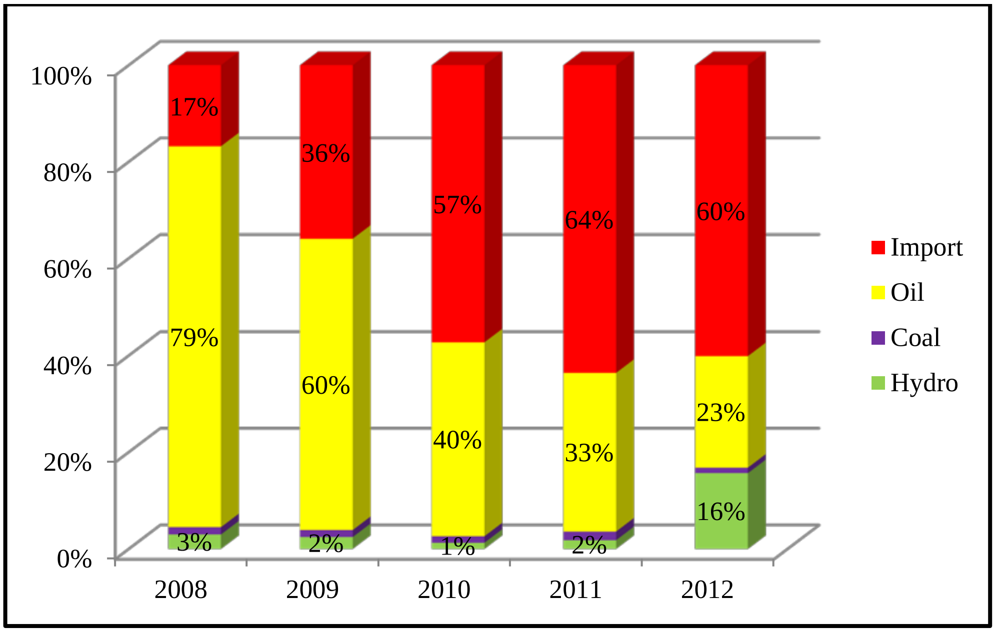


Figure 2. Electricity generation by fuel type in Cambodia.
Source: Ref. [12].

As of December 2012, the total national grid installed capacity was 848 MW, which was a combination of 245 MW from oil-fired power plants, 256 MW from hydropower plants, 10 MW from coal-fired power plant and 337 MW from importing electricity from outside. Consumers' demand for electricity had increased every year hence, the demand installs capacity for producing electricity must be increased. Power generation increased from 906 GWh in 2005 to 3,310 GWh in 2012 due to increasing the proportion of residential and industrial sector.

Table 6. Primary energy supply by source in Cambodia

Plant/source	Installed capacity (MW)			Power generation (GWh)		
	2005	**2010**	**2012**	**2005**	**2010**	**2012**
Oil-based	232	229	245	906	773	764
Hydro	0	11	256	0	35	518
Coal	0	10	10	0	32	38
Imports	0	239	337	0	1,385	1,990
Total	**232**	**489**	**848**	**906**	**2,225**	**3,310**

Source: Ref. [12].

In order to assess the electricity with different plant types for different purposes, oil-fired and coal-fired power plants were used for the base load facilities. Moreover, imports electricity from neighboring countries was used for the intermediate load facility due to low operating cost. During the dry season, in terms of insufficient water source, hydropower was used for the peak load facility and switching to serve the base load facility in the rainy season.

In 2011, Power Strategy Development Plan (PSDP) issued an updated plan to serve as the framework for the accelerated development and advancement of power generation sector as well as the development of strategic programs to increase its utilization. It provided an overall plan of action for the implementation of electric power development plan. Table 7 shows the capacity installation targets as stated by PSDP. In PSDP seeks to increase hydropower capacity up to 2,442 MW (approximately 61.8%), increase coal-fired plants up to 1,105 MW (approximately 28%), increase gas-fired plants up to 400 MW (approximately 10%) of total installs capacity addition from 2015 to 2025.

Table 7. Total power installs capacity target by the government of Cambodia.

Fuel Type	**Installed capacity (MW) in 2012**	**Target capacity (MW) addition by**			**Total install capacity addition (MW), 2015-2025**	**Total install capacity (MW), 2012-2025**
		2015	**2020**	**2025**		
Oil[a]	244.80	0.00	0.00	0.00	0.00	244.80
Hydro	256.28	584.00	958.00	900.00	2442.00	2698.28
Coal[b]	10.00	505.00	400.00	200.00	1105.00	1115.00
Gas[c]	0.00	0.00	400.00	0.00	400.00	400.00
Imports	337.30	0.00	0.00	0.00	0.00	337.30
Total	**848.38**	**1089.00**	**1758.00**	**1100.00**	**3947.00**	**4795.38**

Source: Ref. [42].

"a" : oil-fired plants by burning HFO.

"b" : coal-fired plant equipped with pulverized coal combustion technology.

"c" : gas-fired plant equipped with combined cycle gas turbine technology.

Cambodia is endowed with an abundance of hydropower resources which should be utilized to increase electricity generation. The hydropower potentials of Cambodia which is 50% in the Mekong mainstream, 40% in its tributaries and remaining 10% are in the southwestern coastal area outside the Mekong River Basin. Seasonal variation in availability of water quantity and the average distribution of rainfall in Cambodia is show in Table 8 and Figure 3 belows.

Table 8. Seasonal variation in availability of water quantity in Cambodia.

Season	Dry (million m3)	Rainy (million m3)	Max. Power in dry season (GWh)	Max. Power in rainy season (GWh)
Sesan river	5,741	13,806	603	1,450
Sre Pok river	8,793	21,125	923	2,218
Mekong river	81,309	317,190	8,537	33,305
Total	**95,843**	**352,121**	**10,064**	**36,973**

Source: Ref. [43].

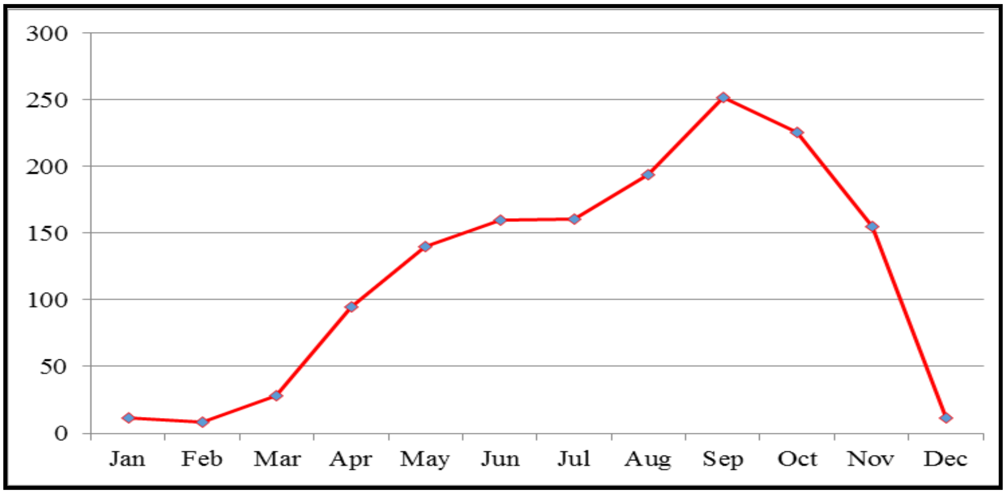


Figure 3. Average distribution of rainfall (mm) in Cambodia.

Source: Ministry of Water Resource and Meteorology of Cambodia, 2014.

To meet the growing demand for electricity and achieving electricity access goals and targets, the Cambodians' government recognizes need to have a balanced development of centralized and decentralized electricity supply systems. Government calls for the extension of the grid-based electricity supply to provincial and district towns and for the promotion of private investments on the development of mini-grids based on diesel and isolated areas. Cambodia's main transmission lines are 220 kV, 115 kV and 22 kV. EDC is overseeing for operating and maintaining the transmission network a whole country. In 2012, the national grid network was not covering all parts of the country which caused the majority of the population are lack of accessing to reliable electricity supply. Figure 5 shows projected of development of transmission lines and it will reach to 2,100 kilometers by 2020. The power loss through transmission and distribution line was dramatically declined from 9.78% in 2007 to 8.63 in 2012.

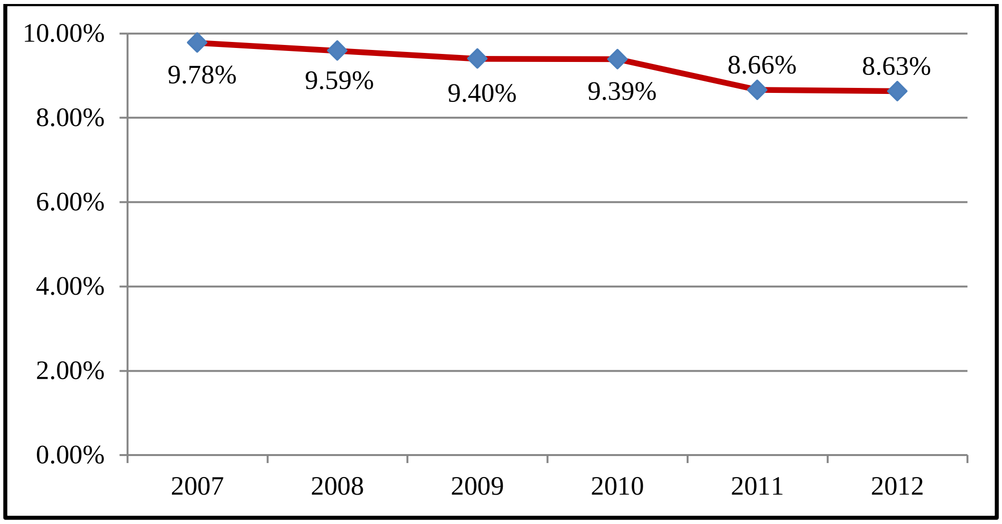


Figure 4. Transmission line loss in Phnom Penh system from 2007-2012.

Source: Ref. [12].

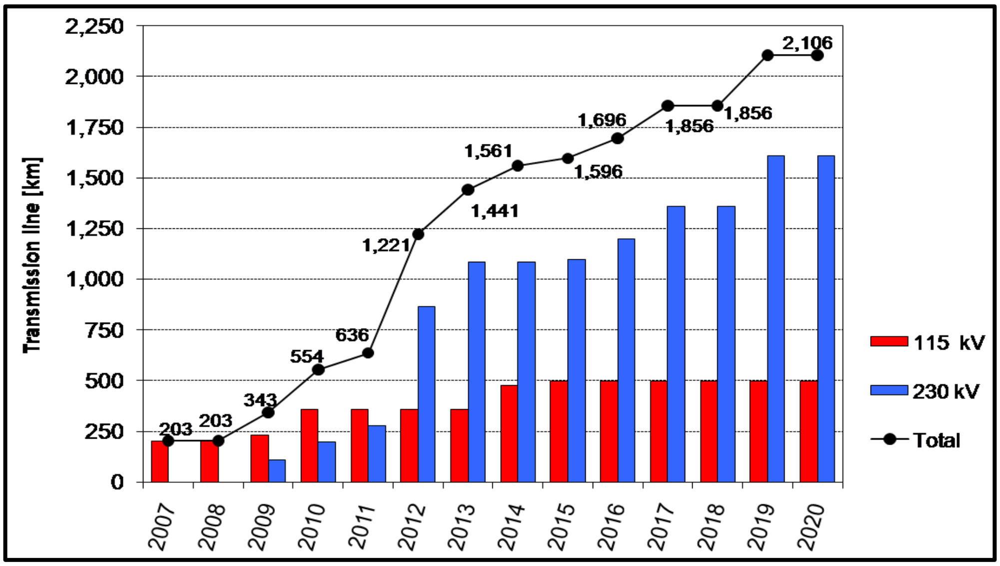


Figure 5. Transmission line development plan.

Source: Ref. [12].

To identify the investment sources is required for the deployment of electricity infrastructure (generation, transmission and distribution). In 2011, the MIME cooperates with Electricite de Cambodge (EDC) studied on generation, transmission and distribution projection for 2025. The power peak demand was projected to increase from 520 to 3,210 MW from 2012 to 2025 (is growing more than 6 times compared to the total installed capacity in 2012).

Table 9. Projected maximum peak demand capacity in Cambodia.

Year	2012	2015	2020	2025
Max. Peak demand capacity (MW)	520	896	1,696	3,210
Min. Peak demand capacity (MW)	366	631	1,195	2,261

Source: Ref. [12].

Electricity tariff is set by electricity service providers (ESPs) which the prices were set for their electric power services supplied to consumers. However, the set prices require approval from the Electricity Authority of Cambodia (EAC). As stipulated in the electricity law, the approval is required to ensure that prices are reasonably affordable by consumers and businesses of ESPs are carried out efficiently, qualitatively, sustainable and transparently [13].

On the one hand, electricity tariff rates in Cambodia vary considerably depending on the sources of electric power generation. Almost 95% of the cost of electricity supply is related to the cost of fuel. Licensees generating electricity from diesel or HFO or purchasing electricity from IPPs, which costs of those electricity purchases linked to the cost of fuel brought the price of electricity supply is extremely high. IPPs importing electric power supply from neighboring countries apparently have the tariff rates lower than local IPPs that generate electric power using diesel or HFO [14].

Presently, the electricity supply in Cambodia is fragmented into 24 isolated power systems centered in provincial towns and cities. All are fully reliant on diesel and heavy fuel oil (HFO) power stations, but most of the existing generates facilities in the country based on diesel generator, depending on imported oil and big losses and low efficiency in distribution lead the electricity price is the highest in the region. The unit cost of generating electricity is still higher as well as different from areas to areas in varying from $0.18/kWh in Phnom Penh (capital city), $0.25 to $0.40/kWh in towns and urban areas, $0.50 to $1.00 per kWh in rural areas with diesel generators, and $0.16 per kWh in communities cross-border connecting to Vietnam, Loas PDR and Thailand.

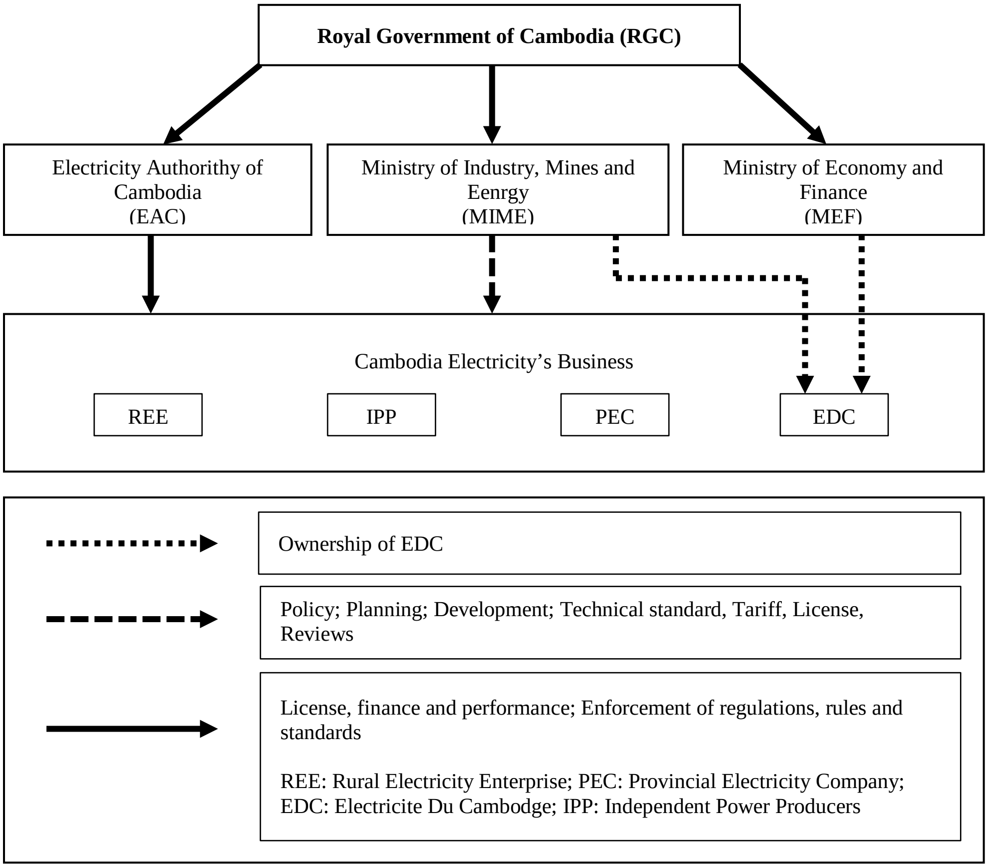
2.3 Energy Policies of Cambodia

Electricity is very important for the improvement of living standards specially for developing on agriculture and industrial sector in Cambodia. The Royal Government of Cambodia (RGC) had approved the Power Sector Strategy Plan (PSSP) for 1999-2016. There are four main policies objective in PSSP which detailed out as i) providing an adequate supply of electricity throughout the country at reasonable and affordable price; ii) ensuring reliable and secure electricity supply which facilitate investment in Cambodia and development of the national economy; iii) encouraging exploration of environmentally and socially acceptable energy resources needed to supply all sectors of the Cambodian economy and iv) encouraging efficient use of energy to minimize environmental effects resulting from energy supply and use. Furthermore, energy security policy in Cambodia context forms part of the overall national energy policy that promotes not only energy sector growth and development but also for economic growth and development.

To ensure sustainable development of electric power sector, an electrification master plan was issued for: i) electricity generation development, including hydropower resources development and development of coal or gas power plant, ii) electricity import to coordinate the development of the border zones of the kingdom and iii) the development of the transmission grid throughout the country in order to establish the electricity transmission system of Cambodia [15]. Furthermore, the RGC will encourage the construction of low cost of electricity generating plants by using local energy sources such as conventional and renewable energy sources.

2.4 Energy Structure in Cambodia

The main institutions involving in the Electricity Industry in Cambodia are the Ministry of Industry, Mines and Energy (MIME), Ministry of Economic and Finance (MEF), Electricité du Cambodge (EDC), the Electricity Authority of Cambodia (EAC), Provincial Electricity Utilities and private sector. EDC is owned and controlled by MIME and MEF.



Ministry of Industry, Mines and Energy (MIME) has overall responsibility for policy formulation, strategic planning and Technical Standards. However, the oil and gas sector is handled by the Cambodian National Petroleum Authority (CNPA). As more specific responsibilities, MIME shall be responsible for setting and administrating the government policies, strategies and planning in the power sector.

MIME shall ensure the communication on a regular basis with the Authority and shall provide to the Authority the information on policies, strategies, planning of the power sector and its decisions on: i). Investments in the rehabilitation and development of the energy sector in the short, medium and long term; ii). Restructuring on private sector participation and privatization of public utilities; iii). Promotion of the use of indigenous energy resources in the generation of electricity; iv). Planning and agreements on the export and import of electricity; v). Consumers of electricity; vi). Promotion of efficiency in generation, transmission, distribution and consumption of electricity and action taken to create a comprehensive electricity conservation program for Cambodia; vii). Electricity sector emergency and energy security strategies.

The Electricity Authority of Cambodia (EAC) is the Regulatory Agency that was established according to the Electricity Law. The EAC is responsible for regulating the provision of electric power services within Cambodia, as described below: i). To issue, revise, suspend, revoke or deny the licenses for the supply of electricity services; ii). To approve tariff rates and charges and terms and conditions of electric power services of licensees, except where the authority (EAC) considers those rates or charges and terms and conditions are established pursuant to a competitive, market-based process; iii). To approve and enforce the performance standards for licensees; iv). To evaluate and resolve consumer complaints and contract disputes involving licenses; v). To approve and enforce a uniform system of accounts for all licensees; vi). To determine the procedures for informing the public about affairs within its duties, in order to ensure that the EAC comply with the principle of transparency; vii). To issue rules and regulations and to make appropriate orders, and to issue temporary and permanent injunction for electric power service; viii). To require the electric power services and the customers to obey the rules relating to the national energy security, economic, environmental and other government policies.

Electricite du Cambodge (EdC), owned and controlled by the Ministry of Industry, Mines and Energy (MIME) and Ministry of Economic and Finance (MEF), was established in March 1996. EDC, the state-owned public utilities entity, has the following functions and responsibilities: i). To develop, generate, transmit and distribute electric power throughout Cambodia; ii). To operate as a commercial entity, independently organizes production and operate in accordance with market demand and seek to earn a profit, increase the value of its assets, create economic, benefits and raise labor productivity; iii). To prepare, build, own, finance, lease and operate power generation and substations, transmission lines, distribution networks and other infrastructure necessary; iv). Eliminate inefficiencies from operations, reduce unnecessary costs; v). Maximize the output and reliability of the assets, customer satisfaction with higher quality and better services; vi). To be polite, receptive, act promptly with customers' concerns.

Chapter 3. Literature Review

3.1 Energy Security

Christian Winzer [16], using a stylized case study of three European countries, to illustrate how the selection of conceptual boundaries along these dimensions determines the outcome. His study also reviewed the multitude of definitions of energy security that can be characterized according to the sources of risk and the scope of the impacts measure. His found that the common concept behind all energy security definitions is the absence of protection from adaptability to threats that are caused by an impact on the energy supply chain.

Brown and Huntington [17], examine the tradeoff arises when policy makers choose the mix of individual technologies which is reducc greenhouse gas emissions and enhance energy security. Their results indicated that the optimal policy is achieved when the cost of the additional use of each technology equals the value of the additional energy security and reduction in greenhouse gas emission that it provides. They suggested an approach may draw more heavily on conventional technologies that provide benefits in only one dimension than on more costly technologies that both increase energy security and reduce greenhouse gas emissions.

Bazilian et al. [18], consider the tensions between climate change and energy security policy imperatives and highlight some concepts that bring clarity to policy maker of these two areas. His studied focusing on developing countries by using case of the Medupi super-critical coal plant in South Africa. Usually, as in the case of South Africa, there are tensions not easily captured in quantitative algorithms between a lack of access to electricity by millions of people and greenhouse gas emissions from electricity generation. General conclusion of his research was that climate change and energy security policy imperatives are often employed do not provide an entirely satisfactory precedent for future planning analyses and the justifications do not adequately reflect the complexity of the decision space.

Nicolas Lefevre [19], present an alternative approach which focuses on gauging the causes of energy insecurity as a way to assist policy making. He also focuses on the energy security implications of fossil fuel resource concentration and distinguishes between the price and physical availability components of energy insecurity. He had defined two separate indexes as the energy security price index (ESPI) which based on the measure of market concentration in competitive fossil fuel markets and the energy security physical availability index (ESPAI) that based on the measure of supply flexibility in regulated markets. He illustrated on two case studies about France and the United Kingdom are looking at the evolution of both indexes to 2030 of ESPI and ESPAI.

His results shows that increasing the rate of penetration of renewable and nuclear energy sources in the fuel mix will have a positive effect on both ESPI and ESPAI. The magnitude of the energy security benefits depends on the energy security profile of the fuel displaced.

Ryu et al. [20], was compared the electricity-generation fuel mixes in two countries (Korea and Mongolia) with multiple energy policy goals and unique circumstances by looking at three scenarios reflecting the carbon emissions mitigation targets, the differences in energy security levels and electricity-generating costs of each nation. Korea and Mongolia shown clear differences in electricity-generating structure related to import dependency, the potential of renewable energy as well as threats to energy security. The two objectives of policies targeting on carbon emissions mitigation and energy security improvement show complementarity in Korea as fossil fuels are replaced by renewable or nuclear power, but emissions mitigation in Mongolia are trade-offs and improve the energy security cannot be achieved with one strategy.

Their conclusion was that national plans to achieve two goals differ by country as in the Korea, the appropriate portion of nuclear energy is the determining policy factor. In the case of Mongolia, carbon capture and storage is the clear alternative to mitigating carbon emissions despite large renewable potential.

Bert Kruyt et al. [21], researched on an overview of available indicators for long-term security of supply (SOS). They distinguished four dimensions of energy security that relate to the availability, accessibility, affordability and acceptability of energy and classified indicators for energy security according to this taxonomy. Their analysis shows that accelerate depletion of currently known fossil resources due to increasing global demand. Oil production is projected to become increasingly concentrated in a few countries up to 2030, after which production from other regions diversifies the market.

3.2 Cost Analysis of Fuel Mixes

The Levelized Cost of Electricity (LCOE) is an indicator of the cost of generating electricity which defined as the price of the electricity produced by a specific technology that assumed constant in real money units makes the present value of the revenues resulting from the selling of the electricity equals to the present value of all the expenses met during the plant life-cycle (investment costs, operating costs, incremental capital costs, decommissioning costs and possibly carbon charges). LCOE describes the generating costs at the plant level and it does not include transmission and distribution costs and possibly all the network infrastructures adjustments. LCOE value determined on the basis of the equality between proceeds and costs and it also guarantees that the electricity break even sale price which allowing comparing the costs of generating electricity by alternative technologies.

Ouyang and Lin [22], examined the levelized cost of electricity (LCOE) of renewable energy in China. The development and utilization of renewable energy is a good strategic choice for energy structural adjustment and high cost of large-scale development of renewable energy. Their study found that feed-in-tariff (FIT) of renewable energy should be improved and dynamically adjusted based on the LCOE to provide a better support for the development of renewable energy. Moreover, the FIT in China can only cover the LCOE of wind (onshore) and solar photo-voltaic energy (PV) at a discount rate of 5%. Subsidies to renewable based electricity generation except biomass energy are still need to be increased at higher discount rates. They also recommended as first that government policy should focus on solving the financing problem of renewable energy projects because fixed capital investment exerts considerable influence over the LCOE and the second is that the problem of high cost could be solved by providing subsidies in the short term and more importantly by reforming electricity price in the mid and long-term to make the renewable energy competitive.

IEA [23], studied the expected plant level costs of base-load electricity generation by power plants that could be commissioned by 2015 by using the levelized cost of electricity generation (LCOE). Their study reaches two important conclusions. First, in the low discount rate case, more capital-intensive and low-carbon technologies such as nuclear energy are the most competitive solution compared with coal-fired plants without carbon capture and natural gas-fired combined cycle plants for base-load generation. Second, in the high discount rate case, coal without carbon capture equipment followed by coal with carbon capture equipment and gas-fired combined cycle turbines (CCGTs) are the cheapest sources of electricity.

IRENA [24] use levelised cost of electricity (LCOE) to analyze the costs and performance of renewable power generation technologies. Results show that the levelised cost of electricity (LCOE) is declining for wind, solar PV, CSP and some biomass technologies, while hydropower and geothermal electricity produced at good sites are still the cheapest way to generate electricity.

Branker et al. [25] used the levelized cost of electricity generation (LCOE) for solar PV in order to be compared to other electricity generation technologies. Their results found that lack of clarity in assumptions and justifications in some LCOE estimates could lead to the wrong outcomes and policy initiatives. This study also illustrated that the most important assumptions were system costs, financing, lifetime and loan term. Given the state of the art in the technology and favorable financing terms it is clear that PV has already obtained grid parity in specific locations and as installed costs continues to decline, grid electricity prices continue to escalate and industry experience increases, PV will become an increasingly economically advantageous source of electricity over expanding geographical regions.

Khatib et al. [26] reviewed the jointing report by the International Energy Agency (IEA) and the OECD Nuclear Energy Agency (NEA) on a series of studies into electricity generating costs by using the LCOE. Their study presents the main results of the work carried out in 2009 for calculating the costs of generating base-load electricity. The results found that it is quite comprehensive in covering almost all financial aspects facing investors in the electricity generating system. It also deals with the effect of taxes, interest rates, currency exchange rates, weighted average cost of capital (WACC), inflation and the impact of the recent economic recession. However, it ignores external costs and cost of transmission and country specific investment considerations, particularly specific country risk and technology risk. In addition, the most important are variations in fuel prices, particularly recent reduction in the price of natural gas, which has rendered some of its costing, particularly for CCGT generation.

3.3 Carbon Dioxide (CO_2) Emission from Fossil Fuels

Recently, global warming has been a major issue due to increasing greenhouse gas emissions from different sources. Carbon dioxide emission is a major greenhouse gas is blamed for more global warming. In 2012, 43.9% of CO_2 emissions from fuel combustion were produced from coal, 35.3% from oil and 20.3% from gas [41]. Coal-fired power generation is projected to have a major increase share by 2020 due to strong growth in some countries such as China and India. Gas-fired plant is projected to continue to grow strongly in many world regions reflecting the increasing availabilities of natural gas while oil will lose market share [1].

Henriques et al. [27] discusse the potential for reducing carbon dioxide (CO_2) emissions from energy use by the Brazilian industrial sector in a low-carbon scenario over a horizon until 2030. They were evaluated the main mitigation measures the quantities of gas avoided and the respective abatement costs. In relation to a benchmark scenario projected for 2030, the reduction of CO_2 emissions estimated here can reach 43% by adopting energy efficiency measures, materials recycling and co-generation, shifting from fossil fuels to renewable or less polluting energy sources and eliminating the use of biomass from deforestation. The set of measures studied would be bringing emissions reductions of nearly 1.5 billion tCO_2 over a period of 20 years (2010-2030). It would require huge investments, but the majority of them would have significant economic return and negative abatement costs.

Sims et al. [28] review and compare the major technological advances and carbon dioxide mitigation options for the global electricity supply industry. By comparing a burning coal or gas in conventional power generating plant, there are several alternative technological ways to generate electricity and reduce the cost of greenhouse gas emissions effectively. Their result found that most technologies have potentials to reduce both generating cost and carbon emission avoidance by 2020 with the exception of solar power and carbon dioxide sequestration.

Tino Aboumahboub et al. [29] investigate the influence of different factors on CO_2 emission of the global electricity generation system. The results show that the introduction of a global carbon price of 18 euro/ton would lead to a total abatement of several hundreds of million tons in 2006. Through a sensitivity study, they show that the CO_2 price relation between natural gas and coal price is crucial for the abatement achieved through fuels witching. On a long-term horizon, integration of wind is determined as the most economic option responds to ambitious emissions reduction targets. Increasing a capacity of wind power allows reducing CO_2 emissions.

Jan Eide et al. [30] applied a stochastic generation expansion model to determine the impact of CO_2 emission standards on generation investment decisions and in particular for coal plants with CCS technology. The results shows as that i) currently proposed levels of emission standards are more likely to shift fossil fuel generation from coal to natural gas rather than to incentivize investment in CCS; ii) tighter standards that require some carbon reductions from natural gas-fired power plants are more likely than proposed standards to incentivize investments in CCS, especially on natural gas plants but also on coal plants at high gas prices; and iii) imposing a less strict emission standard is more likely than current proposals to incentivize investment in coal CCS technology.

Ari et al. [31] studied the electricity generation associated CO_2 emissions and fuel specific CO_2 emission factors was calculated based on the IPCC methodology using the data of fossil-fueled power plants in Turkey. The estimated CO_2 emissions from fossil-fueled power plants between 2009 and 2019 are calculated using the fuel specific CO_2 emission factors and data on the projected generation capacity of the power plants that are planned to be built during this period. Four scenarios based on using different fuel mixtures are developed to overcome this deficiency. The results of those scenarios show that a significant decrease in the amount of CO_2 emissions from electricity generation can be achieved if the share of the fossil fueled power plants is lowered.

3.4 Secured Capacity of Renewable Sources

Intermittent electricity generating from renewable sources such as hydro, wind and solar power is increasing the challenge. Many have sought to determine whether electricity markets will be able to provide a reliable and secure supply of electricity, even in the case of a higher share of intermittent feed-in.

Mac Cormack et al. [32] analyze the impact of large-scale integration of wind generation operating in a deregulated market on prices and on reliability of supply. Their study shows that, during a transition period, increased penetration of wind generation can lead to lower electricity prices and increased reliability of supply. But average costs of conventional production increase as the capacity factor declines.

Hannes Weigt [33] analyzes historical data from 2006 to 2008 of Germany's case. For his calculation, the lower boundary of the capacity credit is only about 1%. Taking into account the actual generation of electricity during peak load times, the credit rises to 15%.

Battle and Rodilla [34] analyze the relevant regulatory design elements throughout an updated assessment of the broad range of international experiences and highlighting the lessons from they have learned so far in a variety of contexts. The security of supply at the generation level can be decoupled into four major components such as i). Security is a very short-term issue, as the ‘‘ability of the electrical system to support unexpected disturbances such as electrical short circuits or unexpected loss of components of the system. ii). Firmness is a short to medium-term issue, defined as the ability of the already installed facilities to supply electricity efficiently. This dimension is conditioned by the characteristics of the existing generation portfolio and the medium-term resource-management decisions of the generators (fuel provision, water reservoir management, maintenance scheduling). iii). Adequacy, a long-term issue, defined as the existence of enough available generation capability, both installed and expected to be installed, to meet efficiently demand in the long term. iv). Strategic expansion policy, which concerns the very long-term availability of energy resources and infrastructures. Finally, they concluded that by providing a set of principles and criteria that should be considered by the regulator when designing a security of supply mechanism.

Paul L. Joskow [35] examined the evidence from the U.S. and some other countries indicates that organized wholesale markets for electrical energy and operating reserves do not provide adequate incentive to stimulate the proper quantity or mix of generating capacity consistent with mandatory reliability criteria. The main problem from failure of wholesale spot markets for energy and operating reserves to produce prices for energy during periods when capacity is constrained that are high enough to support investment in an efficient mix of generating capacity. He found that the policy reform program is compatible with improving the efficiency of spot wholesale markets, the continued evolution of competitive retail markets and restores incentives for efficient investment in generating capacity consistent with operating reliability criteria applied by system operators.

Chapter 4. Research Methodology

In this chapter, four indicators will be propose which they related to energy security price index of electricity generation, cost analysis of fuel mix, carbon dioxide (CO_2) emission from fossil fuels and secure capacity of renewable energy sources (especially, hydropower energy).

4.1 Measuring the Energy Security

Many papers have been studied on the conceptualization of energy security in varying dimensions [16] as well as measuring energy security levels [19] due to raising energy security issues. While the definition and scope of energy security vary between studies and researchers categorize with the results into different type according to each criteria and then they develop an index to measure the energy security levels.

There are two components for measuring the price implications due to resource concentration [19]. First, a measure of market concentration in each international fossil fuel market based on energy security market concentration (ESMC), which represents the price risk resulting from fossil fuel resource concentration. Second, exposure to price risks is incorporated into an energy security price index (ESPI) for a given country. In the other words, the levels of energy insecurity of each country is depend on the share of each fossil fuel in primary energy supply that is affected by international market concentration.

4.1.1 Energy Security Market Concentration

To calculate energy security market concentration, Herfindhal Hirschman Index (HHI) is to be used, which is equal to the sum of the square of the individual market shares of all the participants. HHI is a useful tool for government to assist them in determining market power in the scope of competition law and it's well-established measure of market concentration [19].

While energy security concern caused by uneven distribution of energy resources, it is through the physical development of the international market that this concern materializes. Measuring the actual market concentration may not reflect energy insecurity as well as changing in welfare. Thus, basing on measure of market shares on resource is therefore inappropriate. Whether production or exports should be used depends on prices and physical export capacity. Using a measure of net export potential as the basis for the definition of market shares seems well suited as it encompasses physical limitations and whether countries' price domestic consumption is different from exports or not. Therefore, for each fossil fuel f, ESMC is defined by:

$$\text{ESMC} = \sum_i S_{if}^2 \qquad (1)$$

where S_{if} is the percentage share of each supplier *i* in the international market for fuel *f* defined by its net export potential (S_{if} varies from 0 to 100). Values of ESMC vary between 0 to 10,000. Zero is suggest a highly competitive market and 10,000 is a pure monopoly. Therefore, the higher value of energy security market concentration (ESMC) mean a higher insecurity supply.

In this study, ESMC for each fuel is calculated based on the estimated market share from the five top-ranked countries in net exports as projected for 2025 (the estimated data referred to the International Energy Agency, IEA [23]).

4.1.2 Accounting for Political Stability

Bohi and Toman (1996), has defined energy security as “the loss of welfare that may occur as a result of changing the price or availability of energy” fossil fuel price and availability become the main concerns in energy supply security measurements. In particular, price fluctuations of fossil fuel are considered a main source of energy insecurity [19] and energy policymakers need to examine the levels of fuel types used in electricity generating system because exposure to price risk in the international market depends on the composition of the fuel mixes.

While Eq. (1) has modified, it might be appealing to better account for the specificities of energy security concerns [19]. Nevertheless, accounting for political stability seems particularly important in the scope of fossil fuel resource concentration. Fossil fuel resources are often located in politically sensitive areas of the world which depend on the reliability of supply from top exporting countries. ESMC for political stability defined as follows:

$$\mathrm{ESMC}_{\text{pol-f}} = \sum_{\mathrm{i}} \left(\mathrm{r_i} \times \mathrm{s}_{\mathrm{if}}^{2} \right) \tag{2}$$

where r_i is a political risk rating for country *i* (which ranges from 1 to 3). The inclusion of this parameter should scale up market concentration risks when participants are politically unstable. The extent of the scale-up should be reflected the importance given to political stability. There are two dimensions of World Bank worldwide governance indicators, “political stability and absence of violence” and “regulatory quality”, were used for calculating r_i.

Political stability ratings can be defined as a number. The World Bank’s Worldwide Governance Indicators were used for the scope of this study. The Worldwide Governance Indicators target six dimensions of governance through separate indicators. Two of these are of particular relevance for energy security [19].

The “Political Stability and Absence of Violence” indicator measures perceptions of the likelihood that the government in power will be destabilized or overthrown by possibly unconstitutional and violence means including domestic violence and terrorism. The “Regulatory Quality” indicator measures the incidence of market-unfriendly policies such as price controls, as well as perceptions of the burdens imposed by excessive regulation in areas such as foreign trade and business development.

These indicators are defined on an annual basic and range from about -2.5 to +2.5 with higher values indicating better governance performance [19]. A composite indicator is used in this study based on the average of the two scaled to the chosen range for r (the average value of the year 2008-2012 were used to avoid giving too much importance to calculation in a specific year).

4.1.3 Energy Security Price Index

The share of the country's total final primary energy supply exposed to each $ESMC_{pol\text{-}f}$ value needs to be identified to capture the exposure of a given country to the price risks associated with resource concentration. The energy security price index is the sum of the products of $ESMC_{pol\text{-}f}$ and the corresponding share of the fuel mix exposed:

$$\mathrm{ESPI} = \sum_f [\mathrm{ESMC_{pol-f}} \times \frac{E_f}{\mathrm{TEPS}}] \quad (3)$$

Where E_f is the country's supply exposed to the price risk of fuel *f*, and TPES is the county's total primary energy supply (E_f and TPES should be both measured in energy units so E_f/TPES is in percentage point).

4.1.4 Electricity Generation Supply Security

Ryu et al. [20] have been modified ESPI to calculate energy security levels of the electricity-generating system in a given country. To measure the electricity-generation supply security, total primary energy supply replaces with total electricity-generation supply and also the share of each fossil fuel with the electricity-generation supply from each fossil fuel reflecting each fossil fuel attributes and efficiency of generating technologies. Therefore, ESPI can be modified as follows:

$$\mathrm{ESPI_{gen}} = \sum_{\mathrm{f}} [\mathrm{ESMC_{pol-f}} \times (\mathrm{toe/MWh})_f \times \frac{\mathrm{EGS}_f}{\mathrm{TEGS}}] \quad (4)$$

Where $(toe/MWh)_f$ is a heat rate for electricity generation of the fossil fuel *f* based on considerations of the characteristics of fossil fuel resources and efficiency of the electricity-generating technologies, TEGS is total electricity-generation supply and EGS_f is the electricity-generation supply from fossil fuel *f*. The modified terms allow for the conversion process from primary energy resource for electricity.

Table 10. Projected energy security index by 2025 for Cambodia.

Source	**Technology**	**$ESMC_{pol-f}$**	**(toe/MWh)**
Oil	HFO[a]-fired	311.38	0.100
Hydro	Water	-	0.156
Coal 1	PCC[b]	1685.63	0.210
Coal 2	IGCC[c]	1685.63	0.172
Gas	CCGT[d]	846.82	0.151
Import Elec.	Transmission line	818.65	0.094

Source: Ref. [23], [44], [45].

[a] : Heavy Fuel Oil, [b] : Pulverised coal combustion,

[c] : Integrated gasification combined cycle, [d] : Combined cycle gas turbine.

4.2 Cost Analysis of Fuel Mixes

In this section will introduce the methodology for determining the levelized cost of electricity (LCOE). This method is being used widely for the purpose of electricity generation technology comparisons. The LCOE is useful for the comparison of electricity generation technologies. It allows comparing different technologies on the basis of what it costs to generate one unit of electricity by dividing all costs incurred throughout a project's lifetime by the total amount of electricity generated during that lifetime. Therefore, the LCOE's concept goes back to the economic principles outlined above which enabling energy planners and policy makers to compare generation costs of conventional and renewable resources. Eq. (5) is describe the LCOE model and used for the calculation of the cost of electricity generating in Cambodia. All variables needed for calculate the LCOE can be identified in the below equation.

In this study, we use the average costs of non-OECD countries for Cambodia's case. The projected costs of alternative technologies in 2025 depend heavily on the underlying assumption of cost reduction with increased demonstration and learning with economics of scale [36]. Even though estimates of costs are inevitably subjected to great uncertainty, more reasonable policy decisions can be made under the principle of the least cost among the alternative.

The cost of alternative technologies are referred to Organisation for Economic Co-operation and Development (OECD) data in the year 2010 for comparison of generating costs by 2025, which were calculated by the levelized cost of electricity (LCOE) per mega-watt hour. It would correspond to the cost of an investor assuming the certainty of production costs and the stability of electricity prices. In the other words, the discount rate used in LCOE calculations reflects the return on capital for an investor in the absence of a specific market or technology risks. Therefore, LCOE can be defined as follows:

$$\mathrm{LCOE} = \frac{\sum_{t=0}^{T} \frac{I_t + O\&M_t + C_t + F_t + D_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{E_t}{(1+r)^t}} \qquad (5)$$

where, *LCOE* is the levelized cost of electricity per unit in period *t*, T is the economic life of the project, *t* is the year of operation (0,1,2,3,4…n), where $t = 0$ is the year of installation and starting operation, I_t denotes that the initial investment, $O\&M_t$ stands for operation and maintenance costs, C_t is the carbon costs in year *t*, F_t denotes the fuel costs in year *t*, D_t are the decommissioning costs, *r* is the discount rate and E_t are the amount of electricity produced in year *t*.

Table 11. Projected cost ($/MWh) of each technology by 2025 for Cambodia.

Resource	Candidate technology	Investment cost	Fuel cost	O&M cost	Total cost
Oil-based	HFO-fired plant	50.37	16.79	19.91	104.63
Coal 1	Black (PCC)	7.29	38.94	3.57	49.80
Coal 2	Black (IGCC)	27.75	23.24	8.32	59.31
Gas	LNG (CCGT)	20.66	57.79	5.40	83.85
Hydro	Water	15.10	0.00	2.31	17.41
Imported	Trans. line	25.68	0.00	2.56	28.24

Source: Ref. [23] and [37].

4.3 Carbon Dioxide Emission from Fossil Fuels

Recently, global warming has been a major issue due to increase in greenhouse gas emissions from different sources. Electricity generating and heat were the largest producer of CO_2 emissions and they were responsible 41% of worlds' CO_2 emissions in 2010 [3]. On the same year, 43% of CO_2 emissions from fuel combustion were produced from coal, 36% from oil, 20% from gas and 1% from other. Carbon dioxide emission (CO_2) is a major greenhouse gas and it is blamed for more global warming. Different industrial plants such as power plants, oil refineries, steel plants as well as cement plants are the main emitters of CO_2 emission. Coal plays a major role in greenhouse gas emissions, which mainly from burning of fossil fuels.

According to non-Annex I parties, Cambodia is not obligated to reduce carbon emissions under the Kyoto Protocol. The targets for developing countries needs reduction about 20 to 30% by 2020 from business as usual (BAU) in the Copenhagen Accord Voluntary. With this range reflect on the business as usual standard level of reduction from each country. Carbon reduction efforts in Cambodia are associated with implementation of emission reduction levels articulated in the Clean Development Mechanism (CDM) of the Kyoto Protocol, which allows for the introduction of energy related technology while air pollution is mitigated.

In this study, we compare the amount of carbon emissions from each technology of power generation in the year 2025. In addition, to identify the significant changes in aspects of electricity generation as well as the country's potential to reduce carbon emissions a couple scenarios will propose. Alternative technologies for carbon emissions are arranged according to the Intergovernmental Panel on Climate Change (IPCC) inventory guidelines [38]. Furthermore, we create scenarios to calculate all the carbon dioxide emissions from power generation by changing the fuel mix.

Many studies, for instance Gnansounou [39], measured this indicator by calculating a ratio of the total amount of CO_2 emission to produce a unit of final energy or kilograms of CO_2 per kWh of electricity generated (if the final energy is electricity) as shown in Eq. 6 below:

$$\mathrm{CO_2 \text{ per unit of electricity produced}} = \frac{Total\ CO_2\ emission}{Total\ electricity\ generation} \quad (6)$$

Table 12. Projected carbon emissions (TC/MWh) in the power generation by 2025.

Energy Source	Candidate technologies	Carbon emissions (TC/MWh)
Coal	Black (PCC)	0.3404
Coal	Black (IGCC)	0.3391
Oil	HFO-fired plant	0.2785
Gas	LNG (CCGT)	0.2303
Renewable	Hydro	0.0070
Import electricity	Transmission line	-

Source: Ref. [38] and [42].

4.4 Measuring the Secure Capacity of Renewable Sources

Security of supply in electricity generation can measure by generating capacity balances which allows electricity at peak demand and the contribution of each energy source to cover that demand [4]. A balance can be compiled for one single or several points in time during each year. To secure adequate supply in electricity generation, the total available generation capacity has to be at least as high as electricity demand for the investigated period of time [4].

Secure capacity is a method to estimate the total available generation capacity as a single point of time. The secured capacity is getting from a combination of several probabilistic distributions on the availability of each type of generation capacity. To calculate the secured capacity of a given power plant fleet is carried out as the density function of secured capacity of the conventional power plant blocks multiplying the conditional non-usability of all conventional power plant blocks [4]. The results in the inclusion of renewable energies in the density function of the complete generation fleet. The increase of the total secured capacity of the generation fleet by including renewable energy sources for electricity can be approximated as secured capacity of renewable energy.

In this study will also use hourly demand deterministically by applying country-specific load profiles that respect seasonal demand characteristics. Annual peak demand is defined by the hour to which the load profile assigns the highest electricity demand in a year.

For each thermal power plant that is not in maintenance, assigned a probability *p*, with which the block generates electricity at maximum capacity and a probability (1-*p*) of an unscheduled non-usability. The cumulated joint probability distribution that results from the convolution of the non-availability distributions of each single thermal block defines the secured capacity of the thermal generation fleet, which is at least available during annual peak electricity demand given a certain confidence level [4]. In contrast to thermal capacities, non-availabilities of renewable energy sources show regional patterns.

In calculating the secured capacity of renewable energy source, we concentrate only on hydropower energy. Secured capacity of hydropower energy influenced less during the dry season, while providing more capacity in the rainy season which depends on the amount of water and reservoir.

Electricity generation of all exogenous generation technologies is deducted from total gross electricity demand. These residuals demand has to be covered by another energy supply such as conventional power plants.

Chapter 5. Results and Analysis

5.1 Summary Input Data

To find the energy security price index of electricity generation ($ESPI_{gen}$), which is related to energy security, the market concentration accounting for political stability ($ESMC_{pol-f}$) was considered from the top five exporting countries' market concentration of oil, gas, and coal. Table 13 shows that the energy security of hydropower technology is higher than those of the other technologies as hydropower is a domestic energy resource. The energy security price index of electricity generation from imported electricity is slightly higher than that of electricity generation from hydropower technology because the imported electricity is generated from fossil fuel energy (e.g., coal, gas, or oil). The ESPIgen of oil is higher than those of gas and coal because the market concentration of oil decreased after the 2007 economic crisis, which prodded many countries to change their primary energy supply to coal or gas.

As shown in Table 13, the projected generation cost of hydropower plants in Cambodia is the lowest among the alternative technologies. The generation cost of imported electricity, however, is also relatively lower than those of the fossil fuel technologies as the former involves no expense on fuel costs, but there is a need to spend on the building of a transmission line and on operation-maintenance. Presently, the electricity being imported by Cambodia from its neighboring countries accounts for the main share of the electricity supply in Cambodia due to the shortage of power plants therein. Oil-fired plants are relatively the most expensive among the alternative technologies due to their high investment and fuel costs. Gas-fired plants equipped with CCGT are the second most expensive technology due to their low investment cost but high fuel and operation costs. Electricity generation from coal-fired plants equipped with the integrated gasification combined cycle (IGCC) technology is slightly less expensive than that from gas due to the former's high investment and operation-maintenance costs.

Table 13. A summary of reliable technology.

Technology	Energy Security (ESPIgen)	Cost ($/MWh)	CO_2 emission (TC/MWh)	Resource Reliability (%)	Summary results
Oil	2	5	3	100	3
Coal (PCC)	5	2	5	100	5
Coal (IGCC)	4	3	4	100	4
Gas (CCGT)	3	4	2	100	2
Hydro	1	1	1	99	1
Import Elec.	2	1	1	100	1

Note: "1" is the most reliable technology and "5" is least reliable technology.

The CO_2 emissions of the alternative technologies were arranged according to the IPCC inventory guideline. Table 13 shows also that coal-fired plants using the pulverized coal combustion (PCC) technology have higher CO_2 emission than the other technologies, and that the clean-coal technology IGCC is the second highest CO_2 emitter among the alternative technologies. Gas-fired plants equipped with the CCGT technology have lower CO_2 emission than oil due to the emission factor of natural gas is lower than oil. Hydropower is a renewable energy technology that has lower CO_2 emission compared to the fossil fuel combustion technologies. Imported electricity has very low CO_2 emission from the electricity generation supply side. In this study, imported electricity was assumed to have zero CO_2 emission.

The resource reliability of the conventional technologies is shown 100%. In other words, all these technologies can operate for an entire year to generate electricity (the few hours devoted to maintaining the plants are not included). Imported electricity can provide full reliability through a contract between the seller and the buyer. The resource reliability of the hydropower technology in Cambodia is approximately 99% due to the amount of water available in the reservoirs in the dry and rainy seasons. Furthermore, the country's specific energy resource condition is very important in defining how reliably each technology can be distributed for the power generation supply.

Regarding the $ESPI_{gen}$, the total costs (investment plus fuel and operation-maintenance costs), the CO_2 emission, and the reliability issue, each technology has its own strengths and weaknesses. In summary, based on Cambodia's energy conditions, hydropower technology is the most reliable alternative technology. The imported-electricity technology was also shown to be the most reliable technology, but the limited imported-electricity capacity has become a concern. Gas-fired plants equipped with the CCGT technology is the second most reliable technology, and the oil technology is the third. Coal-fired plants equipped with the PCC technology is the least reliable technology, while coal-fired plants equipped with the IGCC technology is the second least reliable.

5.2 Candidate Technology for Electricity Generation

In this paper, future technologies for the year 2025 are proposed under the candidate technologies category. Only three main technologies will be emphasized herein: hydropower, coal-fired plants with the clean-coal technology IGCC, and liquefied natural gas (LNG) with CCGT technology.

Hydropower is a major energy source among the renewable energy sources, and it provides economic and environmental benefits, thus making an important contribution to the future world energy mix, particularly in the developing countries, including Cambodia. Hydropower has much lower greenhouse gas emissions compared with other energy options. In addition, by storing water during the rainy season and releasing it during the dry season, dams and reservoirs can help control the water during floods and droughts. Hydropower has the following advantages: flow regulation, protection against floods, fossil fuel avoidance, multiple uses, long depreciation period, revenue through an adequate electricity rate, and low operating and maintenance costs because it does not entail any fuel expense. Moreover, it easily meets the load demand and has a long economic life and a low environmental impact compared with alternative energy resources [41].

The environmental impacts of hydropower plants will be discussed in the section below. The important points being considered by Cambodia as it seeks to avoid an electrical-energy shortage in the coming years are the following: some policies support the encouragement of private-sector participation, and improving hydraulic energy for sustainable socioeconomic development. As regards small hydropower plants as well as according to the hydrological and topographical conditions of Cambodia, it is estimated that there is a considerable amount of small hydropower potential in the country. As the investment costs of small hydropower plants are high when they are implemented individually, it would be useful to standardize the manufacturing of electromechanical equipment and to build them in groups to decrease the transmission and distribution costs.

Global warming concerns make it a priority to reduce greenhouse gas emissions. To pursue this aim, the sustainable use of fossil fuels is required, addressing the need for innovative and more efficient technologies for a lower environmental impact. In addition, the use of coal for power generation is increasing the emissions of pollutants and of CO_2. IGCC in power generation is one of the clean-coal technologies for reducing greenhouse gas emissions in coal-fired electricity generation. The IGCC technology, however, offers a significant advantage over PCC plants in terms of CO_2 capture, and it has been proven to be commercially viable against the conventional coal-fired power plants. The IGCC technology in coal-based power plants has high thermal efficiency, low environmental impact, and marketable by-products, making IGCC an attractive technology for the next century.

At present, the cost of electricity produced by IGCC plants is slightly higher than the cost of electricity produced by PCC plants, and the thermal efficiency of IGCC plants is high, approximately in the region of 45-47%, and for advanced new technologies, the efficiency can go up to 55% [23]. The IGCC plants will produce electricity at a competitive price compared to other fuel-burning technologies when 50% IGCC plant efficiency is achieved [23].

Fossil fuel power plants are among the major sources of electricity generation, although they invariably release greenhouse gases. Due to international treaties and country regulations, CO_2 emission reduction is increasingly becoming a key in the generator's economics. Gas-fired power plants equipped with the CCGT technology constitute a widely used generation technology. The integrated gasification combined cycle (IGCC) is a technology for power generation in which the feedstock is partially oxidized with oxygen and steam to produce syngas. In a conventional IGCC design without carbon capture, the syngas is purified for dust and hydrogen sulphide removal and then sent to a CCGT plant for power production.

The economic advantage of the CCGT technology is that the capital equipment is very cheap compared to most other generating options. This characteristic is particularly important in deregulated energy markets, in which the power investors use short payback times and high discount rates for their investments. This built-in economic advantage is reinforced by the fact that the CCGT construction times are very short. New plants can be completed in less than two years rather than four to ten years, which characterize other large-scale technologies.

CCGT's technological process delivers thermal efficiencies of up to 60% while the coal-fired power plants deliver efficiencies between 40 and 46%. CCGT's emissions are lower than those of other fossil fuel technologies. A typical CCGT plant emits around 65% less CO_2 than a traditional coal-fired power plant for each unit of electricity generated.

5.3 Scenario Analysis

5.3.1 Hydropower-oriented Scenario (SC1)

The top panel yield shown in Figure 7 is the duration of the demand at which each technology is economical from a total cost perspective. The lowest cost mix of investment in a generation technology can then be determined by the total cost of building and operating each generation technology to the load duration curve for the system (as electricity cannot be stored) [34]. The projected power demand capacity in Cambodia is less than or equal to 2,261 MW for the entire year (8760 h) and 3,210 MW for only 1 h during the year. Moreover, the system demand between 2,261 and 3,210 MW are realized for between 8,760 and 1 h during the year.

The secured capacity of hydropower is estimated from the amount of water reservoir of the river in Cambodia. With regard to this, the estimation data [43] show that during the dry season, hydropower energy has a secured capacity of approximately 2,795 MW while in the rainy season, it reaches 10,550 MW.

As shown in Figure 7, when the power demand is less than or equal to 2,261 MW, the base load facility will be hydropower technology as the marginal as well as perfectly competitive market price will be US$2.31/MWh due to the low investment and low operating costs compared to other fossil fuel technologies. In addition, the adequate secured capacity of hydropower can cover the demand capacity during the rainy season, and in the dry season, it can respond to the demand capacity equal to or less than 2,795 MW.

Figure 7 also shows that when the demand lies between 2,261 and 3,100 MW, hydropower technology is still as a marginal unit (the area between 0 and 8040 h demand duration). The perfectly competitive market price of the operation cost of this technology will be US$2.31/MWh. During the demand duration between 8,040 and 8,760 h (from November to December), with a power demand capacity between 2,261 and 2,795 MW, hydropower technology is still a marginal unit due to its low operating costs and lack of expense for fuel costs. In addition, the secured capacity of hydropower technology in the dry season has been limited to only 2,795 MW. Moreover, in the same periods, when the demand capacity increases from 2,795 to 3,210 MW, gas-fired plants equipped with the CCGT technology is a marginal unit due to their low investment cost and high operation cost, but the plants run for short operating hours. The perfectly competitive market price of fuel plus operation costs will then be US$63.2/MWh.

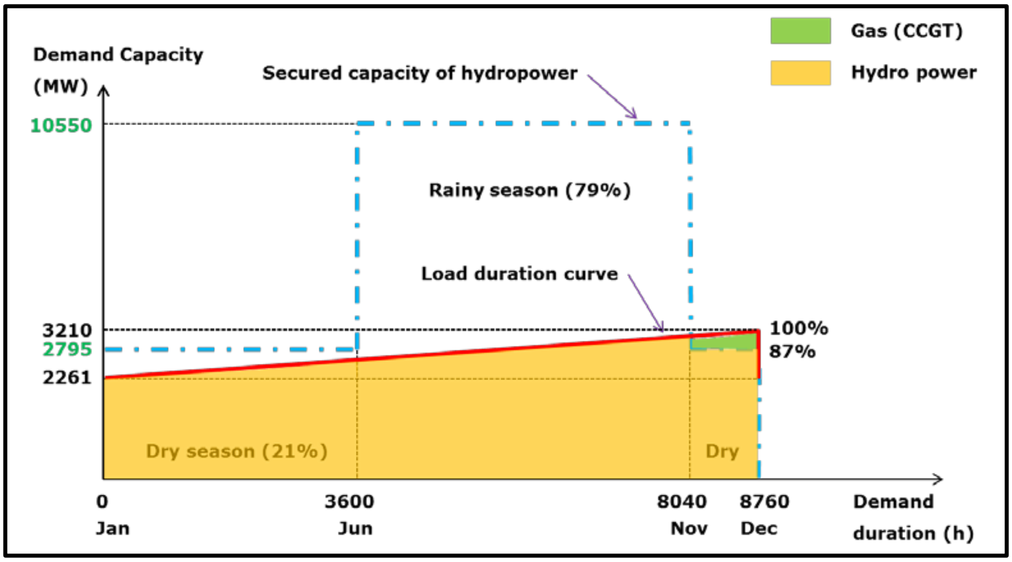


Figure 7. Hydropower oriented scenario.

5.3.2 IGCC-oriented Scenario (SC2)

The second approach (SC2) is to introduce the IGCC technology into fossil-fuel-generating plants, especially coal-fired plants. In other words, all new coal-fired power plants will be adopted with the IGCC clean-coal technology.

As electricity does not require storage and as its demand varies widely over the course of a year, the most economical of generating plants will include technologies with a variety of capital cost and operating cost ratios. Base load generation facilities have relatively high capital costs and low operating costs. These facilities are economical to build if it is efficient to operate them for a large fraction of the hours of each year. Intermediate load facilities have lower capital costs and higher operating costs than base load facilities. These facilities typically operate between 20 and 50% of the total hours in the year. Finally, peak facilities have the lowest capital costs and the highest operating costs per unit of capacity. These facilities are expected to be economical to operate for a few hours per year up to 20% of the total hours in the year.

In Figure 8, when the power demand increases up to 1,444 MW (45% of the peak demand capacity), the base load capacity is hydropower technology as it is marginal with the perfectly competitive market price of US$2.31/MWh due to its low investment and operating costs and lack of fuel cost compared to other technologies. When the demand capacity increases from 1,444 to 3,050 MW (50% of the peak demand capacity), the IGCC technology becomes a marginal unit due to its high investment cost and low operating and fuel costs. The perfectly competitive market price for the operating cost will be US$31.56/MWh. When the demand duration is between 7,320 and 8,760 h (from October to December), with a power demand capacity of 160.5 MW (5% of the peak demand capacity), the CCGT technology is a marginal unit due to its low investment cost and high fuel cost. The perfectly competitive market price of fuel plus operation costs will then be US$63.2/MWh.

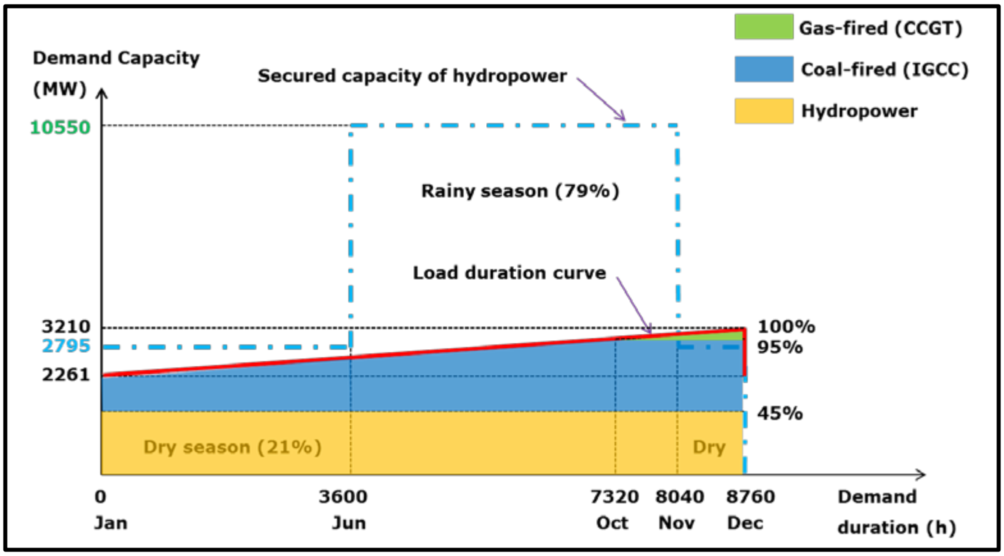


Figure 8. Integrated gasification combined cycle (IGCC) oriented scenario.

5.3.3 CCGT-oriented Scenarios (SC3)

The third approach (SC3) is to introduce gas-fired plants attach the CCGT technology. There are two reasons that gas-fired plants should appear in the power generation mix in Cambodia by 2025: (1) power generation using natural gas is far more competitive than other fossil fuel energy sources, such as coal or oil fuels, in terms of the low capital cost of the plants; and (2) the power generation technology for natural gas is more efficient and has lower CO_2 emission than other thermal power generation technologies.

Figure 9 shows the three technologies of electricity generation that are proposed to be used for fitting with the demand capacity by the year 2025. Hydropower technology is supposed to be used for base-load generation facilities with an installation capacity of 963 MW (30% of the peak demand capacity), and a US$2.31/MWh perfectly competitive market price of fuel plus operation costs. Coal-fired plants equipped with the IGCC technology are supposed to be used as intermediate load generation facilities with an installation capacity of 963 MW (30% of the peak demand capacity) and a competitive market price of US$31.56/MWh. Gas-fired plants equipped with the CCGT technology are supposed to be used to meet the peak load demand with an installation capacity of 1,284 MW (40% of the peak demand capacity) and with a competitive market price of US$63.2/MWh.

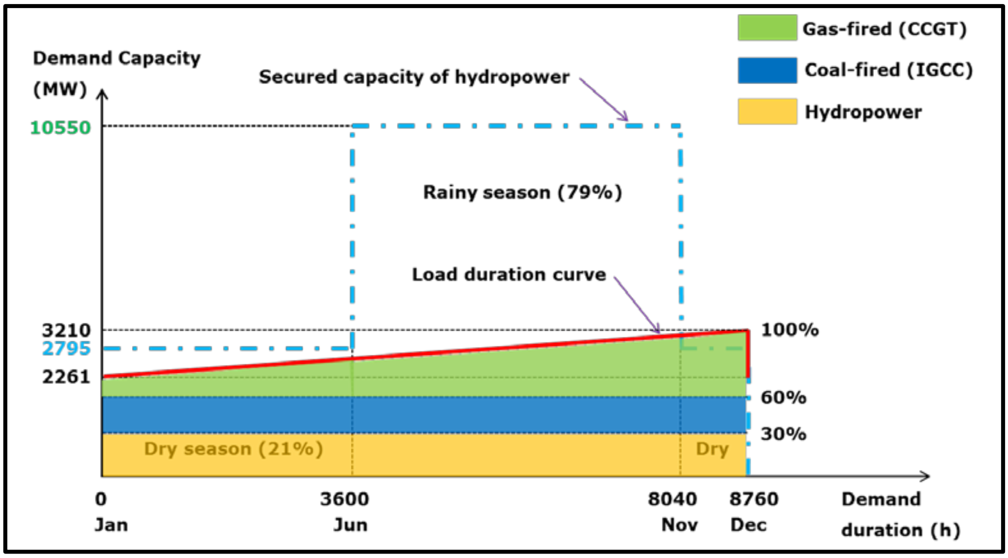


Figure 9. Combined cycle gas turbine (CCGT) oriented scenario.

5.4 Results

5.4.1 Scenario Comparison

The first scenario, SC1_Hydropower, depicts the introduction of renewable energy (especially hydropower technology). Under this scenario, the installation capacity of hydropower is expected to increase to up to 3,100 MW (97.5%) of the total peak demand capacity by the year 2025 for operating in the entire year, and using gas-fired plants, the installation capacity is expected to reach 415 MW (13%) of the total peak demand for operating from November to December. As shown in Figure 10, with this rate, the CO_2 emission is expected to be 0.143 million tons. The energy security price index of electricity generation appeared to be 1.45 units, which is from the used gas-fired plants during the period of peak demand capacity. Moreover, the total cost of electricity generation is USD4.69 billion.

In the second scenario, SC2_IGCC, the IGCC technology is introduced. In other words, the proportion of coal-fired plants equipped with the IGCC technology in the power generation is expected to increase to up to 50% of the peak demand capacity by the year 2025. As shown in Figure 10, under this scenario, by increasing the proportion of IGCC options in electricity generation from fossil fuels, 2.463 million tons of CO_2 are expected to be emitted. While the security index appears to be 145.53 units due to the high market concentration of coal, the ESMC coal values are expected to be higher than the $ESMC_{gas}$ and $ESMC_{hydro}$ values. Moreover, the total cost of this scenario is USD7.74 billion.

The third scenario, SC3_CCGT, shows an increase in the proportion of gas-fired power plants equipped with the CCGT technology to up to 40% of the peak demand capacity by the year 2025. The energy security price index of electricity generation ($ESPI_{gen}$) appeared to be 133.78 units due to the increase in the proportion of gas- and coal-fired plants. The total cost of electricity generation is around USD5.161 billion. Under this scenario, 2.944 million tons of carbon are expected to be emitted.

Only one scenario appeared to have the potential of exerting a good influence on energy security, CO_2 emission reduction, and low total cost of electricity generation, which confirms the validity of introducing a greater proportion of hydropower energy in power generation. The improvement of energy security ascends in the order of SC1_Hydropower. Maximizing the share of hydropower in power generation to replace fossil fuels is an alternative to fossil fuel use. Furthermore, to meet the expected demand capacity by the year 2025, replacing fossil fuels with hydropower is a better option in terms of low expansion costs and low CO_2 emission as well as improved energy security levels than introducing the IGCC and CCGT technologies. The $ESPI_{gen}$ value of the SC1_Hydropower scenario is lower than those of the SC2_IGCC and SC3_CCGT scenarios because the coal and gas resources are imported from outside Cambodia. In addition, these resources (coal and gas) are dependent on the market concentration situation of the exporting countries. The CO_2 emission reduction of the SC1_Hydropower scenario is also lower than those of the SC2_IGCC and SC3_CCGT scenarios due to the high CO_2 emission from coal- and gas-fired plants. In other words, the more the coal and gas that are used, the more the CO_2 emitted. The higher costs of the SC2_IGCC and SC3_CCGT scenarios compared to the SC1_Hydropower scenario result from the big changes that will occur through the use of coal and gas resources for electricity generation supply. Furthermore, Cambodia has huge potential resources of hydropower energy, which has relatively lower operating costs and do not entail fuel costs, leading to a decrease in the total cost compared to the other scenarios.

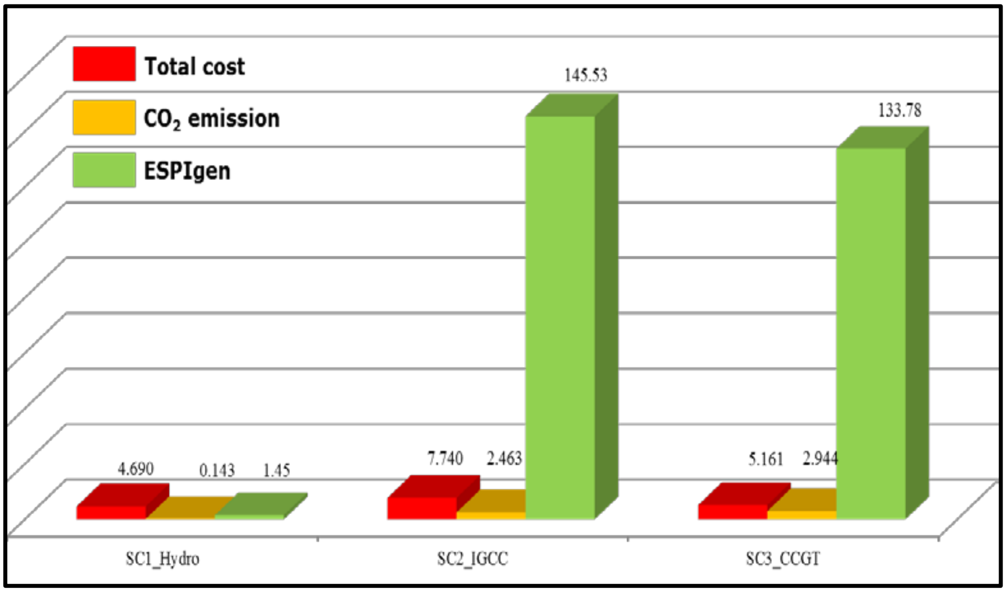


Figure 10. Change of $ESPI_{gen}$, rate of cost expansion and CO_2 emission in Cambodia.

5.4.2 Interaction between All Scenarios

The interaction between the targets of energy security, the CO_2 emission reduction, the least-cost generation capacity mix, and the secured capacity of hydropower appeared to vary depending on the origin of the national energy security threats. There are a few factors that are identical, such as the energy security threats coming from the use of more fossil fuel energy in the electricity generation supply. To reduce the CO_2 emissions, more hydropower energy should be introduced in power generation, and CDM projects should be implemented, which can also reduce the security threats. The least-cost generation capacity of hydropower is a marginal technology, and it can have a competitive market price at a low operating cost for long operating hours as well as no fuel cost compared to other fossil fuel technologies. In addition, hydropower plants can provide a long depreciation.

5.4.3 Environmental Impact of Hydropower Energy

The electricity demand in Cambodia has grown steadily of late, and it is predicted to continue to grow. Moreover, hydropower energy can provide significant power generation to meet the electricity demand in Cambodia, but hydropower projects still have a few social and ecological impacts. Therefore, before deciding to build hydropower plants, the country has to assess the outcome of the latter.

A country like Cambodia, however, has sufficient water resources for power generation by storing water in reservoirs, but these water reservoirs can produce biogenic gases by decomposing organic matter underwater and emitting principally methane (CH_4), which is more damaging than CO_2. If increasing the proportion of hydropower energy in power generation will be considered, the methane emissions will also increase significantly. Methane emissions can be captured, however, through the proper design of dams, which can significantly reduce the methane emissions to the atmosphere.

Fishing is the main source of livelihood for most of the people living in the areas around lakes and rivers. Nonetheless, the hydropower project is expected to impact the fishers living around the project site and the dam, by creating a barrier to fish spawning both upstream and downstream from the site. The hydropower project proposes to mitigate the impacts on fisheries by constructing other dams downstream to create spawning areas, and by releasing indigenous fish species like those from rivers.

Water quality is an important issue related to the provision of drinking water for the people living around hydropower project areas. There are two important issues related to this: (1) the need to monitor the effects of the hydropower project on the sediment flow downstream, which may result in the decreased fertility of the agricultural land in the future; and (2) saltwater intrusion from the river's estuary. To reduce these effects, the dam should increase the water flow in the dry season, which may reduce the level of saltwater intrusion and improve the water quality for the provision of drinking water to the people living around the project site.

When hydropower projects start construction, some people will lose their agricultural land to flooding, road construction, and construction of poles for transmission wires. To address these issues, the hydropower project's owner should give just compensation to those who lost their agricultural land and fruit trees.

Before the commencement of hydropower construction, the lake and river waters were known to be very clear, but the waters became contaminated after heavy drilling started at the construction site. Due to these issues, the tourism industry suffered during the construction stage, and the number of visitors dropped. After the completion of the project, however, the dam can improve the environment in the surrounding area. Also, the number of tourists is expected to increase with the dam serving as a tourist attraction.

Chapter 6. Conclusion and Recommendations

6.1 Conclusion

This study focused on enhancing Cambodia's electricity generation mix by considering the country's energy security level, the total cost of electricity generation, the carbon dioxide (CO_2) emission from fossil fuels, and the secured capacity of renewable energy resources (especially hydropower). To measure the country's energy security level, the fossil fuel resource supply concentration (ESMC) and the energy security price index of electricity generation ($ESPI_{gen}$) were used for the evaluation of the electricity generation mix. The levelized cost of electricity (LCOE) was used to compare the total cost per megawatt hour of electricity generated from the fossil fuels (or technologies) in 2025, and the average costs of non-OECD countries like Cambodia were also used. Furthermore, the amounts of CO_2 emission from all the fossil fuel combustion technologies on the power generation side were estimated and compared. Moreover, the secured capacity of hydropower was determined based on the amount of water in the reservoirs in Cambodia.

The study results show that during the dry season, the secured capacity of the hydropower technology almost covers the peak demand capacity while the rest is covered by the gas power technology. In addition, during the rainy season, the secured capacity of hydropower can supply more than three times the peak demand capacity in the year 2025. Moreover, the hydropower-oriented scenario (SC1) was found to be better than introducing the integrated gasification combined cycle (IGCC) and combined cycle gas turbine (CCGT) scenarios, which is complementary to Cambodia's policy objectives. The improvement of hydropower as part of the electricity generation supply, to make it have higher energy efficiency, will increase the future energy supply security in Cambodia. Therefore, the Cambodian energy policymakers need to decide the proper proportion of hydropower and gas energy supply in the country's fuel mixes.

Cambodia’s specific conditions, such as its domestic fossil fuel reserves, import dependence, national renewable energy potential, and load duration curve, are very important factors for the Cambodian energy policymakers to consider to be able to find the least-cost generation capacity mix on the electricity generation supply side. Considering all these important factors can help the energy policymakers find the best development strategies for attaining the goals of Cambodia.

This study also used the energy security price index of electricity generation ($ESPI_{gen}$) to measure the degree of exposure to the price risk in certain countries based on the energy source concentration levels in the international market. The index results were obtained from the international market supply concentration data as well as the political risk associated with supplier countries and the proportion of fossil fuels in the country analysis. To consider the range of the policies addressing the security threats, the supply concentration and the risk posed by the supplier country can be classified as international factors, and the proportion of fossil fuels can be considered a domestic factor. Reducing the proportion of fossil fuels may be a direct and fundamental policy solution to improve the security level of certain countries. The energy security indices show that comparative evaluation is possible, but such indices are limited in terms of grasping the socioeconomic welfare, which cannot be determined quantitatively.

Hydropower is one type of renewable energy resource. Hydropower development can provide a number of benefits, such as GHG emission reduction and electricity production and supply flexibility. In addition to power generation and efficiency, hydropower has extensive positive characteristics, such as fossil fuel avoidance, long depreciation periods, provision of revenues through an adequate electricity rate, and low operation-maintenance costs. Hydropower plants are also often better than other power plants from the standpoint of socioeconomic and environmental considerations. The environmental impact of hydropower plants should be a main concern when start doing the feasibility study of hydropower projects.

6.2 Recommendations

As the demand for electricity is projected to increase in the coming years, the challenges of energy security and sustainability have become greater concerns for policymakers. In addressing the energy security and sustainability challenges, harnessing and utilizing hydropower can be a viable alternative given that Cambodia has significant water resources. Hydropower is very important for the electricity supply security in Cambodia as well as for the economic growth in the region, which possesses abundant water resources. Furthermore, reducing the proportion of fossil fuels by increasing the proportion of hydropower in the power generation sectors is a good policy solution, which can improve the security level of certain countries, including Cambodia.

Based on the hydrological and topographical conditions of the country, it is estimated that there is a considerable amount of small hydropower potential in Cambodia. As the investment costs of small hydropower plants are high when they are implemented individually, it would be useful to standardize the manufacturing of electromechanical equipment and to build them in groups to decrease the transmission and distribution costs.

Additionally, it is important to restructure the policies in the power generation sectors in Cambodia towards the development of renewable energy, and to put special emphasis on the related socioeconomic bodies, laws, and legal regulations. In this respect, particular attention and priority should be given to the development of the country's hydropower potential as hydropower is the country's most important natural renewable resource, and as less than 10% of the country's economically utilizable hydropower potential has been developed thus far.

The integration of Cambodia's power grid with those of the other countries in the Greater Mekong Subregion (GMS) is also important. Specifically, the electric-power networks in Cambodia are well connected to those of its neighboring countries, such as Thailand, Vietnam, and Loa PDR. Hence, more investment is required to hasten the development of the national power grid.

Increasing the power generation to reduce the demand-supply gap through public-private partnership (PPP) for hydropower development appears to be a preferable solution as long as it is accompanied by good environmental policy. Moreover, the joint development of hydropower resources with the other countries in the GMS region is one of the viable options for electricity sector development in the country. Participating in energy source development projects involving obtaining fuel quantities that can be directly transferred without the international market can also help Cambodia escape from the influence of the international market.

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Appendix A: Estimation the total cost of electricity generating

Generating Technology	Install capacity (MW)	Annualized Cost ($/MW)	O&M + Fuel Cost ($/MWh)	Running Hours (h)	Total Cost (USD)
Scenario 1:					
Hydro	2261	1,361,000	2.31	8760	3,122,973,691
Hydro	839	1,361,000	2.31	8040	578,730,621
Hydro	534	1,361,000	2.31	720	727,662,148
Gas (CCGT)	305	678,000	63.19	720	220,666,524
Gas (CCGT)	110	678,000	63.19	720	39,792,324
Total					**4,689,825,310**
Scenario 2:					
Hydro	1444.5	1,361,000	2.31	8760	1,995,194,824
Coal (IGCC)	816.5	2,666,000	31.56	8760	2,402,523,162
Coal (IGCC)	788.5	2,666,000	31.56	7320	1,142,149,819
Coal (IGCC)	788.5	2,666,000	31.56	1440	2,137,975,486
Gas	160.5	678,000	63.19	1440	61,711,736
Total					**7,739,555,029**
Scenario 3:					
Hydro	963	1,361,000	2.31	8760	1,330,129,883
Coal (IGCC)	963	2,666,000	31.56	8760	2,833,594,373
Gas (CCGT)	335	678,000	63.19	8760	412,567,374
Gas (CCGT)	949	678,000	63.19	8760	584,367,817
Total					**5,160,659,447**

Note: to calculate total cost is based on each oriented scenario figure.

Appendix B: Estimation the CO_2 emissions

Generating Technology	Efficiency (%)	Power gen. (MWh)	CO_2 emission (TC/MWh)	Total CO_2 emission (TC)
Scenario 1:				
Hydro	55	14815020.00	0.007	103705.14
Gas (CCGT)	57	170316.00	0.231	39343.00
Total		**14985336.00**		**143048.14**
Scenario 2:				
Hydro	55	6959601	0.007	48717.21
Coal (IGCC)	51	7029900	0.340	2383839.09
Gas (CCGT)	57	131738.4	0.231	30431.57
Total		**14121239.4**		**2462987.87**
Scenario 3:				
Hydro	55	4639734	0.007	32478.14
Coal (IGCC)	51	4217940	0.340	1430303.45
Gas (CCGT)	57	6411268.8	0.231	1481003.09
Total		**15268942.8**		**2943784.68**

Note: install capacity (MW) for each scenario in appendix “B” refer to install capacity (MW) in appendix “A”.

Appendix C: Measuring $ESPI_{gen}$

Generating Technology	**Power gen. (MWh)**	**ESMCpol**	**(toe/MWh)**	**ESPIgen**
Scenario 1:				
Hydro	14815020.00	0.00	0.156	0.00
Gas (CCGT)	170316.00	846.82	0.151	1.45
Total				**1.45**
Scenario 2:				
Hydro	6959601	0.00	0.156	0.00
Coal (IGCC)	7029900	1685.63	0.172	144.33
Gas (CCGT)	131738.4	846.82	0.151	1.19
Total				**145.53**
Scenario 3:				
Hydro	4639734	0.00	0.007	0.00
Coal (IGCC)	4217940	1685.63	0.340	80.09
Gas (CCGT)	6411268.8	846.82	0.231	53.69
Total				**133.78**

Appendix D: Measuring the secured capacity of hydropower

River's name	Dry season (Million m^3)	Rainy season (Million m^3)	Ratio dry to rainy season	Secured cap. in dry season (MW)	Secured cap. in rainy season (MW)
Sesan	5,741	13,806	0.265	109	413
Sre Pok	8,793	21,125	0.265	168	634
Mekong	81,309	317,190	0.265	2518	9,503
Total	**95,843**	**352,121**		**2,795**	**10,550**

초 록

본 학위논문은 캄보디아에 적용될 수 있는 대체에너지기술에 관한 논문이다. 그리고, 2025 년에 적용할 수 있는 대체에너지기술에 대해 비교하고 평가하였으며, 이는 에너지안보, 발전단가, 온실가스배출량 및 신재생에너지 발전용량 특히 수력에너지를 중점적으로 분석하였다.

본 연구에서는 전력 공급 안보를 측정하기 위해 전력 발전 에너지 안보 가격 지수를 사용하였으며, 2025 년의 각 화석연료별 발전단가를 비교하기 위해 에너지균등화비용을 추정하였는데 캄보디아 에너지 균등화 비용에 사용된 값은 비 OECD 국가 평균가격이다. 그리고 각 기술에 따른 이산화탄소 배출량은 IPCC 인벤토리 가이드라인에 따라서 추정하였다. 또한, 발전 공급 적정량을 측정하기 위해서 발전가능용량 데이터를 사용하였다.

본 연구 결과, 수력 에너지 시나리오가 복합가스터빈보다 유리한 결과를 보였을 뿐만 아니라, 석탄가스화 복합발전 사례보다도 우세한 결과를 보였다. 그리고 2025 년 전망 결과, 우기에는 피크수요량의 3 배 이상의 용량을 수력에너지만으로 충족시킬 것으로 나타난 반면에, 건기에는 피크수요량을 충족하기 위해서 오히려 수력과 가스에너지가 필요할 것으로 전망되었다. 그러므로, 향후 캄보디아 에너지 정책을 제안시 수력과 가스에너지 공급량 믹스를 신중하게 결정할 것이라 생각된다.

캄보디아 에너지 정책에서 최소비용이 드는 공급발전용량 믹스를 선택하기 위해서는 현재 캄보디아 화석연료 매장량, 수입의존도, 신재생에너지 잠재량, 전력부하 지속시간 등을 고려하는 것이 매우 중요하다. 그리고, 캄보디아 에너지정책 및 전략을 효과적으로 달성하기 위해서는 위의 모든 요인들이 각각 중요한 역할을 하게 될 것이다. 수력발전시 발생하는 환경 효과 또한 고려해야 할 중요한 사안임이 분명하지만, 그럼에도 불구하고 수력발전 기술을 발전시키고 에너지 효율을 증대시킴으로써, 캄보디아 미래 에너지공급안보를 확보할 수 있을 것이다.

주요어: 효율증가, 발전 믹스, 지속가능성, 캄보디아

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